Doctoral Dissertation

# DEVELOPMENT OF CHEMISTRY AND ENVIRONMENTAL EDUCATION TEACHING MATERIALS FOR HIGH SCHOOLS IN ZAMBIA

Kabunga NACHIYUNDE

Graduate School for International Development and Cooperation
Hiroshima University

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Kabunga NACHIYUNDE

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Committee on Final Examination:

Hideo Ikeda

IKEDA Hideo, Professor
Chairperson

BABA Takuya, Professor

Takao Yamashita

YAMASHITA Takao, Professor

Kinya Shimizu

SHIMIZU Kinya, Associate Professor

Haruhiko Tanaka

TANAKA Haruhiko, Emeritus Professor
Graduate School of Education, Hiroshima University

Date: July 30, 2013

Approved:

FUJIWARA Akimasa, Professor
Dean

Date: Sep. 6, 2013

Graduate School for International Development and Cooperation
Hiroshima University

# Dedication

This dissertation is dedicated to whoever will read and find it useful

# Acknowledgments

I deeply appreciate my supervisors and members of the committee on the final examination. Equally I would love to take this opportunity to thank all professors who took time to share their invaluable knowledge and experiences through various classes and lectures. Members from my research laboratory, friends and relatives are deeply appreciated for their support throughout the preparation of this work. All those who took time to proofread and edit this dissertation are deeply appreciated.

Thank you ALL and God bless.

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# List of Acronyms

| | |
|---|---|
| AAS | Atomic Absorption Spectrophotometer |
| AAS | Atomic Absorption Spectroscopy |
| AC | Activated Carbon |
| AIEMS | Action to Improve English, Mathematics and Science |
| CB | Copperbelt |
| CDC | Curriculum Development Centre |
| DDT | Dichlorodiphenyltrichloroethane |
| DO | Dissolved Oxygen |
| DOC | Dissolved Organic Carbon |
| DWA | Digital Water Analyser |
| EC | Electroconductivity |
| ECZ | Environmental Council of Zambia |
| EDS | Early Dry Season |
| EE | Environmental Education |
| ERS | Early Rain Season |
| ESD | Education for Sustainable Development |
| GIS | Geographic Information System |
| HOTS | Higher Order Thinking Skills |
| ICP | Inductively Coupled Plasma |
| KB | Kabwe |
| KF | Kafue |
| LED | Light Emitting Diode |
| LCC | Low Cost Colorimeter |
| LDS | Late Dry Season |
| LRS | Late Rain Season |
| LSK | Lusaka |
| LWSC | Lusaka Water and Sewerage Company |
| MF | Mufulira |
| MG | Magoye |
| MOE | Ministry of Education |
| MOESVTEE | Ministry of Education, Science, Vocational Training and Early Education |
| MZ | Mazabuka |
| ND | Ndola |
| $NH_3$-N | Ammonia Nitrogen |
| NSC | National Science Centre |
| PV | Permissible value |
| PCA | Principal Component Analysis |
| PCB | Polychlorinated Biphenyls |
| ppm | parts per million (mg/l) |
| SADC | Southern African Development Community |
| SL | Solwezi |
| TB | Turbidity |
| TDS | Total Dissolved Solids |

| | |
|---|---|
| TOC | Total Organic Carbon |
| TP | Total Phosphorus |
| TSS | Total Suspended Solids |
| UNEP | United Nations Environment Programme |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| VOCs | Volatile Organic Compounds |
| WHO | World Health Organisation |
| WPI | Water Pollution Index |

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# Abstract

## Introduction

The southern African nation of Zambia is confronted by numerous environmental problems whilst constrained by limited fiscal resources. This study examines the current environmental and educational situation in Zambia and how the Ministry of Education through a revision of its curriculum might inculcate hands-on interactive solutions to local environmental problems and enhance student learning.

The current Zambian educational curriculum has integrated environmental issues across grade levels and subject matter areas, but the subject matter remains abstract with a lack of hands-on activities connecting actual environmental problems to the formal educational material. Just as most Zambian pupils lack the ability to connect the local environment and the theoretical knowledge they learn in schools, the general citizenry demonstrates a lack of concern for the environment as people continue to discard trash and waste indiscriminately without regard for the consequences on human health.

The study examines the current conditions of potable, river, ground and lake waters with research showing areas of impact of different pollutants, especially heavy metals and examines how the Ministry of Education and individual schools could implement a pollutant detection system based on Colorimetry for use in determining water pollution and analysing local solutions as an extension of the high school chemistry curriculum.

The study was divided into five objectives: (1) To investigate the suitableness of curriculum materials for delivering Environmental Education (EE) lessons; (2) To investigate water quality in the Zambian water systems; (3) To develop a pollutant detection method based on Colorimetry; (4) To devise methods of reducing and/or removing pollutants from contaminated water; and (5) To develop a chemistry module for effective teaching/learning of EE in high schools.

## Method

The Zambian curriculum was extensively reviewed including the national policy documents; the basic school environmental science syllabus and environmental science textbooks; the high school chemistry syllabus; and corresponding approved chemistry textbooks. Analysis of the textbooks showed what can be improved in the curriculum based on contemporary practices and inadequacies uncovered through the analysis. A subsequent document analysis led to further research in unexplored territories and other areas/regions of the country.

To get an overall picture, 39 parameters and diverse analyses methods were employed for the analysis of water samples obtained from five provinces of Zambia. Analysis provided first-hand information about the nature and extent of water pollution in Zambia. Water is the environmental problem that most affects Zambians and resources remain vulnerable and under constant assault from in-situ latrines, backyard landfills, open dumping, farming related pollution from fertilizers and pesticides, mining, and industries.

## Results and discussion

### *Analysis of syllabus and textbook*

The review of the Zambian curriculum revealed weaknesses: the content is mainly descriptive; pupils are not required to do practical work in EE, nor to engage and connect with the local environment; and facts and concepts are the learning goals. The Zambian Curriculum promotes low order thinking skills such as learning facts and recall. Higher order skills like critical thinking, analysis and problem solving are not emphasised.

### *Water quality analysis of common ions, DOC and miscellaneous other parameters*

Five provinces with different environmental characteristics were evaluated for water pollution with the aim to identify the sources and area(s) most affected. It emerged that the water in Lusaka Province is significantly higher in nitrate ($NO_3^-$) and sodium (Na) than other provinces covered in the study. Groundwater is most affected by $NO_3^-$ and Na whilst dissolved organic carbon (DOC) was found to be significantly higher in surface water in like amounts in all studied provinces. Results show that pollution is primarily a function of human activities, social amenities and industrial activities in the study areas. The regions with a higher user rate of pit latrines, backyard landfills, and open dumps registered nitrate levels beyond acceptable rates for drinking water.

### ***Heavy metal analysis***

Analysis for heavy metals revealed that dissolved manganese (Mn) was the major pollution factor in surface water. Groundwater both near illegal dumpsites and on-site sanitation facilities did not reveal any severe pollution problems beyond drinking water permissible values (PVs). With higher prevalence rates of Mn in the Copperbelt and Lusaka regions, EE activities on pollution can focus on this metal as well as other heavy metals of interest since pollution is dependent on social activities and changes as society evolves.

### ***Seasonal variation of pollution in the Zambezi Watershed***

The study reported the seasonal variation of water quality along Lake Kariba, Zambezi River and its tributaries in 2011. Water in the Zambezi River and its tributaries was most polluted in the Late Rain Season (LRS), that is, January to March, with a Water Pollution Index (WPI) of 4.02. The water was least polluted during the Late Dry Season (July to September) with a WPI of 0.44. Water exiting Lake Kariba was generally free of any significant pollution across all seasons. The study proved that pollution changes with season. Therefore, the curriculum should match seasonal trends to make it more relevant. The study of pollutants along the Zambezi river watershed can be scheduled for the LRS since it is the season that is most affected by pollutants.

### ***Development of low cost colorimeters***

The colorimeters in this study were designed to use inexpensive electronic components which are readily available. The aim of this study was to present a low-cost design of a colorimeter with regard to the maximum achievable accuracy, precision and versatility in application. After testing the prototype instruments, it was found that Atomic Absorption Spectroscopy (AAS), Inductively Coupled Plasma (ICP), Digital Water Analyser (DWA) using pack test and the Low-cost Colorimeter (LCC) yielded identical results. It can be said that Mn in a mine effluent water sample and other streams in Lusaka were determined successfully using the LCC and hence can be adopted and applied to measure water related pollution prevalent in a given area.

### *High school activities on pollution detection and treatment*

The study demonstrated how chemistry concepts and their practical applications can be used in EE. The following concepts were utilised in the design of EE lessons: Colorimetry, titrations, precipitation of heavy metal ions using a metal hydroxide, hydrolysis reaction of acid on lignocellulose material, and pyrolysis reaction. The activities under this section were designed to assist pupils find application of the knowledge they learn, a hardly emphasised concept in the Zambian curriculum. These activities not only help in decontaminating water, but also give pupils the chance to engage in hands-on and meaningful activities, and to connect with their environment with activities that are relevant to their lives. This view is supported by Bigge (1964) who reported that activities or materials which are meaningful to students are remembered much better than those which are not.

## Conclusion

In making the curriculum flexible and responsive to learners and societal needs, this study bridged the gap of localising some aspects of the high school chemistry curriculum. The localisation of school curriculum, as advocated by the Ministry of Education in Zambia, will allow schools to adapt some aspects of the curriculum to match the local needs and circumstances, especially, water pollution detection and how it can be treated.

To have a strong basis for adding appropriate content for localising the curriculum, a detailed water analysis was conducted and determined Mn to be the major problem related to heavy metal pollution in Zambia. Mn and Cu were successfully treated from contaminated water. Nitrate was another prevalent problem in areas with in-situ sanitation and illegal landfills. Therefore, this study recommends that pupils are made aware of the sources of nitrates and possible detection methods (through classroom activities). Thereafter embark on lifestyle changes and proper land-use management practices such as refraining from indiscriminate dumping of garbage, avoiding the use of unprotected pit latrines, and careful assessment of the possible sources of contamination relative to the wells/boreholes and other sources of water in their community. Using the LCC, pupils can determine the contaminated sources of water and recommend the suitability of such for school or public service. This study found surface water to be relatively free of $NO_3^-$ contamination. Therefore, it is recommended, where possible, to blend high-nitrate groundwater with surface water that has lower nitrate concentrations, and in the process applying the chemistry concept of dilution. The analysis of the water from Lake Kariba, Zambezi River and its tributaries revealed that water was most polluted during the late rain season (January to March); the major pollutants were different from season to season, and so it would be appropriate to design the curriculum to take into account the changing nature and intensity of the pollutants across the seasons. The curriculum development process in Zambia covers a global view of the new trends, strategies and practices (for example, lead poisoning in the global context, greenhouse effect, ozone layer depletion, acid rains and its effects). Nonetheless, this study recommends to curriculum developers to embrace and accord higher priority to activities that have a direct bearing on the pupils' lives, and ideas which could fit in the local and national situations.

# Chapter 1

## 1. Introduction

### 1.1 Examining the Zambian educational policy documents

The Education Act of 1966 was the first post-independence Government Law on education. It was intended to overhaul the colonial education system in order to meet the aspirations of an independent Zambia. The act paved way for a number of curriculum reforms. For example, the reform to teach science subjects in a practical manner was one remarkable achievement in science teaching (Ministry of Education, Science, Vocational Training and Early Education [MOESVTEE], 2012).

The first major educational policy pronouncements are contained in the Educational Reform Document (Ministry of Education [MOE], 1977). The policy emphasised education as an instrument for personal and national development. The curriculum alluded to the importance of "the ability to apply the achievements of science and technology to one's work in confronting the developmental problems of the country" (ibid, p. 28). Furthermore, it was strongly emphasised that educational materials and equipment should, as much as possible, be produced and obtained locally.

The second educational policy document was Focus on Learning, which was released in 1992 (MOE, 1992). It emanated from the World Declaration on Education for all, held in 1990 in Jomtien, Thailand. The conference stressed the importance of access to educational opportunities that every child, youth and adult shall be able to benefit from educational opportunities designed to meet their basic learning needs. The goals included: universal access to learning; a focus on equity; emphasis on learning outcomes; broadening the means and the scope of basic education; enhancing the environment for learning; and strengthening partnerships by 2000 (World Conference on Education for All, 1990). The Focus on Learning policy document recognises that "the principal purpose of a school system is student learning: learning to think, investigate, question, reflect, discover, appreciate; achieving competency in the essential skills of reading, writing and numeracy; acquiring knowledge and skills that enhance the quality of life; laying the basis for skills that can be useful in making a living or providing goods and services; forming a sense of value and growing in the ability to evaluate a situation" (MOE, 1992, p. 27). Apart from increasing access to education for all, the policy recognised the importance and relevance of education to real-life situations. The document also upheld the importance of learning materials by stating that students cannot reach relative satisfactory levels of learning and achievement in the absence of appropriate learning materials. During this period of the implementation of the policy, there was massive mobilisation of financial resources from local and international donors for the provision of learning materials and equitable distribution of resources.

The third educational policy document, Educating Our Future of 1996 (MOE, 1996), was a product of a lengthy and broadly-based consultation process involving various stakeholders, the entire field of formal institutional education, paying particular attention to democratisation, decentralisation and productivity on the one hand, and curriculum relevance and diversification, efficient and effective management, capacity building, cost sharing, and revitalised partnerships on the other. Flexibility, pluralism, responsiveness to needs, and the protection of quality are recurrent themes. On the issue of relevance, the Educating Our Future policy echoed the previous policies which also point out the importance of education to learners and society, or importance of education as an agent of personal change.

The goal of science teaching is clearly stated in the Education Policy of 1996, Educating Our Future (MOE, 1996, p. 35) which states that:

> A prime goal for science teaching… should be to help develop processes of scientific thinking in children… it is not sufficient that pupils[1] are told about certain processes or even that they can observe them. It will be necessary, in science as in all other subjects, for pupils to be enabled to apply their own ideas, use their own hands, and conduct their own investigations however simple.

In making comments about the current trends in science education with regards to practical activities, MOESVTEE (2012, p. 6) writes that:

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[1] The words Pupil and student are used to mean the same thing throughout this dissertation

> Quality education requires the availability and use of educational materials. The current situation in Secondary Schools is that educational facilities and resources are not available for the learning process, effective teaching and learning. Most of the teaching and learning is done theoretically, even for Practical and Science subjects.

The need for teaching of science by utilising hands-on activities in the post-independent Zambia was mentioned as early as the Education Act of 1966 (MOESVTEE, 2012). However, 47 years later, teaching and learning of science is done theoretically despite several initiatives outlined in the various policies initiated by the Republic of Zambia.

If the objective of teaching science by using practical activities is to become a reality (that is, the representativeness of education to surroundings of pupils and teachers), it is necessary that equipment and situations which allow pupils to use their own hands and conduct investigations are identified. In this vein, there is need to encourage creativity in teachers to engage in fabrication and improvisation of equipment for hands-on activities.

Clark and Starr (1976, p.7) contend that “realistic learning situations help make the learning meaningful to the pupil and thus help to avoid verbalism.” The problem of verbalism, among other things, is that it encourages learning isolated facts or bits of information; and also teaching generalisations presented as isolated facts or bits of information or a combination of facts and generalisations stated as isolated facts or bits of information (ibid). The argument to support hands-on activities is given by Levenson (1985, p. 2) who contends that “young children (and those who have not been exposed to science) should learn about science through a multitude of hands-on experiences with real physical objects or models or real things.” Furthermore, Sanyikosa (2011) recommends, among other things, that Zambia must mobilise domestic and foreign investments into the manufacture of educational toys for all kindergartens in public institutions; as well as the manufacture of laboratory equipment and requisites.

The review of the Zambian curriculum in the mid-1990s was necessitated by the need to improve the quality of education as stipulated in the 1996 national policy document, titled “Educating Our Future”. In addition, the preface of the Zambian chemistry syllabus (Curriculum Development

[CDC], 2012, p. iv), clearly states that: "Quality education raises the standards of living for all. This leads to sustainable national development." The revised curriculum also address issues of national concern such as EE …life and values education. Another reason for revising the Zambia curriculum (syllabus) was to fully localize the High School Examinations which were formerly set by University of Cambridge Local Examination Syndicate, UK.

In line with the view stated above, it is important to link pupils' environmental problems in the learning process. Association for Supervision and Curriculum (1954) argues that a curriculum which uses students' own problems has vitality. Furthermore, it is important to note that a curriculum that is not adapted to pupils' interest can lead to boredom and rebellion, and therefore to behavioural problems (Muijs & Reynolds, 2005). The importance of linking the local environment (and not only local examinations) and student's life can be supported by Goldenberg (2011) who contends that students indicated that their science teachers make learning "fun," not only by being funny but by incorporating their "personal [lives] into topics" and relating to students' lives. Furthermore, she reveals that students desire the following: … more hands-on and lab activities; opportunities for active and interactive learning; consideration that they are people, not just recipients of information; narratives and stories to illustrate science concepts.

When pupils study science, the intended learning outcome as stipulated by CDC (2012) should be to: follow a sequence of instructions; use techniques, apparatus and materials; make and record observations, measurements and estimates; interpret and evaluate observations and experimental results; plan an investigations, select techniques, apparatus and materials; and evaluate methods and suggest possible improvements. But in the absence of apparatus/equipment (locally improvised or purchased from any supplier) that are affordable, this noble objective or prescription of how science should be taught will ever remain mere rhetoric, at least in the case of Zambia. And not doing investigations or practical work will inevitably make pupils lose out on the benefit of learning the nature of science as argued by Wellington (1994). Practical activities in the context of this study incorporate: manipulative skills, observational and recording skills, interpretation, and planning ability.

## 1.2 Review of pertinent literature on Environmental Education

The model by which EE is implemented in primary and secondary schools in some countries include: EE as a separate subject area; the infusion model by which EE is taught as a cross-curriculum topic embedded in various curricular disciplines; and a model based on transversal thematic modules (with topics such as: water pollution, solid waste management, energy depletion, sustainable production and consumption, etc.) (Scoullos & Malotidi, 2004).

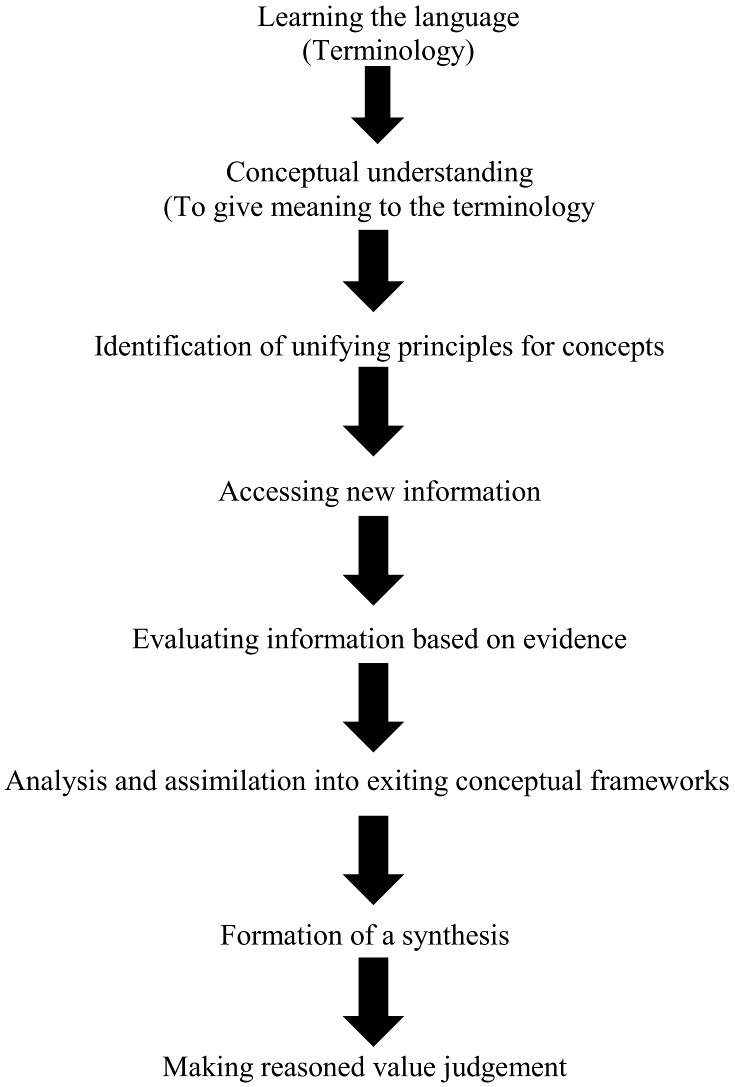

**Figure 1.** A Hierarchical Model for developing environmental literacy
Source: adapted from Grayford (2002)

EE movement around the world has evolved over many years (Palmer, 2002) and it is often discussed with reference to environmental literacy. Just like literacy in reading and writing, environmental literacy should be defined in terms of observable behaviours. “That is, people should be able to demonstrate in some observable form what they have learned, their knowledge of key concepts, skills acquired, disposition toward issues, and the like” (Roth, 1992, p. 14).

There are also a number of aspects that students need to understand about the nature of science, which are considered important for the concept of scientific literacy and contribute directly to environmental literacy. These according to Grayford (2002) include:

1. Science has an important contribution to make to environmental literacy, but only one contribution among several. It can help to decide what is possible, but there will usually be many possibilities that could be followed. From among the possibilities, judgements will then be made on economic, political, ethical or other grounds;
2. Scientific knowledge is not the same as ‘fact’. It is provisional and therefore likely to change with time; thus, it is not appropriate to criticise scientists, as is popular in the media, for changing their thinking as new evidence becomes available;
3. The limitations of science need to be understood. In other words, there should be an appreciation of the sort of questions that scientists are competent to answer and those that are not within their range of competence.

Many curricular around the word include most or some of the issues listed below: climate change and the greenhouse effect, biodiversity reduction, agribusiness, energy use, transport, urbanisation, population expansion, pollution in its various forms, resource depletion, poverty, lowering of the water table in many parts of the world, the use of pesticides and herbicides, ozone depletion, waste disposal and recycling, nuclear power, deforestation and desertification.

For each of the above issues, it is suggested that teachers should attempt to relate their teaching to the model shown in Figure 1 (Grayford, 2002).

Abu-Hola (2009) contends that:

> Environmental education and environmental literacy have been shown to be vital and crucial to be included in all curriculums. They can be seen as two parts of the same theme of how individuals and institutions can collaborate in building a better,

> sustainable world locally, nationally and globally. In practice, this means that when considering environmental literacy in different universities and schools' programs can simultaneously enhance the goals of EE, if the syllabus is methodically well planned. Also, if environmental literacy is understood in a broader sense and carried out including the social and cultural as well as the ecological dimension of sustainability, this literacy will additionally work for the goals of effective education. It is argued that students nowadays have a somewhat fragmented image of the world: they do not understand the interconnectedness of people, society and the environment. Because of this, students are confused and doubtful; they are unable to see their role in environmental issues, they are not convinced of their potential in influencing the future and do not know what they can do for the environment. If culture and nature were more tightly linked in education, children could perhaps better understand their part in the web of life on this planet, and see that their actions are inseparable from the rest of the world. Environmental literacy should, therefore, co-operate in building a sustainable society. To become knowledgeable, caring and active global citizens in the twenty-first century, students must develop attitudes, skills and behaviours that are both environmentally and culturally sustainable.

It is also important to give a balanced view in EE about the dynamics that affects any level of society. Issues of recycling, for example, are heavily promoted as if they are the panacea to the dilemmas facing mankind today. However, it is important to note that promoting recycling without explaining that it is not cost-effective to recycle all materials, that returns for recycled materials vary greatly with time and market conditions, and that there are by-products of the recycling process that also need safe disposal. For example, the recycling of heavy metals, such as is common in Zambia, may produce dangerous by-products such as dioxins and furans from burning plastic glued to the metal being recycled and a number of very toxic minor metals (used to make alloys) such as Pb, Cr and Mn. Recycling may not be economically justified in most cases (Ayres, 1997). Giving students oversimplified answers to complex problems does not make them effective citizens and can even breed cynicism; EE clearly show that students do not lack concern; they lack understanding (Salmon, 2000).

Levels of the individual environmental behaviours can undoubtedly remain low amongst the pupils, regardless of concern, unless an environmental issue is linked to immediate personal concerns, or societal arrangements exist that help to reduce the costs of compliance and facilitate cooperative action (Wall, 1995). Knowledge of environmental issues is important and the Zambia curriculum has done a good amount of work in providing the pupils with knowledge about environmental issues. It has been argued that knowledge or knowing about something alone cannot lead to responsible behaviour. One reason, according to Morrone, Mancl, and Carr (2001) is that knowledge does not lead to responsible behaviour. Although behaviour begins at home, individuals have more knowledge about global environmental conditions instead of local ones; and hence the need to reinforce local knowledge. Alternatively, raising sensitisation that environmental issues affecting other human beings elsewhere will eventually affect them. As long as an issue does not affect them and their loved ones, little effort will be made to act. EE must do more to move the community dialogue away from a not-in- my-backyard response, and from its exclusionary insularity, where it still occurs, toward the more progressive not-in-anybody's-backyard solidarity (Heiman, 1990). Concern for all is the most effective form of EE. Pollution upstream can affect people further downstream who have nothing to do with the pollution and do not benefit from the activity (e.g. mining) causing pollution. The other concern of EE among other things is that texts for young children do not engage their curiosity about the natural world, and that texts for older students focus on the politics of the environment rather than the science (Pollak, 1999). It is therefore important that environmental literacy calls for incorporating environmental considerations into everyday decisions about consumption and lifestyle taken to a level of automatic reflectivity that is part of one's behaviour (Feeg, 2009). One important outlook to the EE issue is reflected in Shri Prabhu speech in which he mentioned that children could actually be taken to a badly polluted stretch of river to check the water quality themselves. They could then use simple water testing kits which are readily available. These experiences will make the subject interesting, but will also set children into thinking why the condition of the environment is the way it is. This would in turn lead to better interaction between students and teachers (Indian Government: Give new thrust to environment education in schools, 1998).

Orr (1995) gives a poignant reflection of the predicament that humanity is facing with regards to education. He laments that:

> …we still educate the young for the most part as if there were no planetary emergency. It is widely assumed that environmental problems will be solved by technology of one sort or another. Better technology can indeed help, but the crisis is not first and foremost one of technology. Rather, it is one within the minds that develop and use technology. The disordering of ecological systems and of the great biogeochemical cycles of the Earth reflects a prior disorder in the thought, perception, imagination, intellectual priorities, and loyalties inherent in the industrial mind. Ultimately, then, the ecological crisis has to do with how we think and with the institutions that purport to shape and refine the capacity to think. The ecological crisis, in other words, is a crisis of education, not one in education; tinkering won't do.

In language, perspectives of literacy are generally assumed to exist. Literacy can be defined as the ability to read and write; literacy can be conceived as focusing on correctness and convention and involves instruction in at least one privileged type of writing (e.g. essay writing); on the other hand it can be viewed as one which can be called the "high cultural" strand involving the transmission of cultural knowledge and the development of cultural knowledge and the development of aesthetic appreciation, literary sensibility, and a cultural spirit (Kern, 2000). With respect to environmental literacy, Roth (1992) proposed the identification of three levels: Nominal, indicating "ability to recognize many of the basic terms used in communicating about the environment and to provide rough, if unsophisticated, working definitions of their meanings"; functional, indicating "a broader knowledge and understanding of the nature and interactions between human social systems and other natural systems"; and operational, indicating "progress beyond functional literacy in both the breadth and depth of understandings and skills."

In support of Roth's argument, Moseley, Moseley and Pense (2002) write that people tend to progress along the continuum of proficiency in environmental literacy in stages that include awareness, concern, understanding, and action. They further argue that a person who is environmentally aware is not yet environmentally literate, nor is a person who possesses broad environmental understanding, who demonstrates environmental concern or who takes action on a single environmental issue. Therefore, an individual demonstrates operational environmental literacy only when all the components come together in the actions taken. Responsible environmental behaviour is a learned response or action (ibid). The ultimate goal of EE is synonymous with environmental literacy (Moseley, 2000). Put differently, the ultimate aim of [environmental] education is shaping human behaviour in its totality (Hungerford & Volk, 1990).

### 1.3 Environmental education and hands-on learning

EE may have slightly different connotations across individuals and organisation. The 1977 Tbilisi Conference spearheaded clarification on the nature of EE. This conference resulted in a declaration which listed some guiding principles for EE programmes (UNESCO-UNEP, 1977). These are summarized as follows:

1. consider the environment in its totality - natural and built, technological and social (economic, political, technological, cultural-historical, moral, aesthetic);
2. be a continuous lifelong process, beginning at the pre-school level and continuing through all formal and non-formal stages;
3. be interdisciplinary in its approach, drawing on the specific content of each discipline in making possible a holistic and balanced perspective;
4. examine major environmental issues from local, national, regional and international points of view so that students receive insights into environmental conditions in other geographical areas;
5. focus on current and potential environmental situations, while taking into account the historical perspective;
6. promote the value and necessity of local, national and international co-operation in the prevention and solution of environmental problems;
7. explicitly consider environmental aspects in plans for development and growth;
8. enable learners to have a role in planning their learning experiences and provide an opportunity for making decisions and accepting their consequences;

9. relate environmental sensitivity, knowledge, problem-solving skills and values clarification to every age, but with special emphasis on environmental sensitivity to the learner's own community in early years;
10. help learners discover the symptoms and real causes of environmental problems;
11. emphasize the complexity of environmental problems and thus the need to develop critical thinking and problem-solving skills;
12. utilise diverse learning environments and a broad array of educational approaches to teaching/learning about and from the environment with due stress on practical activities and first-hand experience.

According to the guiding criteria, as set by UNESCO-UNEP (1978, p. 2), for EE implementation at national, regional and world level, it is stated among other things that "biological and physical features constitute the natural basis of the human environment, its ethical, social, cultural and economic dimensions also play their part in determining the lines of approach and the instruments whereby people may understand and make better use of natural resources in satisfying their needs." In essence, advocating and promoting EE supplements sustainable development in that it produces enlightenment which leads to better choices as people interact with the natural world.

Education for Sustainable Development (ESD) is a distinctive form of environmental related education, which focuses on adopting an educative approach about sustainability issues to improve the capacity of learners to comprehend, participate in and become better at resolving the contentious clash of ecological, social and economic interests in our environment (Robottom, 2007). A sustainable future depends on a pervasive shift in values. One way of achieving such a shift is through ESD. Its purpose is twofold. At an academic level, EE raises both understanding and awareness of environmental issues. At a more practical level it provides the basic concepts and skills needed by those with direct responsibilities for looking after the environment. Just like matters of the environment, ESD should be a central part of the curriculum. There is no more important goal for education than that of contributing to sustainable environmental change. To achieve this goal, we must first change ourselves (Blowers, 2004). Scoullos and Malotidi (2004) proposed a three-dimensional pyramid, Figure 2, with each facet showing, environment, society and economy and are based on education that is the education for Sustainable Development, an education which combines specific components to enhance learning about Environment, Society and Economy while it permeates and change the entire education for all towards sustainability.

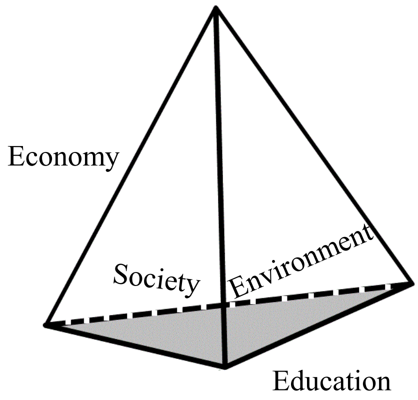

**Figure 2.** Four faceted pyramid showing representation of sustainable development
Source: Scoullos and Malotidi (2004)

MOESVTEE (2012) recounts that:

> Learning institutions at all levels should provide aspects of Education for Sustainable Development, and EE in their programmes so as to impart knowledge, skills, positive attitudes and values. This should enable learners and teachers to uphold the values and importance of the environment. Schools should also ensure that they come up with appropriate activities that will promote the teaching and learning of EE.

In making the curriculum flexible and responsive to learner and societal needs, institutions of learning, teachers and teacher educators are encouraged at all sectors and sub-sectors of the Zambian education system to localise some aspects of the school curriculum. The localisation of the school curriculum is expected to allow schools to adapt aspects of the curriculum to match local needs and circumstances. In this way, the curriculum will provide some compensation for the indigenous knowledge, values and practical skills that learners would have acquired in their home/local environment if they had not been attending school (MOESVTEE, 2012).

The curriculum development process should take a global view of the new trends, strategies and practices, and on the other hand embrace indigenous heritage and thoughts which could fit in the local and national situations, and stress on practical activities and first-hand experience (ibid).

It is important that teachers and teacher educators use a variety of teaching methodologies and techniques in order to cater for the range of learning needs taking into account the available local resources. The teachers and teacher-educators should as much as possible, use methods which promote active learners' participation and interaction. In addition, they should use methods which encourage learners to reflect, think and do rather than reproduce from rote learning. In this regard, teachers and teacher educators are strongly advised to use the learner-centred approach in the teaching and learning process (MOESVTEE, 2012). It is also important to note that learner-centred approach emphasises learning and taking responsibility for individual choices (Karseth & Sivesind, 2011). Nunan (1988) explains that content selection is an important component of a learner-centred curriculum and that a clear criterion for content selection gives guidance on the selection of materials and learning activities and assist in assessment and evaluation. In line with Nunan (1988), an in-depth study was conducted on water quality in order to come up with appropriate content for hands-on and learner-centred learning. In relation to the study of water quality, it is fitting to argue that educators should try to construct learning activities around big ideas and explorations that allow pupils to construct meaning (Muijs & Reynolds, 2005). Larson and Keiper (2007) contend that no teaching approach has a greater potential for student involvement and engagement than student-centred directed investigation. They further point out that student-directed investigation offers an opportunity to learn through experience in an environment that: involves the real world and offers, meaningful, personally interesting challenges; requires active learning; provides opportunities to solve problems, answer questions, or address real needs; allows student ownership, responsibility, and choices and; offers students an opportunity to perform as experts or professionals. This is in line with constructivist ideas of learning. Muijs and Reynolds (2005) sheds more light on this issue by explaining that an exploratory phase of a constructivist approach would involve an activity dealing with real-life situations or material, and allow group work; the activity should be structured in such a way that pupils confront issues which allow them to develop understanding, and should be challenging but not beyond their abilities.

Research is an important intervention at all levels of education. There is need to find out what obtains and what needs to be adjusted or changed completely to suit the obtaining situations. Therefore, in curriculum design and development it is cardinal to carry out both Action Research and Case Studies to cater for content and the learners respectively (MOESVTEE, 2012). The Zambian curriculum insists on the activity based learning with an emphasis on hands-on activity but the extent to which it is practised is not only questionable but not well documented. In addition, the curriculum fails to ask for deliberation about the boundaries between what knowledge to include and not to include in public schooling. No purposeful selection of what school and school alone should be offering and achieving depending on location and local circumstances of the learners. The curriculum should be relevant to both the needs of the pupils and society (Clark & Starr, 1976). A relevant curriculum is also an important prerequisite to the learning of relevant attitudes for an intended task (Gagné, 1977). Hence there is need for stringent content prescription in the curriculum guidelines.

Many researchers have used the term hands-on activities (Bilgin, 2012; Greenbaum & Kyng, 1991; Poudel et al., 2005; Stohr-Hunt, 1996) and hence the need to clarify the implications of this terminology. The term may have slight variations across different individuals. Nonetheless, Haury and Rillero (1994) compiled views from teachers, curriculum developers, and other writers to arrive at a general notion of hands-on learning in science which encompasses its use in school classrooms, museums, and other learning environments. From the collected responses and writings, the definition of hands-on learning in science can be regarded as any educational experience that actively involves people in manipulating objects to gain knowledge or understanding (ibid).

Benefits for students are believed to include increased learning; increased motivation to learn; increased enjoyment of learning; increased skill proficiency, including communication skills; increased independent thinking and decision making based on direct evidence and experiences; and increased perception and creativity (Haury & Rillero, 1994).

Stohr-Hunt's (1996) analysis concludes that significant differences exist across the hands-on frequency variable with respect to science achievement. He argues that, specifically, students who engaged in hands-on activities every day or once a week scored significantly higher on a standardized test of science achievement than students who engaged in hands-on activities once a month, less than once a month, or never.

Students participating in the hands-on reinforcement activity have a significantly more positive attitude toward the subject matter than did students in the worksheet group. It was established that hands-on activities were superior to worksheets in developing positive student attitudes toward academic subject matter (Johnson, Wardlow & Franklin, 1997).

One question that begs answering is what it means for students to be engaged in hands-on science activities. Flick (1993) put forward three conditions that are necessary for an activity to be considered as a hands-on: Condition 1, Students individually or in groups are manipulating objects or events in the natural environment; condition 2, students are applying various facets of their intelligence for the purpose of understanding a part of their natural environment; condition 3, students are being held accountable for their observations, inferences, and conclusions.

Students can be held accountable for their observations, inferences, and conclusions by among other things setting the requirement that they provide a product of their research, which typically includes a class presentation and a graph (Huber & Moore, 2001).

## 1.4 Gagne's instructional design theory

Gagne and Dick (1983) argues that theories of instruction attempt to relate specified events comprising instruction to learning processes and learning outcomes, drawing upon knowledge generated by learning research and theory. Often instructional theories are prescriptive in the sense that they attempt to identify conditions of instruction which will optimize learning, retention, and learning transfer (ibid). In relation to instructional theories, this research was intended to identify efficient procedures by means of which instruction may be designed. Gagne and Dick further contends that the set of events external to the learner which are designed to support the internal processes of learning are conceived as taking place in an approximately ordered sequence as follows: (a) gaining attention, (b) informing learner of the objective, (c) stimulating recall of prerequisites, (d) presenting the stimulus material, (e) providing "learning guidance," (f) eliciting the performance, (g) providing feedback, (h) assessing the performance, and (i) enhancing retention and transfer. Gagne's nine proposed events of instruction are a sequence of steps to guide the teacher or instructional designer. According to the theory, using this sequence should help to insure that the learner masters the desired objective.

It is the contention of this theory that traditional factors in learning, such as contiguity, exercise, and reinforcement, even though of relevance, are much too general in their applicability to be of particular use in the design of instruction.

Several characteristics of this prescriptive instructional model suggested in this theory, make it distinctive from others in several ways as discussed in the subsequent section.

The model does not attempt to propose new theory pertaining to learning and memory, but only to use existing theory as a basis for the conceptualization of instruction.

The theory is comprehensive in the sense that it attempts to include all of the kinds of learning outcomes to which instruction is usually addressed. The theory proposals five kinds of learning outcomes; learning outcomes, conceived as acquired capabilities of human learners, are classified as (a) verbal information, (b) intellectual skills, (c) cognitive strategies, (d) motor skills, and (e) attitudes. In addition to these, the theory also includes attitudes and motor skills as well as cognitive capabilities.

A third distinctive feature is the fact that the theory provides a rational basis for instruction as a set of events which interact with internal learning processes, and also with previously acquired contents retrieved from the learner's long-term memory. This third distinction, which is also a central notion in Gagne's theory, stipulates that different kinds of learning outcomes have different internal and external conditions that support them. The external conditions are things that the teacher or instructional designer arranges during instruction. The internal conditions are skills and capabilities that the learner has already mastered (such as those that would be revealed by a learning hierarchy).

This study attempts to design a module which taps on the previous learned knowledge or pre-existing information according to Gagne’s theory. Furthermore, Gagné and Briggs (1979) argue that “the learning of each skill representing a lesson objective will occur most readily when the learner is able to bring to bear those recalled, previously acquired skills which are relevant to the new task” (p. 145).

According to Gagne's theory, the way to determine the prerequisites for a given learning objective is to conduct a learning hierarchy. A learning hierarchy (sometimes called a task analysis) is constructed by working backwards from the final learning objective. Suppose, for example, that the desired learning outcome is to be able to determine water quality in the community. We would ask ourselves, what are the component skills of determining water quality? They might include things such as, identifying the relevant information on a map and identifying the point sources of pollution, accurately determining the water parameters to focus on, and knowing how to analyse the identified threats. Assuming we decided that these were, in fact, the four component skills, we would then need to analyse each of these into more basic component skills. How many levels further down would we need to go in such a hierarchy? One answer to that question would be, until we reach the level of skills that we know the target learners already possess (Recker, 1999).

The framework suggested by Gagne has been adapted for use in a variety of classroom settings, including college teaching and was used to assemble the various outcomes of this study into a teaching module.

## 1.5 Objectives of the study

The purpose of the study was to delve into the Zambian environment and especially the state of the water with an ultimate objective of recommending teaching materials involving hands-on activities that have a direct bearing to the Zambian environment and subsequently link the pupils to their everyday life experiences. Water is the most vulnerable resource in the environment; yet it is one natural resource that is required by all living things to survive. This research assumes that water is the substance that can make the most appeal to the student if explained to them how this resource can become contaminated and the resultant impact on them (or other human beings) and other living things and the ecosystem in general. Furthermore, the study aims at providing a roadmap on how the water quality can be evaluated for pollutants and treated with low cost methods that are within the budget of even the most deprived school. With this background the study was guided by the following objectives:

1. To investigate suitableness of curriculum materials for delivering of EE lessons;
2. To investigate water quality in the Zambian water systems;
3. To develop a pollutant detection method based on Colorimetry;
4. To devise methods of reducing and/or removing pollutants from contaminated water; and
5. To develop a chemistry module for effective teaching/learning of EE in high schools.

## 1.6 Research questions

The study was guided by five main questions and some accompanying minor questions to address specific details. The minor questions are specifically intended to add focus to the main questions. The research questions are presented below.

1. How suitable are the curriculum materials for delivering of EE lessons?

The answer to research question 1 is addressed in chapter 3.

2. What are the major water related environmental problems in Zambia that affects the pupils in various regions? The minor question accompanying research question 2 is:
   - How can the curriculum forge a strong linkage between pupils and the local environmental problems in relation to water?

The answer to research question 2 is addressed in Chapters 4, 5 and 6.

3. Is the colorimeter accurate enough and cost effective for adoption for analysis of pollutants based on the Zambian Environmental issues? The answer to research question 3 is addressed in chapter 7.
4. What methods of remediation or removing pollutants from contaminated water by using high school chemistry concepts is suitable for EE lesson in Zambia? The answer to research question 4 is addressed in chapter 8.
5. How can the teaching/learning process build on previous knowledge, the local environment and integrating several concepts across the different subjects for effective delivery of EE

lessons for pollutant detection and treatment? The minor questions accompanying research question 5 are:

- How can the chemistry teaching/learning materials accommodate the following in pollutant detection and treatment in EE lessons;
  - Creating – bringing together more than one idea in the learning/teaching process?
  - Evaluating – Consider evidence to support conclusions about their local environment?
  - Analysing – “Take apart” information to examine different parts?
  - Applying – Apply what has been learned from previous lessons/grades and everyday life experiences to new situations?

The answer to research question five is addressed in chapter 9.

### 1.7 Significance of the study

As mentioned earlier, the revision of the Zambian curriculum in the mid-1990s was to, partly, localise the examination system which was handled by the Cambridge Local Examination Syndicate. It is imperative to note that education reforms based on the test-focused content standards remove teachers and students from engagement with an input into the compelling problems of the day. Kincheloe (2007, p. 749) argues that “this is a fatal pedagogical mistake as it sets up a dichotomy between school and the ‘real world’.” Students can learn about EE and sound management of their environment through a formal course of study, but they will learn to be constructive members of the country if they have experience and practice what they learn in their everyday lives (Thomson, 2007). Scientific knowledge may be collective but the cultural and social values of people differ and the perceptions in terms of importance and relevance to everyday life also differ; environment, needs and wants also differ (Takemura & Manzano, 1998). With this study, it is hoped that creation of awareness, is going to be achieved through classroom activities, of the local environmental problems and especially unveiling what is hidden behind the water which the students use every day.

The reasons for classroom activities are, among other things, to develop practical skills and techniques, to illustrate and illuminate issues of the environment, to give a feeling of size and orders of magnitude of the extent of the problem, to generate results for analysis, to entertain, and to challenge the students about possible solutions to the problems (Wellington, 1994). Determination of pollutants in the local water has hitherto not been done in the Zambia curriculum as equipment/tools used to achieve such a feat are considered to be costly to purchase by local schools. It is hoped, through this study, that hands-on knowledge on how to deal with the local environmental problems will be achieved and in the process and progressively, develop new attitudes towards environmental protection and sustainability. Because the students are expected to gain new insights on how to make their own analytical instruments, it is expected that upon their graduation from formal school system, they will have gained enough proficiency to make their own instruments and in the process increase participation and involvement in the community and this will enhance and bolster the responsibility for helping to solve environmental problems.

On the same issue, Association for Supervision and Curriculum (1954) argues that educators should apply scientific knowledge to develop schools that serve society. Jorgensen, Kawashina and Kira (1998) argue that the goal of EE is to develop a world that is aware of, and concerned about, the environment and its associated problems, and which has the knowledge, skills, attitudes, motivations and commitment to work individually and collectively toward solutions of current problems and the prevention of new ones. When teachers and students are not encouraged to engage in such research [inquiry], teaching and learning are less immediate, less connected to the conditions of the community, less involved with what motivate student, less with moral and ethical issues in the life of the school, less connected with other bodies of knowledge produced in different situations (Kincheloe, 2007). Because of lack of connecting activities, it can be said that most Zambian pupils lack the ability to connect with their local environment and late on apply the theoretical knowledge they learn in schools. This view is supported by Masalila (Southern and Eastern Africa Consortium for Monitoring Educational Quality (SACMEQ) acting director) who argues that children should get the practice that they need so that they are able to apply what they learn (Mulenga, 2013). Research on water pollution and giving pupils ample knowledge and hands-on experience can be very important to affirm citizenship. Some of the expected responsibilities of schools in developing citizenship according to Henson (1995) include: acquiring skills; developing a desire to protect the society; developing a desire to improve society (or the environment) and; developing of social responsibilities. The study is intended to provide alternative methods of engaging pupils in both hands-on activities and teacher centred learning and in the process help in solving environmental problems. It is also hoped that teachers through the suggested activities will help pupils search for rational solutions to environmental problems and use the community as a vast resource for learning.

## 1.8 Environmental issues on the world stage, regional and local level

### 1.8.1 Environmental issues on the world stage

Water quality degradation from human activity continues to harm human and ecosystem health. Water-related diseases kill a child every 8 seconds, and are responsible for 80% of all illnesses and deaths in the developing world (UNESCO, 2006). Pollutants of primary concern include microbial pathogens and excessive nutrient loads (UNEP, 2007).

Unlike the pressures of climate change, those of water use are exerted mostly within basins. “Some of their drivers are global, but their remedies may be local, though enabled by transboundary conventions” (UNEP, 2007, p. 120). Figure 3 shows situations in relation to (a) drinking water and (b) sanitation coverage, in 2011. With a low coverage (<50%) on sanitation facilities, in many African countries, there is likelihood of pollution of both ground and surface water. Furthermore, the low coverage on drinking water in some countries means that people use unimproved water sources such as open wells, rivers and other sources not proved to be safe by a local regulatory body.

The drivers of change in the water environment are largely the same as those influencing change in the atmosphere and on land. These include population, agriculture production, deforestation (including forest fires), industrial production, electricity production, transport, consumption of basic goods, and consumption of luxury goods as well as scientific and technological innovation and institutional arrangements (UNEP, 2007).

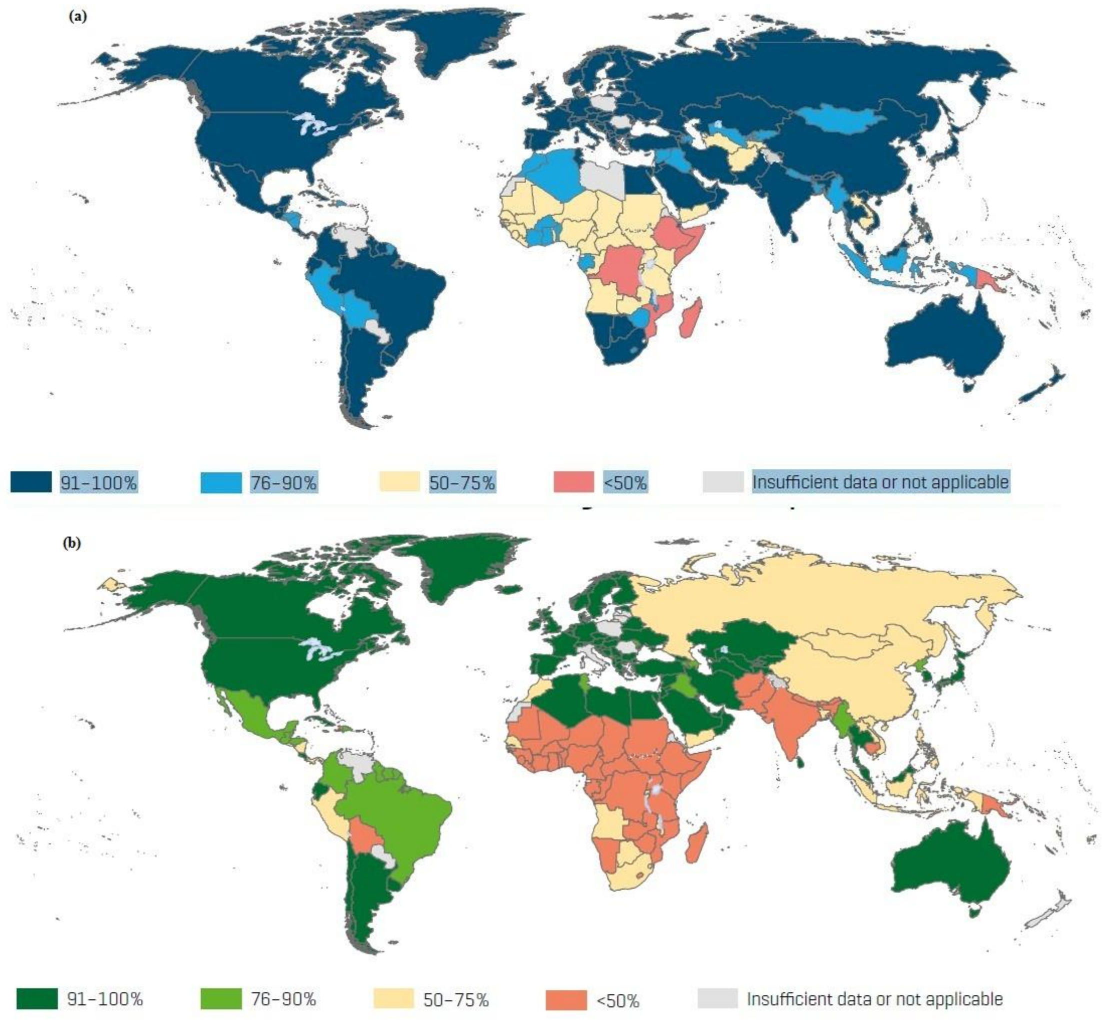

**Figure 3.** The situation in relation to (a) drinking water and (b) sanitation coverage, 2011
Source: Adapted from WHO and UNICEF (2013)

Table 1 shows the dynamics between state changes (from an equilibrium state considered as the norm to another completely different condition, for example, a drop in ground water levels or increased nutrient levels in water) in the water environment and environment impacts and human impacts. The table further shows highlights of major links between water and human well-being.

**Table 1.** Linkages between state changes in the water environment and environmental and human impacts

| **STATE CHANGES** | **Mediating environmental/ ecosystem impacts** | **HUMAN WELL-BEING IMPACTS** | | | |
|---|---|---|---|---|---|
| | | **Human health** | **Food security** | **Physical security and safety** | **Socio-economic** |
| **Human water-use related issues – disturbance to the hydrological regime at basin and coastal scale** | | | | | |
| ⇓ Groundwater levels | ⇑ Drying of shallow wells[1]<br>⇑ Salinity and pollution | | ⇓ Available irrigation water[1]<br>⇓ Water quality[1] | ⇑ Competition for groundwater[1] | ⇑ Access costs[1]<br>⇑ Premature well abandonment[1]<br>⇑ Inequity[1] |
| | ⇓ Discharge to surface water | ⇓ Available surface water[1] | ⇓ Freshwater for irrigation[1] | | |
| | ⇑ Land subsidence | | | | ⇑ Buildings and infrastructure damage[1] |
| | ⇑ Saline water intrusion | ⇓ Available drinking water[1] | ⇓ Available irrigation water[1]<br>⇑ Salinization[1]<br>⇓ Water quality[1] | | ⇑ Water treatment costs[1] |
| | Reverse groundwater flow<br>⇑ Downward movement | ⇑ Pollution from land surface and canals[1] | ⇓ Water quality[1] | | ⇑ Treatment costs for public supply[1] |
| **Human water-use related issues – water quality changes at the basin and coastal scale** | | | | | |
| ⇑ Microbial contamination | | ⇑ Water-borne diseases[1]<br>⇑ Fish, shellfish contamination[1] | | | ⇓ Working days[2]<br>⇓ Recreation and tourism[1] |
| ⇑ Nutrients | ⇑ Eutrophication | ⇑ Nitrate contamination of drinking water[1] | ⇑ Production of macrophytes for animal fodder[1] | | ⇑ Cost of water treatment[1] |
| | ⇑ Harmful algal blooms | ⇑ Fish and shellfish contamination[1]<br>⇑ Neurological and gastrointestinal illnesses[1] | ⇓ Livestock health[1]<br>⇓ Food available for humans[1] | | ⇓ Recreation and tourism[3]<br>⇓ Livelihood income[1] |
| ⇓ Oxygen-demanding materials | ⇓ Dissolved oxygen in waterbodies | | ⇓ **High oxygen-demanding species[1]** | | ⇓ Recreation and tourism[3] |
| ⇓ Suspended sediment | ⇓ Ecosystem integrity | | ⇓ Fish and livestock health[1] | | ⇑ Cost of water treatment1 |
| Persistent organic pollutants (POPs) | | ⇑ Fish and livestock contamination[1]<br>⇑ Chronic disease[2] | | | ⇓ Commercial fish value[1] |
| Heavy metal pollution | | ⇑ Seafood contamination[1]<br>⇑ Chronic disease[1] | ⇑ Flood contamination of agricultural lands[1] | | ⇑ Cost of water treatment[1] |
| ⇑ Solid waste | ⇑ Ecosystem and wildlife damage | ⇑ Threat to human health (infections and injuries)[1] | | | ⇓ Recreation and tourism[2]<br>⇓ Fisheries[2] |

Source: Adapted from UNEP (2007)

Arrows show trends of state and impact changes

| | | |
|---|---|---|
| ⇑ increase | ⇓ decrease | |
| $^{1}$ well established | $^{2}$ established but incomplete | $^{3}$ speculative |

| |
|---|
| MDG Goal 1, Target 1: Halve, between 1990 and 2015, the proportion of people whose income is less than US$1 a day. |
| Target 2: Halve, between 1990 and 2015, the proportion of people who suffer from hunger. |
| MDG Goal 6, Target 8: Halt by 2015 and begin to reverse the incidence of malaria and other major diseases. |
| MDG Goal 7, Target 9: Integrate the principles of sustainable development into country policies and programmes, and reverse the loss of environmental resources. |
| MDG Goal 7, Target 10: Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation. |

UNEP (2007) recognises that domestic and industrial effluents are also major sources of pollution, with inadequately treated wastewater discharged directly into waterways. Virtually all industrial activities generate water pollutants, as do unsustainable forestry (land clearing, forest fires and increased erosion), mining (mine and leachate drainage), waste disposal (landfill leachate, land and sea litter disposal), aquaculture and mariculture (microbes, eutrophication and antibiotics), and hydrocarbon (oil) production and use.

Various management responses have been adopted to address the water environmental challenges. Although actions that should be taken by individuals and agencies at different levels have been identified, the primary focus is on decision-makers facing water-related challenges. In providing management guidance, the linkages and interactions between the water environment and other components of the global environment (atmosphere, land and biodiversity) must also be considered. For example, the quantity and quality of water resources can determine the types of agriculture that occur. The management options include actions and strategies for prevention, and for mitigation and adaptation (the former seeks to solve the problems and the latter focuses on adjustment to the problems) (UNEP, 2007). “Changes in water quality are primarily the result of human activities on land that generate water pollutants, or that alter water availability” (UNEP, 2007, p. 131). Table 2 shows the linkage between state changes in aquatic ecosystems and the resulting environmental and human impacts.

**Table 2.** Linkage between state changes in aquatic ecosystems and environmental and human impacts

| Aquatic ecosystems | Pressures | SELECTED STATE CHANGES | HUMAN WELL-BEING IMPACTS | | | |
|---|---|---|---|---|---|---|
| | | | Human health | Food security | Physical security and safety | Socio-economic |
| Inland ecosystems | | | | | | |
| Rivers, streams and floodplains | Flow regulation by damming and withdrawal Water loss by evaporation<br>Eutrophication<br>Pollution | ⇑ Water residence time<br>⇑ Ecosystem fragmentation<br>⇑ Disruption of dynamic between river and floodplain<br>⇑ Disruption to fish migration<br>⇑ Blue-green algal blooms | ⇓ Freshwater quantity[1]<br>⇓ Water purification and quality[1]<br>⇑ Water purification and quality[1] | ⇓ Inland and coastal fish stocks[1] | ⇑ Flood protection[1] | ⇓ Tourism[3]<br>⇓ small scale fisheries[1]<br>⇑ poverty[1]<br>⇓ livelihoods[1] |
| Lakes and reservoirs | Infilling and drainage<br>Eutrophication<br>Pollution<br>Overfishing<br>Invasive species<br>Global warming induced changes in physical and ecological properties | ⇓ Habitat<br>⇑ Algal blooms<br>⇑ Anaerobic conditions<br>⇑ Alien fish species<br>⇑ Water hyacinth | ⇓ Water purification and quality[1] | ⇓ Inland fish stocks[1] | | ⇓ Small-scale fisheries[2]<br>⇑ Displacement of human communities[1]<br>⇓ Tourism[2]<br>⇓ Livelihoods1 |

Arrows show trends of state and impact changes

| | | |
|---|---|---|
| ⇑ increase | ⇓ decrease | |
| [1] well established | [2] established but incomplete | [3] speculative |

| | |
|---|---|
| MDG Goal 1, Target 1: | Halve, between 1990 and 2015, the proportion of people whose income is less than US$1 a day. |
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| MDG Goal 7, Target 9: | Integrate the principles of sustainable development into country policies and programmes, and reverse the loss of environmental resources. |
| MDG Goal 7, Target 10: | Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation. |

Source: Adapted from UNEP (2007)

According to Fact sheet N°330 published by WHO (WHO, 2013) diarrhoeal disease: is the second leading cause of death in children under five years old; it is both preventable and treatable; kills around 760 000 children under five Each year; a significant proportion of diarrhoeal disease can be prevented through safe drinking-water and adequate sanitation and hygiene; Globally, there are nearly 1.7 billion cases of diarrhoeal disease every year; Diarrhoea is a leading cause of malnutrition in children under five years old.

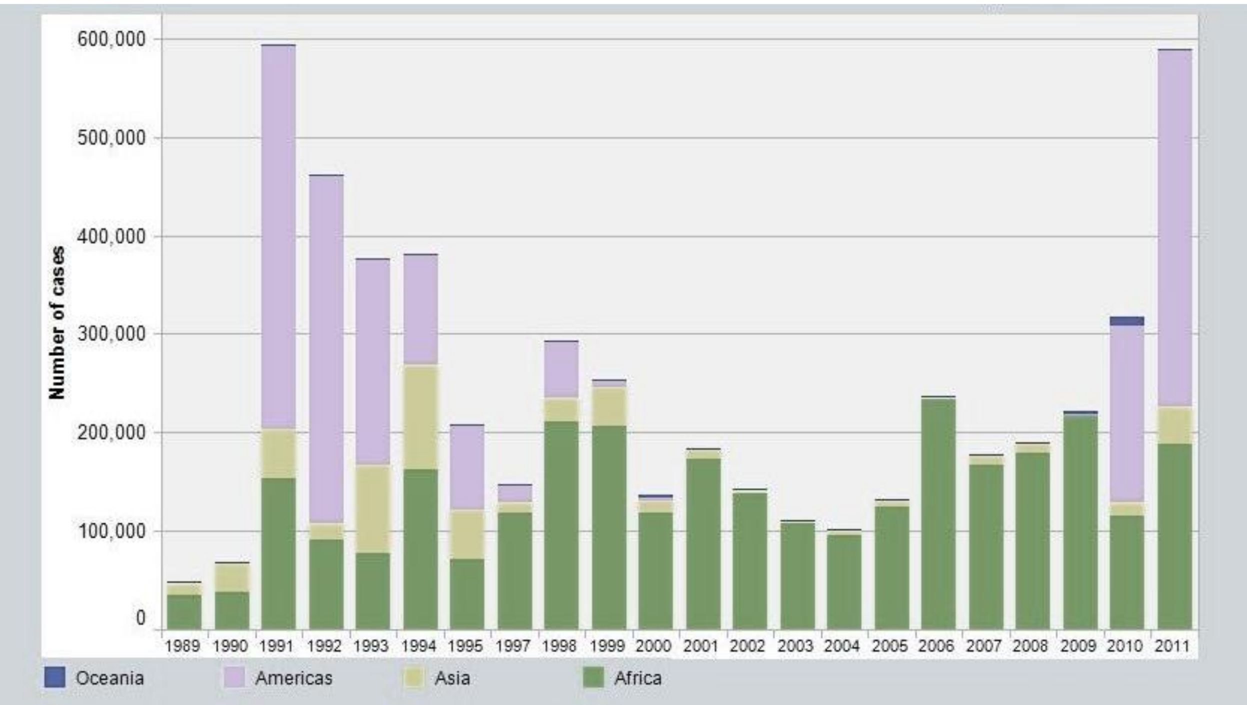

**Figure 4.** Cholera cases reported to WHO by year and by continent, 1989–2011
Source: WHO (2012)

In Africa, there has been a marked decline in case fatality rates since 1970. However, Africa continues to have the highest reported case fatality rates (close to 5% in 1998) compared to the rest of the world (WHO, 2000) of which Zambia forms a substantial part of these statistics. The root cause of most of the diarrhoea cases can be traced back to water pollution resulting from inadequate sanitation, poor waste management practices and a large sector of the population using unimproved sources of water. Figure 4 shows that Africa has had a significant number of reported cholera cases by 2011. The number of cases fluctuates every day and the situation is not showing any signs of abetting. Figure 4, obviously, excludes unreported cases in remote areas and hence the situation could be much worse than is presented by WHO. The problem, to a large extent, can be traced to water contamination.

### 1.8.2 Regional Level

On the region level, Southern Africa Development Community [SADC] (2012) singles out waste management as one problematic issue. It reports that:

> Waste Management is one of the priority issues affecting the SADC Region. The rising quality of life and high rates of resource consumption patterns have had an unintended and negative impact on the urban environment. They have resulted in generation of waste beyond the handling capacities of the majority of waste management authorities. The majority of SADC cities are now grappling with the problems of high volumes of waste, low capacity to management and the high costs involved in the management. This is further exacerbated by the lack of proper disposal technologies and methodologies, inadequate manpower and equipment. This coupled with poor enforcement results in rampant illegal dumping of domestic and industrial waste that is a common practice. This has had serious health and environmental impacts resulting from littering, generation of foul smell and proliferation of pests and insects that transmit diseases.

Waste management and associated problems such as unsanitary landfills has been a contentious issue and the pollution resulting from not managing waste properly. It is a problem at a global scale and affecting millions of people as identified by UNEP (2007). In reducing some of the problems associated with solid waste, a guide was published by CSIR (2011) which encourages waste reduction across all levels of society, including at household level. CSIR further contends that awareness and education campaigns play an important role in the success of any reduce, re-use and recycling initiative. The socio-economic conditions prevailing in a specific municipality must be taken into consideration when establishing waste management programmes, as well as when deciding on the type of communication campaign to use. In the case of this study and with reference to Zambia, this study targets managing of the problem at school level by reforms that are responsive to the prevailing conditions in the local environment where the students reside.

### 1.8.2.1 Households

At the household level, trash or garbage that comprises materials such as paper, metal and glass are recoverable, reusable and recyclable. Recycling of plastic is particularly important because discarded plastic is a nuisance. It is known, in cities such as Lusaka, to have blocked drains and causes flooding during the rainy season. Blocked drainage in the rainy season usually results in water stagnation and creates a breeding ground for mosquitos and leads to serious health risks such as malaria. Diseases, provision of breeding grounds for mosquitoes, and emission of unpleasant odour are some of impacts of water pollution (Abeygunawardane, Dayawansa & Pathmarajha, 2011).

As mentioned earlier, plastic forms a large part of the solid waste. In order to get rid of solid waste such as plastics, an unconventional measure of burning or burying the waste in the backyard is usually carried out (Environmental Council of Zambia [ECZ] & Lusaka City Council [LCC], 2008), but the downside is that open-burning of plastics generates toxic fumes (Lemieux, Lutes, & Santoianni, 2004) further posing health risks (Thornton et al., 1996).

Lack of access to sanitation facilities, especially in urban areas and urban slums, has serious health implications. One of the Millennium Development Goals (MDGs) is to halve the proportion of the population without sustainable access to safe drinking water and basic sanitation by 2015. In an effort to improve this scenario and meet the Millennium Development Goals, the SADC Regional Water Supply and Sanitation Programme is in place to facilitate the development of a regional framework for water supply and sanitation. The framework includes institutional strengthening, rationalisation, knowledge management, and monitoring and evaluation systems (SADC, 2012).

On the local scene, ECZ (2008) observes that water pollution is a challenge in water management especially where you have to strike a balance between the environment and economic activities such as mining and agriculture. This is further exacerbated by poor solid waste management with leachate from these wastes reaching water bodies. In the same vein, ECZ and LCC (2008) notes that ground water pollution may continue as long as the existing sewerage system remains in its present condition and on-site disposal facilities (such as pit latrines, are not designed and constructed to the minimum standards.

While public drinking water systems are regulated by the ECZ, private drinking water wells are not regulated, and are not required to meet ECZ drinking water standards. Furthermore, unlike public water systems, private wells aren't required to undergo routine testing by experts. As a result, individuals that rely upon private drinking water wells are especially vulnerable to the harmful effects of water pollution from diverse sources. With a suitable curriculum which encourages schools to research in the local environment or local communities using unregulated borehole/tube-wells and open wells, a larger population can be made aware of the dangers of the water in their localities.

Undoubtedly agriculture is one of the major sources of water pollution because of the extensive use of nitrogenous/phosphorus fertilizers and other chemicals and/or pesticides. Some other waterborne microorganisms do not originate on farms, but develop as a result of eutrophication caused by high nutrient levels (Pfiesteria piscicida, for example, thrives in many areas where algal blooms grow) (Bowers et al., 2000), and causes lesions in fish and large-scale unusual fish mortality (Fairey et al., 1999). In addition, industrial agriculture is among the leading causes of water pollution in the United States today (Covalla et al., 2001). Nitrogenous compounds can also degrade ecosystems by making water more acidic and killing some aquatic plants while promoting the growth of other kinds of plants. The high concentrations of nutrients such as nitrates and phosphates (frequently exceeding Environmental Council of Zambia of standards) have contributed to proliferation of Water Hyacinth (Sinkala, Mwase & Mwala, 2002). Such pollution can be transboundary as it can affect ecosystems further downstream.

Excess nutrients in bodies of water can contribute to the excessive growth of plant life, a process known as "eutrophication," which, in turn, can make water "hypoxic," or low in oxygen. The effects of eutrophication can be vast. Wiebe and Gollehon (2007, p. 43) writes that "as much as 15 per cent of the nitrogen fertilizer applied to cropland in the Mississippi River Basin makes its way to the Gulf of Mexico." This pollution is one of the leading causes of the so-called Gulf "Dead Zone," an oxygen-deprived area as large as 8,000 square miles, in which no fish can survive (Achenbach, 2008).

In the case of the major Zambian rivers, namely Zambezi, Kafue and Luangwa, adverse effects of pollution will be felt (if pollution continues unchecked) further downstream as far as Mozambique and near the mouth of the Zambezi River where it discharges its waters into the Indian Ocean.

### 1.8.3 Environmental issues at local level

Waste management is a challenge for Lusaka city and other Zambian towns. The main waste streams in the city include domestic, commercial, industrial and other hazardous waste. The increase in urban population, both from rural-urban migration and high birth rates, has resulted in increased amounts of waste. Limited financial capacity and inadequate trained human resource has made it difficult for the local authority to fulfil its obligations concerning waste management. The problem is exacerbated by inadequate infrastructure especially for non-municipal waste and lack of recycling facilities. Waste generated from all sectors of the city's economy is currently not adequately managed (ECZ & LCC, 2008).

In Zamia there is a well-developed mining sector which is the backbone of the economy. The mining sector is dominated by Cu and Co production. The country ranks among top eight producers of Cu (The world Copper Factbook, 2010). Heavy metals (Ag, As, Cd, Cu, Cr, Hg, Ni, Pb and Zn) can be present in the aquatic system in both dissolved forms, which can cause toxic effects on a wide diversity of organisms, including vertebrates, and particulated ones (including adsorbed on sediments, suspended particulate matter or colloids, in transitional metal complexes, and Fe/Mn hydroxides nets, linked to organic matter and carbonates…) (Marcovecchio, Botte & Freije, 2007). The health effects of heavy metal pollution are not well documented by Ministry of Health, and the education system does not require the pupils to determine effects of this kind of pollution and extent of the problem in their local communities.

Some heavy metals, such as copper and zinc, are essential nutrients for animal growth—especially for cattle, swine, and poultry. Farm animals excrete excess heavy metals in their manure—which in turn gets spread as fertilizer, leading to soil and water pollution (Nicholson et al., 1999). Heavy metals are known to markedly alter the metabolism and function of some essential trace elements, such as copper, zinc, iron, calcium, manganese, and selenium, by competing for ligands in the biological system. This competition for ligands results into adverse effects on the disposition and homeostatic of essential trace elements (Abdulla & Chmielnicka, 1990). The health hazards resulting from exposure to heavy are numerous, and among them cardiovascular and nervous system problems from arsenic, which is also known to cause cancer (Wang et al., 2002).

#### 1.8.3.1 Organic matter and other solids

In addition to the biodegradable organic matter naturally present in manure, animal bedding, wasted feed, soil, dust, hair and feathers are often mixed with manure in storage and can end up in waterways. The decomposition of organic matter can cause increased levels of bacteria, which in turn reduces oxygen levels in water and negatively affect marine species. This decomposition can also negatively affect the colour, taste, and smell of water.

With appropriate sensitization starting at an early age in school, regional and government efforts of sensitising the masses about the dangers of pollution can be reduced as the schools will have done their part. Introducing practical work involving determination of pollutants in different local communities is a step in the right direction towards environmental sustainability.

### 1.8.4 Environmental issues relevant to Zambia

Zambia is overwhelmed by a diversity of environmental problems and some of the more important ones are briefly discussed.

Intensive farming which results into among other things, overgrazing, irrigation, monoculture, slash and burn, pesticide drift; unsound farming practices like the Chitemene system of slash and burn prevalent in the Northern part of the country. The production of the same type of food crops on the same plots of land every year.

Land degradation which include issues like land pollution and desertification; this phenomena is observed more in the western and southern parts of the country and general pollution across country due to non-operational social amenities such garbage collection.

Soil management issues which include: soil conservation, soil erosion, soil contamination, soil salination; as a result of rampart deforestation, there has been a challenge of removal of top soils leaving behind impoverished soil which is less productive.

Land use issues which include: urban sprawl, habitat fragmentation, habitat destruction; urban land is particularly a major problem as there is mushrooming of unplanned settlements across various towns and this has led to environmental challenges in waste management.

Climate change dilemmas which include: global warming, fossil fuels, greenhouse gas; this phenomena is most observable in erratic weather patterns; too much rain in some years and drought condition in certain years, for example, in 1994/1995, 2004/2005.

Conservation issues which includes: species extinction, pollinator decline, invasive species, poaching, endangered species; some of these challenge have been more pronounced in extinction of animals like the white rhinos and dwindling population of other wild animals.

Energy issues which include: energy conservation, renewable energy, efficient energy use, renewable energy commercialization, environmental impact of the coal industry; just as oil supplies diminish year by year, Zambia is not spared from this scarcity. Other renewable energy sources like wood biomass are also constantly been used without a corresponding replanting of trees.

Environmental degradation which include: eutrophication, habitat destruction, invasive species; the phenomenon has manifested itself in a number of ways, and among them, the accumulation of water hyacinth in the Kafue and the general accumulation of solid waste in rivers and streams.

Issue of overpopulation which has manifested itself in water crisis and tragedy of the commons. This environmental challenge is more pronounced in urban centres like Lusaka and has brought about substandard housing, roads and these have resulted in degradation of the water quality.

Ozone depletion issues which include: chlorofluorocarbons, hydrochlorofluorocarbons and halons; this is not a localised problem although emphasised in the local curriculum.

Water pollution which generally includes environmental impact of the coal industry, acid rain, eutrophication, urban runoff, water crisis, wastewater, fish kill and algal bloom. These problems are experienced in almost all parts of the country. Water pollution in form of chemical, physical and bacterial (e.g. Cholera) has been occasionally reported across the different provinces of Zambia.

Air pollution which include: smog, indoor air quality, volatile organic compound, atmospheric particulate matter; the most serious form of air pollution is most localised in the Copperbelt. Other non-mining towns experience pollution mainly in form of poor air quality due to dust particles.

Resource depletion issues which include exploitation of natural resources affecting some mining towns like the Kabwe Zinc and Lead Mine as a result shut down indefinitely leaving behind a town scared by high levels of lead in the soil. However, the problem of resource depletion is not only confined to Zambia.

Fishing issues which include: blast fishing, illegal, unreported and unregulated fishing, overfishing and also fishing using poisonous substances and sometimes using fishing nets (e.g. mosquito nets) that harm fish ecosystem as the fledging fish are caught in the process.

Logging issues, which include among other things clear-cutting, deforestation and illegal logging. This is an on-going environmental problem and there is no alternative in sight as many rural and city dwellers depend on wood biomass/charcoal for their everyday household use, wood is cut down for other commercial purposes.

Mining related environmental problems such as acid mine drainage, environmental impact of hydraulic fracturing and slurry impoundments. This phenomenon is predominantly a problem of the Copperbelt and North western provinces which are the main mining provinces.

Toxins in the environment which include chlorofluorocarbons, dichlorodiphenyltrichloroethane (DDT), endocrine disruptors, dioxin, toxic heavy metals, herbicides, pesticides, toxic waste and Polychlorinated Biphenyls (PCB). Though not well documented, the problem of such toxins is expected due to rampart use of chemicals for mosquito and farm/garden/household pests and transformer cooling oil.

Waste in miscellaneous forms include: electronic waste, litter, waste disposal incidents, marine debris, medical waste, landfill, leachate, incineration; Zambia being a recipient of old electronic goods nearing the end of their useful lifespan, electronic waste is common, other types of solid waste are also common as the system of waste treatment is not well developed.

This study is delimited to the intricate connection of the different water pollutants in a given ecosystem. The problems discussed above have both a direct and an indirect bearing on the quality of water; the problem of environmental pollution best manifests itself in water and hence water samples were collected from five provinces across Zambia and analysed for 39 parameters. In addition 2011 monthly data of the Zambezi River, Lake Kariba and its tributaries was obtained from the Zambezi river authority. The most prevalent and acute pollutants that were determined in the water environment were then used to plan hands-on activities (and generally curriculum enhancements) suitable for high school level. Furthermore, treatment methods and remediation of the observed pollutants were suggested based on high school chemistry concepts.

## 1.9 Organisation of the dissertation

The dissertation is organised into ten chapters as shown.

*Chapter one* covers the introduction. It contains the preview of the Zambian national curriculum, situation of EE in Zambia, purpose of the study, and the overview of the methodology. It covers the overview teaching and learning materials development, the Zambian environmental problems, organisation of the dissertation, and definition of terms and the list of acronyms.

*Chapter two* describes the research design, sampling locations, nature of water samples, the parameters analysed, pollution analysis methods, and the method for science activity development.

*Chapter three* describes the process taken to analyse the syllabus and textbook. It also reports details of the visual image analysis of the textbooks and the results of how appropriate the textbooks are for delivering of EE which links pupils to their environment and is relevant to their lives.

*Chapter four* describe the results of the water quality across the five provinces with reference to the following parameters: anions ($SO_4^{2-}$, $Cl^-$, and $NO_3^-$) and cations ($Na^+$, $K^+$, $NH_4^+$, $Mg^{2+}$, and $Ca^{2+}$) and $PO_4^{3-}$, $ClO^-$, $O_3$, $H_2O_2$, $CN^-$, Phenol, total hardness (TH), $CH_2O$, $NO_2^-$, B, $SiO_2$; pH; temperature; and dissolved organic carbon (DOC).

*Chapter five* reports the results of the water quality with reference to the heavy metals. The heavy metals considered in this study are Cu and Ni, Cd, Cr, As, Zn and Pb.

*Chapter six* reports the results of the water quality in Kariba Lake, Zambezi River and its network of tributaries. The parameters of interest were: Temperature, pH, EC, DO, TSS, TDS, Alkalinity as $CaCO_3$, Turbidity, TP, and Ammonia-Nitrogen.

*Chapter seven* reports the results of the low cost colorimetric methods for determination of pollutants and how it can be executed at high school. It reports the feasibility of adopting low cost methods for determining of various water quality parameters. It further reports the comparison of low cost colorimeters with high cost and standard analytical methods using AAS, ICP and Pack test (using the digital water analyser).

*Chapter eight* reports the treatment methods that adds some application to the topics taught theoretical and/or practically but without linking the topics to daily circumstances of the pupils. The chapter reports the following themes: dehydrating effect of sulphuric acid of sugar and subsequent activating the result carbon; titrations activities for determining of iodine number of the charcoal by utilising the chemistry of the addition reaction of halogens to double bonds (the titrations activities has been hitherto been used to find the concentration of a solution and for preparation of salts); precipitation reaction for metal hydroxide treatment, this reaction has had no connection to the real-life situations of the students. The chapter further reports, using high school chemistry, practical methods of reducing solid waste which in many cases leads to disease and chemical contamination of the ground and surface water.

*Chapter nine* reports the application of the research findings from the textbooks, the water analysis and colorimetric methods by way of teaching modules.

*Chapter ten* sums up all the finding from eight chapters to come up with an overall relationship of the water quality analysis, low cost colorimeters, water treatment techniques based on the high school chemistry and their overall relation and benefit to the Zambian curriculum.

# Chapter 2

## 2. Methodology

This study is exploratory in design. Part of the study explored curriculum materials with a view of better understanding the Zambian policy documents, the syllabuses and textbooks. The focus was to have an in-depth insight on how EE is covered and structured. The findings of the curriculum analysis and review of the major environmental issues affecting most Zambia citizens directed the research to extensively analyse EE from the perspective of water pollution. Through exploratory research, researchers produced hypotheses about what was causing the environmental problems that can be considered as major. The research was intended to familiarize with the problem or concepts to be studied, and perhaps generate hypotheses to be tested. Water pollution analysis using systematic instruments was undertaken as a way of familiarising with the local environment. Then pollution detection and treatment was undertaken using high school level concepts and a teaching module developed. The exploratory research helped to determine the best research design (by having an in-depth insight of the severe environmental problems in Zambia), data collection method and selection of provinces, towns and various locations within a town.

Instructional Design is the practice of creating “instructional experiences which make the acquisition of knowledge and skills more efficient, effective, and appealing” (Merrill et al. 1996, p. 2). Along the line of the Merrill’s definition, a chemistry module for effective teaching of EE was developed. The design process consisted broadly of determining the current trends in education though curriculum analysis and needs of the learner as judged by the prevailing social conditions (the major environmental issues affecting them), defining the end goal of instruction, and creating some intervention to assist in the transition. Ideally the process is informed by pedagogically (process of teaching or instructors determining what students need to know) and andragogically tested theories of learning that may take place in student-only, teacher-led or community-based settings. Andragogy’s assumption include, among other things, the learner’s need to know why something is important before they will learn it, self-concept, experience, readiness to learn, orientation to learning, and motivation (Smith, 2002). The outcome of these instructions may be directly observable and scientifically measured or completely hidden and assumed (Caspersen et al., 2011). The instructional design models were based on the model which encompasses the five phases: analysis, design, development, implementation, and evaluation.

This instruction design process was based on the premise that we all construct our own perspective of the world, through individual experiences and schema. Constructivism focuses on preparing the learner to problem solving in ambiguous situations (Bopp & Smith, 2011; Schuman, 1996). And hence the research design and hands-on activities designed in this study were meant to adduce constructivism on the part of the pupils. In addition, the learning of capabilities include learners acquiring mental states which influence choices of personal actions (Gagné, 1977); learners may choose to pollute or not to, or reduce the amount of trash they generate as a method of waste prevention. Often instructional theories are prescriptive in the sense that they attempt to identify conditions of instruction which will optimize learning, retention, and learning transfer. The various stages of design of instructional systems are shown in Table 3. There are many other ways in which the entire process could be outlined but the stages shown will be discussed briefly.

Part of this scheme, in Table 3, was used for designing the instructions in this study. The analysis of the water was in conformity with the first recommendation suggested in Table 3; it was meant to assess the needs, goals and identify the priorities in EE. The development of instruction adhered to the scheme in Table 3, up to recommendation number 8. Assessment of student performance and the system level were not considered in this study.

The subsequent sections are intended to explain the method used to delve into the environment with a view of identifying the issues suitable for listing as major environmental problems of Zambia and hence a strong justification for curriculum review and designing instruction for investigating and reducing the identified issues. The subsequent section further shows the procedure for preparation of the materials and reagents for water quality measurement at high school level and other materials and reagents used for water treatment utilising high school chemistry concepts.

**Table 3.** Stages in designing instructional systems

System level
1 Analysis of needs, goals, and priorities
2 Analysis of resources, constraints, and alternative delivery systems
3 Determination of scope and sequence of curriculum and courses; delivery system design
Course level
4 Determining course structure and sequence
5 Analysis of course objectives
Lesson level
6 Definition of performance objectives
7 Preparing lesson plans (or modules)
8 Developing, selecting materials, media
9 Assessing student performance (performance measures)
System level
10 Teacher preparation
11 Formative evaluation
12 Field testing, revision
13 Summative evaluation
14 Installation and diffusion

Source: Adapted from Gagné & Briggs (1979)

### 2.1 Sampling sites and instrumentation – heavy metals

The water samples were collected in September and October 2011, in Zambia, in which five (out of a total of ten) provinces were sampled for water. The samples were collected in the driest period (dry season) to take care of diluting effect of rain water. Eight samples were from public water taps; 34 samples from rivers and/or streams; three samples from dams/water reservoirs; and 28 samples were from ground water sources such as wells and boreholes. Figure 5 shows the sampling locations.

Filtration of all the samples through 0.45 µm filter was performed to remove bacteria and to slow down sample degradation. The following metals As, Cd, Cu and Ni were determined by the Varian 720-ES Inductively Coupled Plasma (ICP) optical emission spectrometer-model 720 ICPOES. The metals Cr, Mn, Pb and Zn were determined by a Perkin Elmer Analyst 100 Flame Atomic Absorption Spectrophotometer (AAS) using an air/acetylene flame. The samples analysed by AAS were initially preserved in 5 ml of 5% nitric acid. To each 10 ml sample analysed by ICP was added 1 ml of concentrated nitric acid. The determination of pH and temperature was determined by As One 392R pH meter. Creation of the water pollution maps was performed using ArcGIS version 9.3.1(ESRI Inc., USA). Further interpretation of the data was done by spearman correlation (r) and Principal Component Analysis (PCA) using SPSS statistical package version 17.0 (SPSS Inc., Chicago, III).

## 2.2 Common ions, DOC and the other parameters

**Figure 5.** Sampling sites (location 1 to 10)

A non-suppressed ion-exclusion/cation-exchange chromatography with conductimetric detection for the simultaneous determination of anions ($SO_4^{2-}$, $Cl^-$, and $NO_3^-$) and cations ($Na^+$, $K^+$, $NH_4^+$, $Mg^{2+}$, and $Ca^{2+}$) was performed on a polymethacrylate-based weakly acidic cation-exchange resin column and a mixed eluent consisting of succinic acid, tartaric acid and 18-crown-6 at pH 2.9; a Tosho IC – 2001 analyser was used. The separation mechanism was based on the ion-exclusion effect for the anions and the cation exchange effect for the cations. Under the optimised eluent conditions (26 mM succinic acid, 4mM tartaric acid and 1mM 18-crown-6 at 0.6 ml/min), the simultaneous separation of the cations and cations was achieved in *ca*. 20 minutes. The other parameters: $PO_4^{3-}$, $ClO^-$, $O_3$, $H_2O_2$, $CN^-$, Phenol, total hardness (TH), $CH_2O$,

$NO_2^-$, B, $SiO_2$; pH; temperature; and dissolved organic carbon (DOC) were determined by diverse methods as shown in in Table 4.

**Table 4.** Analysed parameters and the methods/instruments used

| No | Analysed Parameter | Method/Instrumentation) |
|---|---|---|
| 1 | Phosphate ($PO_4^{3-}$) | Molybdenum blue |
| 2 | Hypochlorite ($C\ell O^-$) | N,N-diethyl-p-phenylenediamine sulphate |
| 3 | Ozone ($O_3$) | 4-Aminoantipyrine with enzyme |
| 4 | Hydrogen Peroxide ($H_2O_2$) | 4-Aminoantipyrine with enzyme |
| 5 | Cyanide ($CN^-$) | 4-Pyridinecarboxylic acid |
| 6 | Phenol | 4-Aminoantipyrine with enzyme |
| 7 | Total Hardness (TH) | Phthalein Complex |
| 8 | Formaldehyde ($CH_2O$) | N-methylbenzothiazolone hydrazone (MBTH) |
| 10 | Nitrate ($NO_2^-$) | Naphthylethylenediamine |
| 11 | Boron (B) | Azomethine H |
| 12 | Silica ($SiO_2$) | Molybdenum blue |
| 13 | pH and Temperature | As One 392R pH meter |
| 14 | Dissolved Organic Carbon (DOC) | Total Organic Carbon Analyser TOC-V CSN Shimadzu |

Parameters 1 to 12 were determined by digital water analyser DPM-MT

Creation of the water pollution index maps was achieved using ArcGIS version 9.3.1(ESRI Inc., USA). Further analysis of the data was done by factor analysis, t-test, spearman correlation and Tukey's Honestly Significant (HSD) test following one-way ANOVA. The statistical analyses were performed using SPSS statistical package version 17.0 (SPSS Inc., Chicago, III).

### 2.3 Kariba Lake, Zambezi and its tributaries

Water quality data of the Lake Kariba/Zambezi River and its tributaries was provided by the Zambezi River Authority (ZRA)-Lusaka office. The water samples were collected from January to December in 2011. The samples were collected from the seventeen locations namely; Victoria Falls, Kariba at Charara area, Lake Kariba at Andora Harbour, Lake Kariba Dam-Wall Downstream, Lake Kariba Dam-Wall Upstream, Lake Kariba at Nyaozda, Lake Kariba at Gatche, Lake Kariba at Sanyati Mouth, Lake Kariba at Sanyati Mouth-Further, Lake Kariba at B51, Lake Kariba at Manchinchi Bay, Lake Kariba at Ulkrs, Lake Kariba at Crocodile Farm, Deka River, Kalomo River, Quayi and Kanzinze Rivers. Figure 6 shows the study area and the water sampling points.

Diverse methods were used to determine different parameters (actual details about sample handling and the instruments used can be obtained from the ZRA offices in Lusaka). Ten parameters: temperature, pH, electroconductivity (EC), dissolved oxygen (DO), total suspended solids (TSS), total dissolved solids (TDS), alkalinity as $CaCO_3$, turbidity, total phosphorus (TP) and $NH_3$-N were considered in this study.

The data analysis compared the variation of water quality over a period of one year. The seasons were categorised as follows: October to December-Early Rain Season (ERS); January to March-Late Rain Season (LRS); April to June-Early Dry Season (ERS); July to September-Late Dry Season (LDS). A one-way analysis of variance (ANOVA) was used to analyse season variation in water quality across the four seasons and Post-hoc comparisons using the Tukey's Honestly Significant Difference (HSD) were performed to show which season(s) was significantly different from the others. Furthermore, Pearson correlation (*r*) was performed on the water parameters to show which parameters correlated over a period of one year. Grouping of the water quality parameters was done by principal factor analysis (PCA). All the statistical analysis was done by SPSS statistical package version 17.0 (SPSS Inc., Chicago, III). The water quality map was generated by ArcGIS 9.3.

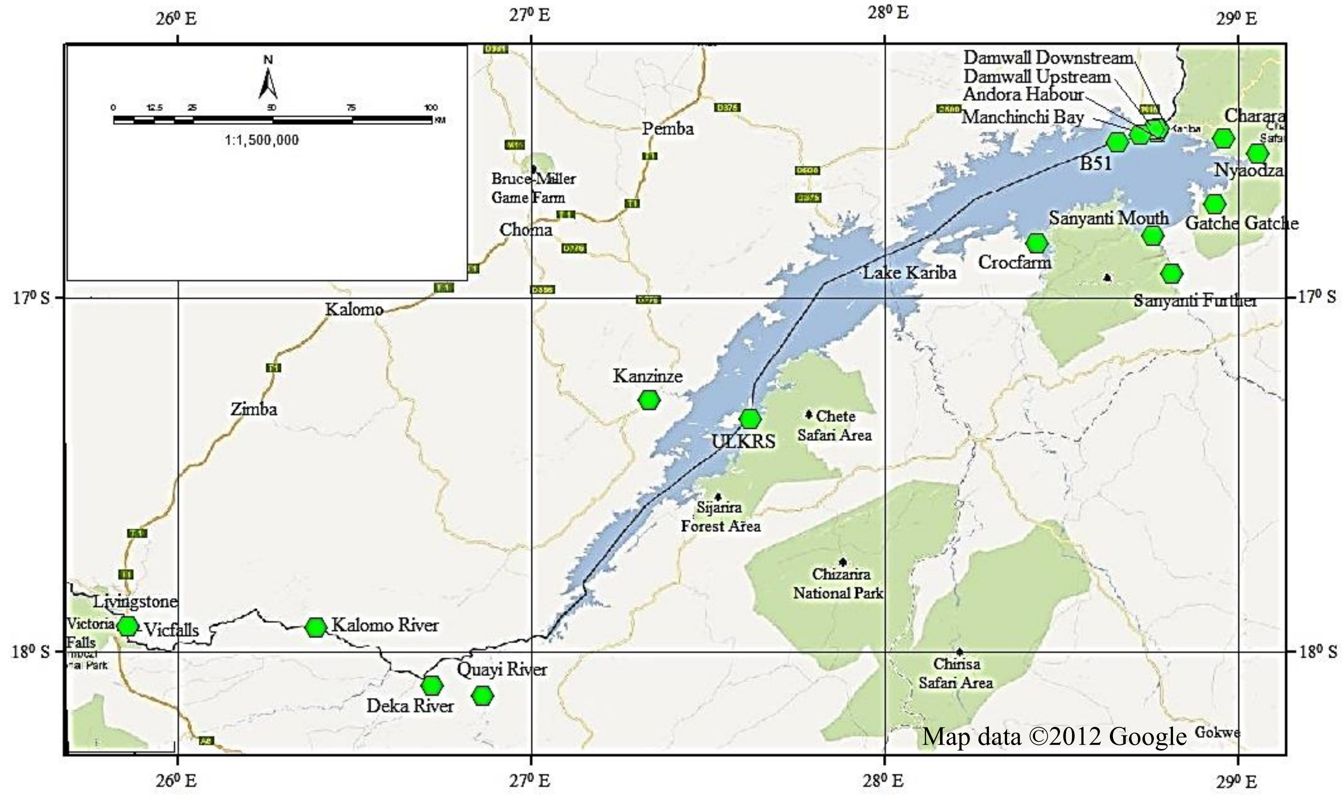

**Figure 6.** Sampling sites along the Zambezi River, Lake Kariba and its tributaries

### 2.4 Water pollution Index (WPI)

Part of the analysis involved use of the Nemerow–Sumitomo Water Pollution Index (*WPI*). The 17 different locales along the Lake Kariba, Zambezi River and its tributaries, and 10 different parameters were analysed by this method. In addition, the 73 water samples from different locales around Zambia (from Magoye to Solwezi) and 20 different parameters were analysed by this method too. However, the following parameters: $CH_2O$, TH, $H_2O_2$, $O_3$, $ClO^-$, pH and DOC were not included in the water Pollution Index (*WPI*) because there are no clear permissible values (*PVs)* in Zambia (or worldwide consensus on safe levels in drinking water) indicating the maximum or minimum permissible values.

The *WPI* was used to evaluate the water quality pattern of portable, river, ground and lake waters in the study areas. The function of this method was to standardize the concentrations ranges for the parameters such that the different concentrations ranges for each water parameter were rescaled by the equation to produce a relative value that lies within a comparable range (Nemerow and Sumitomo, 1970). The *WPI* is a function of relative values ($C_i/L_i$), where $C_i$ represents the concentration of parameter *i* and $L_i$ represents the *PV* of parameter *i* defined by a regulation.

$$WPI = \text{a function of } (C_i/L_i)\text{'s}$$
$$= f(C_1/L_1, C_2/L_2, C_3/L_3 \ldots C_n/L_n) \quad (2.1)$$
$$(i = 1, 2, 3 \ldots n)$$

Then, the *WPI* for a specific water use *j* ($WPI_j$) is further expressed by the following equation:

$$WPI = \sum_{i=1}^{n} \sqrt{\frac{(C_i/L_{ij})_{max}^2 + (C_i/L_{ij})_{ave}^2}{2}} \quad (2.2)$$

Where $C_i$ is the measured concentration of parameter *i*, $L_{ij}$ is the *PV* for the parameter *i* determined for water use *j* (e.g. drinking or irrigation), and $(C_i/L_{ij})_{max}$ and $(C_i/L_{ij})_{ave}$ are maximum and average values of $C_i/L_{ij}$ for water use *j*, respectively.

For the water parameters for which the higher value represents a higher level of pollutions, such as nitrate and heavy metals, the values of $C_i/L_{ij}$ obtained from the field measurements can be directly calculated using the above equation, with a prerequisite. The prerequisite is that if the value of $C_i/L_{ij}$ obtained from measurement is greater than 1.0, then the $C_i/L_{ij}$ value must be standardized by applying the following equation:

$$(C_i/L_{ij})_{new} = 1.0 + x \log (C_i/L_{ij})_{ave} \quad (2.3)$$

Where *x* is a constant value (as a standard value for a relative comparison, 5.0 is arbitrary employed for *x* value in the application of the index for the existing pollution).

For the parameters where the lower value represents a higher level of pollution, such as dissolved oxygen (DO), the $C_i/L_{ij}$ values obtained from the field measurements must be standardized by using the following equation:

$$(C_i/L_{ij})_{new} = \frac{C_{im} - C_i}{C_{im} - L_{ij}} \quad (2.4)$$

Where $C_{im}$ is the saturation value for any parameter at room temperature.

For parameters for which the *PV* ($L_{ij}$) is defined by a range of numbers, such as for pH, where the *PV* ranges from 6 to 9, a standardized value $C_i/L_{ij}$ is required, which is calculated by the following equation:

If $C_i \leq$ average $L_{ij}$

$$(C_i/L_{ij})_{new} = \frac{C_i - (L_{ij})_{ave}}{(L_{ij})_{min} - (L_{ij})_{ave}} \tag{2.5}$$

If $C_i >$ average $L_{ij}$

$$(C_i/L_{ij})_{new} = \frac{C_i - (L_{ij})_{ave}}{(L_{ij})_{max} - (L_{ij})_{ave}} \tag{2.6}$$

Where $(L_{ij})_{min}$ and $(L_{ij})_{max}$ are, respectively, the maximum and minimum values of $L_{ij}$ (e.g. pH: min = 6, max = 9). The $(L_{ij})_{ave}$ is the average value of $L_{ij}$ (e.g. pH: (6 + 9)/2 = 7. 5).

Based on chemical loadings relative to their *PVs*, the results from the water samples were classified into 4 categories. The classification used in this study reflects the suitability of the water for human consumption because only *PVs* for drinking water were used. It did not cater for the suitability of the water for use on animal husbandry purposes or crops. In addition, the *WPI* did take into account of water contamination due to biological activities. So if the water meets the *PV* criteria, it may still need some form of treatment (e.g. chlorination and filtration) but at a far lower cost.

The *PVs* for this study are based on Zambia Bureau of Standards (ZBS)/Environmental Council of Zambia (ECZ) except for $NH_4^+$, $Na^+$ (WHO, 2006), and $K^+$, $PO_4^{3-}$ (USEPA, 2013). Utilizing the *PVs* obtained from ZBS/ECZ, WHO and US-EPA, the *WPI* was classified into four categories expressing the portable water's suitability for human consumption.

Based on chemical loadings relative to their *PVs*, the results from the water samples are classified into four categories. The classification used in this study reflects the suitability of the water for human consumption (after low cost treatment e.g. filtration, boiling or chlorination). The *PVs* for effluent and drinking water were used in this study. For example the *PV*s used for EC, alkalinity as $CaCO_3$ and Ammonia nitrogen were for drinking water standards as shown in Table 5. The *WPI* in this study does take into account of water contamination due to biological activities. So if the water meets the clean water criteria, it may still need some form of treatment (e.g. chlorination) but at a far lower cost.

Utilizing the *PVs* obtained from Environmental Council of Zambia (ECZ) and Zambia Bureau of Standards (ZBS), the *WPI* was classified into four criteria expressing the Zambezi River water pollution levels as listed below.

$0.0 \leq WPI \leq 1.0$ = clean water (meets the *PV* criteria)

$1.0 < WPI \leq 5.0$ = slightly polluted water

$5.0 < WPI \leq 10.0$ = moderately polluted water

$WPI > 10.0$ = highly polluted water

**Table 5.** Water Parameters and their corresponding Permissible Values (PVs) used for Zambezi River

| | | | | *PV* | |
|---|---|---|---|---|---|
| | No | Parameter | Unit | Drinking Water Quality (ZBS) | ECZ Waste water into Aquatic Environment, 1993 |
| Physical | 1 | Temperature | $^oC$ | nd | $40^oC$ at entry point |
| | 2 | Electroconductivity | µS/cm | 2300 | 4300 |
| | 3 | Total Suspended Solids | mg/l | nd | 100 |
| | 4 | Total Dissolved Solids | mg/l | nd | 3000 |
| | 5 | Turbidity | NTU | 10 | 15 |
| Chemical | 6 | Dissolved Oxygen | mg/l | nd | after mixing > 5 |
| | 7 | pH | | nd | 6 - 9 |
| | 8 | Alkalinity as $CaCO_3$ | mg/l | 120** | nd |
| | 9 | Total Phosphorus | mg/l | nd | 1.0 |
| | 10 | Ammonia-N | mg/l | 1.5* | 10.0 |

ZBS - Zambia Bureau of Standards; nd, not determined; NTU –Nephelometric Turbidity Units; * WHO (1996) (1.25mg/l as $NH_3$-N); ** (Lehr et al., 1980); *Ammonia [mg/l] was converted to ammonia-nitrogen [mg/l] for all calculations

## 2.5 Charcoal production

Seven different brands of charcoal were obtained from Zambia. Basically all the charcoal in Zambia, according to Hibajane and Kalumiana (2003) is produced using the earth clamp Method. Charcoal is produced in the earth kiln by covering wood with earth, and then 'burning' it in a process called carbonization. A black solid residue called charcoal remains after the process. Several stages and activities are involved in the production process, and a variety of tools are used. The stages involved in charcoal production are:

(a) felling/cutting of trees and cross-cutting them into short logs (b) piling of the logs into a clamp (c) covering of the clamp with dug up soil lumps (d) applying fire to the kiln to initiate carbonization (e) carbonization of wood into charcoal inside the kiln and (f) 'harvesting' of charcoal from the kiln and packing it into bags.

## 2.6 Calcium chloride activation of charcoal

Charcoal from local tree species were collected from various locations. The following are the tree species whose charcoal was used in this experiment: 1) Mubanga Tree (Pericopsis angolensis), 2) Mupundu (Parinari curatellifolia), 3) Mutondo (Julbernardia paniculata), 4) Muputu (Brachystegia Spiciformis), 5) Mutobo (Brachystegia Boehmii), 6) Musuku (Uapaca Kirkiania), 7) Mupetansofu (Albizia Adianthifolia), and 8) Commercial 20 µm Activated Carbon (cica reagents). The carbonized materials (1 to 7) were soaked in 25% calcium chloride (supplied by Kanto chemicals) solution for overnight. The samples were then washed with deionized water, and filtered through a 20 µm sieve. The resultant filtrate was filtered by suction filtration to recover the carbon which was later dried in an oven at 110$^{o}$C. The samples were then stored in plastic Ziploc bags.

## 2.7 Determination of iodine number of activated charcoal

Fats contain varying amounts of unsaturated fatty acids such as oleic acid which differ from the saturated acids in their power to take up halogen such as iodine at the double bond.

$$\text{-CH=CH-} + I_2 \longrightarrow \text{-CHI – CHI-} \qquad (2.7)$$

The amount of iodine adsorbed is a measure of the extent of unsaturation of fatty acids. The same concept is used to determine the amount of unsaturation of the activated carbon. Determining levels of unsaturation either in fats or carbon (charcoal) is defined by a physical parameter called iodine number. Rastogi (2005) defines iodine number as the number of grams of iodine absorbed by 100 g of fat. In this study, iodine number is expressed as the number of grams of iodine adsorbed by 100 g of charcoal or activated carbon.

### 2.7.1 Reagents

Hanus reagent solution, 6.6 g of pure Iodine (Kanto chemicals) dissolved in 0.5 litre of glacial acetic Wako chemicals) acid and about 1.5 ml of Bromine (Kanto chemicals) solution

Sodium thiosulphate (from Kanto chemicals), 0.1M (to be standardized)

Potassium iodate (Kanto chemicals), 0.0167M

Potassium iodide (Kanto chemicals), 5%

Starch solution (Merck-chemicals), 1%

Hydrochloric acid (Nacalai tesque Inc.), 2M

Calcium chloride (Kanto Chemicals), 25%

Copper (II) Nitrate Trihydrate (cica-reagent)

Iron (III) Nitrateenneahyrate (cica-reagent)

Manganese (II) Nitrate Hexahydrate (cica-reagent)

Nickel (II) Nitrate Hexahydrate (cica-reagent)

### 2.7.2 Standardization of sodium thiosulphate against potassium iodate

Potassium iodate reacts with iodide in slightly acid solution to form iodine that can be titrated with thiosulphate solution.

$$IO_3^- + 5I^- + 6H^+ \longrightarrow 3H_2O + 3I_2 \qquad (2.8)$$

After reaction 2.8, a molecule of $I_2$ reacts with two molecules of sodium thiosulphate.

$$2NaS_2O_3 + I_2 \longrightarrow Na_2S_4O_6 + 2NaI \qquad (2.9)$$

To 12.00 ml of potassium iodate solution was added 0.5 g of potassium iodide and 2.5 ml of 2M HCl. The mixture was titrated with thiosulphate to a pale yellow colour and 1 ml of starch solution was added and titration continued to a sharp colour change from blue to colourless. The process was repeated twice.

### 2.7.3 Hanus iodide bromine method

One gram of activated charcoal was weighed and put into a 100 ml glass stoppered flask. To the flask was added 20 ml of Hanus iodine solution, stoppered, and allowed to stand for 30 minutes with occasional shaking. The solution was filtered by suction filtration and charcoal remaining on the Buchner funnel was thorough washed with 100 ml of distilled water to wash down any free iodine that may have remained on the filter paper. To the filtrate was added 10 ml of 5% potassium iodide solution and shaken thoroughly and titrated with 0.1M sodium thiosulphate until a yellow colour of the solution has almost disappeared. To the resulting faint yellowish solution was added 2 ml of starch solution (as indicator) and the titration continued until the blue colour of the solution has disappeared. Towards the end of the titration, the flask was stoppered and shaken vigorously to complete the reaction.

Three blank determinations on equal portions of the Hanus solution were run.

### 2.8 Preparation of the standard copper solution

A 196.7 mg sample of $CuSO_4.5H_2O$ (MW = 249.7 g/mole) was put into a 50 ml volumetric flask and water added up to the mark in order to prepare a 1,000 ppm solution of $Cu^{2+}$.

The 400 ppm solution of $Cu^{2+}$ was prepared by pipetting a 1.0 ml portion of the 1,000 ppm stock solution to a 250 ml volumetric flask and adding distilled water up to the mark. Three experiments were performed to investigate different attributes of the commercial activated charcoal on the standard solutions of $Cu^{2+}$.

### 2.9 Preparation of the hydrotalcite-like compound ($Mg^{2+}$—$Al^{3+}$—$SO_4^{2-}$)

The compound was prepared by mixing continuously an aqueous solution of sodium hydroxide (3.5 mol/1) and a mixed aqueous solution of magnesium chloride and aluminium sulphate ($Mg^{2+}$: 0.75 mol/1, $Al^{3+}$: 0.25 mol/1) into a beaker using a magnetic stirrer. The sodium hydroxide was discharged from a burette at a controlled flow. White precipitates formed and were taken out, filtered, washed with water and dried at 100°C for 12 hr. The procedure is a modified version of the one used by Miyata and Okada (1976).

# Chapter 3

## 3. Analysis of curriculum materials

### 3.1 Review of the syllabus and textbooks

Chapter 3 answers the first research question: “How suitable are the curriculum materials for delivering of EE lessons?” The curriculum material considered in this study include, national policy on education, chemistry syllabus, Environmental Science Grade 9 Textbook and approved chemistry textbooks. The suitability of the curriculum was analysed from several perspectives. One perspective is the Educating our Future national policy as clarified by the Zambia Education Implementation Framework document (MOESTEE, 2012). According to MOESVTEE “Environmental Education focuses on certain sets of values, knowledge-perspectives and attitudes which can contribute to environmental friendly action and solving of environmental problems” (p. 22). The general aims of the syllabus (CDC, 2012, p. vi) include development of abilities and skills that: are relevant to the study and practice of chemistry; are useful in everyday life; encourage efficient and safe practices; and encourage effective communication. The syllabus’s general aims include developing the skills of enquiry, initiative, and inventiveness. The suitableness of the curriculum in delivering EE was also analysed from the perspective of assessment objectives on “Experimental Skills and Investigating”. The syllabus states that the pupils should be able to: follow instructions; use basic laboratory techniques, apparatus and materials; observe, measure and record; plan investigations;interpret and evaluate observations and results; predicts trends; evaluate methods and suggest possible improvements.

GRZ (2006) outlines the long term goal under the Education and Skills sector that the targets/aims will be to put in place a comprehensive and diversified curricula that is responsive to the social and economic needs of the individual and the community by 2030. The analysis looked at how the current curriculum is taught in schools by looking at how many classroom activities encourage leaners to delve into the local environment and how many issues in the approved textbooks (Chirwa et al., 1994; Horscroft, 2003; Mukuma, Swazi & Chirwa, 1996; Mukuma, Swazi & Chirwa, 1997) tap directly from the local environment for the teaching learning process.

Content, process and language of science teaching must be commensurate with the learner's age-range and cognitive reach (Risch, 2010). In addition, science teaching should engage the learners in acquiring methods and processes that will nurture their curiosity and creativity, particularly in relation to the environment. Part of the analysis of the textbooks focused on whether concern for the environment is emphasized in the curriculum through activities involving outdoor project work. The analysis further looked at how schools, through the curriculum they are obliged to follow, can support curricular activities aimed at stimulating investigative ability, inventiveness and creativity, even if these are not part of the final grade 12 examinations.

The curriculum analysis examined EE at junior secondary school by comparing the syllabus objectives against the textbook content. The comparison of EE content on pollution (water, air, land pollution) as covered at basic school level (in the proceeding section "basic school" shall be used to mean grades 8 and 9) and high school level to check if there is gradual increase in complexity of the content and nature of the suggested activities. A comparison of high school syllabus objectives with reference to content in the approved chemistry textbooks was also conducted. Furthermore, the high school content specifically dealing with EE was subjected to a unit of analysis which involved analysing number (or frequency) of: laboratory activities, hands-on activity and experiments performed; graphical presentation of the content; pictorial representation of the pollution issues; illustrations of EE issues on a global scale; illustrations related to history of science and origin of some of the environmental problems; use of teaching techniques involving analogies; clarity of using concepts of chemistry in EE; cross-linking with other chemistry concepts to reinforce the notion that EE is and should be interdisciplinary. This unit of analysis includes categories similar to the ones used in Souza and Porto's (2012) study. The in-depth visual image analysis was based on the work done by Kress and Leeuwen (2006) and based on an analysis grid developed by Dimopoulos, Koulaidis and Sklaveniti (2003).

## 3.2 Analysis of basic school environmental education

A comprehensive study of EE is first introduced at basic school level. The subsequent sections present a review of the EE content and its gradual evolution as the learners advance towards the higher grades. The EE content is covered under the topic "Ecology" in the ninth grade or basic school level (CDC, 1994). The main aim of the topic is to study some of the results of man's interaction with the environment. Three main themes are considered, these are: Population Growth; Diminishing Resources and; Pollution.

The syllabus objectives are that pupils should be able to:

i. State the main reasons for the recent growth of human population.
ii. State the main problems arising from rapid population increase.
iii. State some of the solutions to the problems in (ii).
iv. State some of the methods of slowing down population growth rates.
v. List some of the Earth's diminishing resources (trees, sulphur, food, iron, copper, coal).
vi. State the importance of such resources to the standard of living in Zambia.
vii. Suggest possible steps that might be taken to reduce the problem of diminishing resources.
viii. State the meaning of pollution.
ix. List some pollutants.
x. List the possible sources of pollutants with particular reference to Zambia.

These objectives were compared to the activities suggested in the authorised textbook to check if there is a match and how accurate these objectives are interpreted into classroom instructions and activities.

Several activities are suggested in the environmental science textbooks (by Horscroft, 2003). The activities include asking students to make a list of:

i. The natural ecosystems that exist in you their areas
ii. The artificial ecosystems to be found locally

The students are further asked to compare the list with those of their classmates and then discuss with their classmates and their teacher why these systems are either natural or artificial.

The second activity is stated as follows:

You will need;

- A pen or pencil
- A ruler
- Some graph paper

Table 6 below provides figures for the total population of Zambia 1990 to 1998.

**Table 6.** Progression of population from 1990 to 1998

| Total population in thousands | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
| 7759 | 8040 | 8331 | 8633 | 8948 | 9112 | 9397 | 9712 | 10036 |

Draw a block graph using this information, to show how the population is increasing. Use the graph to answer the following:

- How large would you expect the population to be in the years (a) 2010 and (b) 2020?
- Can you think of any factors that might change the rate at which Zambia's population may grow?

The third activity is stated as follows:

Every school should have a policy concerning care for its immediate environment. It should consider the pollution produced by the school's activities, the cleaning up and disposing of waste and litter, and care for the trees, plants and grass areas. It should include any gardening or farming activities that the school undertakes.

Get together with your classmates and your teacher to discuss either:

- How effective your school's environmental policy is, and how it might be improved or (if your school does not have an environmental policy);
- What the school's environmental policy should be, and how it could be made to work.

The textbooks generally lack stimulating activities. The syllabus objectives are covered in narrative form and to a large extent teachers are expected to lecture about the environmental issues in manner not any different from a history lesson.

## 3.3 Comparison of basic school and high school content in the approved textbooks

The next part looked at how the EE content in the textbooks is covered at basic school and high school. Particular effort has been made to show the evolution of EE from the lower to the higher grades.

**Table 7.** Comparison of EE content on water pollution as covered in basic school and high school

| Textbook content at basic school level | | | | Textbook content at high school level | | | |
|---|---|---|---|---|---|---|---|
| **Pollutant** | **Source** | **Effect** | **Solution** | **Pollutant** | **Source** | **Effect** | **Solution** |
| Sewage | Industrial and urban effluent | Diseases such as typhoid and cholera. Enriches nutrient content, causing excessive plant growth.<br>Eutrophication of water systems | | | | | |
| Fertilisers | Leaching from agriculture | Eutrophication of water systems | | Fertiliser | Nitrate fertiliser | Eutrophication; blood disorders | |
| Pesticides | Washed from plants and crops by rain | Damages the breeding of mammals and birds that drink the water, and of fish | | Pesticides (e.g. DDT) | Chemical sprays in farms/gardens | birds egg fail to hatch and falling bird population | |
| Metals | Industrial effluent | Health hazard to all forms of life | | | | | |
| Oil | spillage from industry on land and tankers at sea | Kills marine plants and animals by smothering and poisoning them | | | | | |
| Plastics | Garbage washed out to sea or thrown overboard from ships | Kills marine animal that consume them | | | | | |

**Table 8.** Comparison of EE content on air pollution as covered in basic school and high school

| Textbook content at basic school level | | | | Textbook content at high school level | | | |
|---|---|---|---|---|---|---|---|
| **Pollutant** | **Source** | **Effect** | **Solution** | **Pollutant** | **Source** | **Effect** | **Solution** |
| Dust | | | | | | | |
| Pollen | | | | | | | |
| Ash | Volcanic eruptions and forest fires | | | | | | |
| Carbon dioxide | Combustion, particularly of coal and natural gas | Enhances global warming | | $CO_2$ | Fossil fuels | Global warming which result into 1 Forest lines may move towards the poles 2. Deserts may become hotter 3. Droughts will be worse 4. Coastal saltwater marshes 5. Warmer ocean temperatures leading to sea level rise 5 Glacial melting | student to suggest ways of reducing CO2 emissions |
| CFCs (chlorofluorocarbons) | Refrigerator coolant Aerosol sprays (Production and use now generally discontinued) | Destruction of ozone layer | | CFCs | Propellant gas in aerosols | Ozone depletion | Montreal protocol to stop increasing use of CFCs and to reduce the use of CFCs |
| Metals | Heavy metal dust (Zinc, copper, nickel, and cadmium) contained in waste industrial gases. Circulate in atmosphere | Toxic to plants and animals. Can poison soils | | Lead | Leaded petrol | Can cause children to have lower intelligence, poorer memories and less muscular coordination than children who do not carry the burden of lead | Phase out leaded petrol |
| Methane | Decaying rubbish and rotting vegetable material | Contributes to global warming | | | | | |
| Nitrogen oxides | Vehicle exhaust gases | Smog in urban areas Breathing problems such as asthma, tuberculosis and lung cancer | | $NO_x$ | Internal combustion engines | Acid rains | |
| Noise | Industry, traffic, and other human activities (discotheques, etc.) | Damage to hears and possible deafness Can contribute to high blood pressure | | | | | |
| Radioactive materials | Accidental release from nuclear industrial plants (for example the Chernobyl disaster) | many serious effects on human health, some leading to cancer and death | | | | | |
| Sulphur dioxide | Burning of coal and some oils | Sulphur dioxide dissolves in water vapour in the air to give acid rain. This can damage forests and buildings | Remove sulphur from coal before use. Replace thermal power stations with HEP | $SO_2$ | Coal and burning of oil. Contact process. Metal smelting of sulphur containing ores | Kill forests and destroys fish stocks. Alter the fertility of the soil. Attacks buildings | |

The analysis of the textbook content compared the types of pollutants that are considered as important at the two levels of education. Furthermore, the analysis looked at the sources of the pollutants and the effects on society of the identified pollutants and finally the possible solutions to the identified pollutants are discussed.

From the science syllabus review, EE activities (group discussion but no laboratory work) are mentioned only incidentally and there are no direct instructions for teachers about investigating the state of the environment, but only to mention about the types of pollutants and impact on society. Some topics, such as pollution due to solid waste land pollution are discontinued at high school level. Other aspects of solid waste pollution such as sewage, oil and plastics are not mentioned in the high school textbooks.

**Table 9.** Comparison of EE content on land pollution as covered in textbooks for basic and high schools

| **Textbook content at basic school level** | | | | **Textbook content at high school level** | | | |
|---|---|---|---|---|---|---|---|
| **Pollutant** | **Source** | **Effect** | **Solution** | **Pollutant** | **Source** | **Effect** | **Solution** |
| Solid waste | Solid waste disposal, scrap metal from old cars and other vehicles, agricultural chemicals | Not explained | Provide legal dumping sites for solid waste. Enforce the law regarding the dumping of solid waste. Provide effective waste collection etc. | Not covered or taught at high school level | | | |

The traditional teaching methods in science are mainly lectures, discussion sessions, and laboratories. How can the teachers help students learn science better and more efficiently in each format? Although there is no universal best way to teach, some general principles apply, that include: Teach scientific ways of thinking; actively involve students in their own learning; help students to develop a conceptual framework as well as to develop problem solving skills; promote student discussion and group activities; help students experience science in varied, interesting, and enjoyable ways; and assess student understanding at frequent intervals throughout the learning process (American Association for the Advancement of Science, 1990). These activities suggested in the textbooks are mostly lecture type of teaching and occasionally encourage discussion sessions. The methods do not encourage pupils to experiment and help students experience science in varied, interesting, and enjoyable ways. This is also contrary to what is stipulated in the national policy of 1996 which categorically states that it will be necessary, in science as in all other subjects, for pupils to be enabled to apply their own ideas, use their own hands, and conduct their own investigations however simple.

## 3.4 Comparison of high school syllabus with reference to content in the approved chemistry textbooks

To analyse the match of EE content, the high school chemistry syllabus (CDC, 2012) and Zambian approved textbooks were reviewed. Part of the results are shown in Table 10.

**Table 10.** Comparison of high school syllabus objectives with reference to content in the approved chemistry textbooks

| **CONTENT** | **OBJECTIVES (pupils should be able to [PSBAT])** | **NOTES** | **Coverage in Zambian approved textbook** |
|---|---|---|---|
| **2.2 KINETIC THEORY** | 2.2.1 Describe diffusion. | ***Refer to diffusion of toxic gases and effluents.*** | No reference to diffusion of toxic gases and effluents |
| | 2.2.2 State the factors that influence rates of diffusion. | Refer to gas law such as Brownian motion. | |
| | 2.2.3 Describe the evidence of movement of particles in liquids and gases. | Refer to dilution. | |
| **5.2 GROUP PROPERTIES** | | | |
| | 5.2.4 Discuss the importance/use of halogens. | | |
| | 5.2.5 Describe harmful effects of halides. | Refer to production of drugs, pesticides, and their effect. | |
| | | ***Refer to ozone layer depletion.*** | Mentioned with reference to the free radicals under the effects of light on the rates of reactions |
| **6.3 EFFECTS OF ACIDS IN THE ENVIRONMENT** | 6.3.1 Describe the formation of acid rain. | ***Refer to effects on land, plants, animals and water.*** | Sulphur dioxide is a gas which contributes to acid rain (briefly discussed under dynamic equilibrium). No effects are mentioned |
| | ***6.3.2 Describe the harmful effects of acids and acid rain in the environment.*** | ***Refer to corrosion and release of toxic gases.*** | No corrosion and release of toxic gases is discussed |

| **CONTENT** | **OBJECTIVES (pupils should be able to [PSBAT])** | **NOTES** | **Coverage in Zambian approved textbook** |
|---|---|---|---|
| **9.1 REACTIVITY AND ELECTRO CHEMICAL SERIES** | | | |
| | 9.1.5 Relate electro chemical series to the tendency of a metal to form its positive ion. | Refer to copper zinc and iron processing in Zambia. | |
| | 9.1.6 Describe extraction of copper, iron and zinc from their ores. | Refer to important uses of zinc, iron and copper. | |
| | 9.1.7 Discuss the uses of metals. | ***Refer to the toxic gases and effluents from factories.*** | No effluents are discussed |
| | | ***Refer to disposal of scrap metal as contributing to land pollution.*** | Scrap metal disposal is not discussed |
| | | ***Refer to land degradation due to mining and dumping.*** | No land degradation is discussed |
| | | Refer to metals as non-renewable resources. | |
| **12.1 HYDROGEN** | 12.1.7 Discuss water as an important oxide of hydrogen. | Refer to some of the use, of water in homes and industry. | |
| | 12.1.8 Describe a chemical test for water. | ***Include purification of water supply, by chlorination and pollution.*** | No purification of water is discussed |
| **12.2 OXYGEN** | ***12.2.6 Discuss the effects of pollutants arising from reactions involving oxygen.*** | ***Refer to the common pollutants (e.g. CO, $CO_2$, $SO_2$, $PbO_2$, and $N_2$).*** | No linkage to pollution is discussed |
| | ***12.2.7 Discuss the importance of ozone.*** | ***Refer to dangers of ozone layer depletion, skin cancers, and respiratory diseases.*** | No dangers of ozone layer depletion are discussed |
| **12.3 NITROGEN** | 12.3.12 Explain the importance of nitrogen in fertilizers. | | |
| | ***12.3.13 Discuss the effects of nitrogenous fertilizers on the environment.*** | ***Refer to the effluent washed into the river from industries and farms dealing with such products.*** | No effluents are discussed in relation to nitrogen |
| **12.5 SULPHUR** | 12.5.1 Describe the burning of sulphur. | Mention sulphur dioxide as a pollutant. | |
| | 12.5.2 Explain the behaviour of sulphur | As an acid, refer to action on litmus, water and sodium | |

| CONTENT | OBJECTIVES (pupils should be able to [PSBAT]) | NOTES | Coverage in Zambian approved textbook |
|---|---|---|---|
| | dioxide in reactions as acidic oxide and as a reducing agent. | hydroxide. | |
| **12.6 CARBON AND CARBONATES** | 12.6.6 Describe the uses of carbon dioxide. | Refer to processes at a lime industry. | |
| | 12.6.7 Describe the manufacture of lime from limestone. | ***Refer to dangers of over application of lime in agriculture.*** | Dangers not discussed of over-application in the textbooks |
| | 12.6.8 Explain the uses of:<br>(i) lime and<br>(ii) slaked lime. | | |
| **13.1 CHEMISTRY AND SOCIETY** | ***13.1.1 Discuss the importance of chemistry in society.*** | ***Refer to the processes, products and their usefulness. Consider harmful effects as well.*** | Processes products, and their usefulness not discussed |
| **13.2 POLLUTION** | ***13.2.1 Describe pollution.*** | | Described |
| | ***13.2.2 Explain the effects of air pollution.*** | ***Refer to the industrial waste. Refer to effects on animal life, plant life and buildings.*** | Described |
| | ***13.3.3 Explain the effects of water pollution.*** | ***Refer to industrial waste, fertilisers, pesticides and domestic waste.*** | Described |
| | ***13.3.4 Explain the effects of land pollution.*** | ***Refer to bio diversity, land degradation. Refer to industrial waste and human activities*** | Described |
| | ***13.3.5 Discuss the effects of combustion products of fossil fuels in the environment.*** | ***Refer to extraction and use of coal, petroleum products. Refer to the effect of combustion products of fossil fuels.*** | Discussed |
| | ***13.3.6 Outline methods of controlling pollution of air and water.*** | ***Include recycling and bio degradable materials. Refer to agencies involved in monitoring environmental pollution.*** | Described |

Most of what is suggested under the objectives and notes columns, as revealed by Table 10, is not covered in the approved chemistry textbook. The other recommended textbooks, Certificate Chemistry (by Atkinson, 1983) and GCSE Chemistry (by Early & Wilford, 1995) equally do not adequately address the syllabus objectives as presented in Table 10.

Just like the basic school syllabus, the syllabus objectives are covered in narrative form and to a large extent teachers are expected to lecture about the environmental issues. The syllabus is less explicit on levels of inquiry. Furthermore, it has no suggested inquiry activities and guidelines for inquiry-based teaching and learning. No laboratory or hands-on activities are suggested. The pupils are not required to use the local environment to get an insight about environmental issues and help them see how they fit in the overall picture of environmental degradation. A similar study by Mumba, Chabalengula and Hunter (2012) found evidence that students were mainly asked to manipulate apparatus, carry out observations and measurements, record results, interpret results and draw conclusions. Furthermore, Chabalengula and Mumba (2012) found that there is much emphasis on lower inquiry tasks and skills in textbooks and exams with regards to, not only EE content, but all science activities analysed in their study.

The topic, "Pollution and Pollution Control" in the approved textbook (Mukuma, Swazi & Chirwa, 1997), specifically dealing with pollution was subjected to further analysis which focused on ten themes. The topic, to a large extent, addresses section 13.1 and 13.2 of the syllabus whose excerpt is shown in Table 10. The topic, as presented in the approved chemistry textbook has seven units, and from them, the nine themes of analysis were considered as explained in section 3.5 below.

### 3.5 Units of analysis of the textbook content on environmental education

1. Number of laboratory activities, hands-on activity and experiments performed: These are contrived learning experiences in which students interact with materials to observe phenomena. These activities may include phases of planning and design, analysis and interpretation, and application as well as the central performance phase (Hofstein & Lunetta, 1982).
2. Graphical presentation of the content: These are visual illustrations of verbal statements. They include flow charts, pie charts, line graph, histogram and family trees, spider maps, fishbone maps, network tress, and compare/contrast matrices.
3. Pictorial representation of the pollution issues: These are visual representation of environmental issues by photography or painting.
4. Illustrations of EE issues on a global scale: The issues were analysed in the context of how environmental issues are tackled and the extent to which the said issues are recognised as affecting the whole world, or problems that are global in scope. Some of the issues covered in the chemistry 12 textbook include:
    - Pb poisoning;

- $CO_2$ and global warming;
- Effects of ozone depletion;
- Effects of Acid rain; and
- Effects of $NO_3^-$.

5. Illustration of EE issues to Zambian daily life. These are problems which are local in scope. Two issues were:
   - pictures showing industrial pollution in Zambia;
   - pictures showing pesticides used in Zambia.
6. Illustrations related to history of science and origin of some of the environmental problems: This category looked at how current problems can be traced from past environmental problems. Review of past environmental issues was considered cardinal for understanding the present situation and predicting what might happen in future.
7. Use of teaching techniques involving analogies: An analogy is a similarity between concepts. Analogies can help students build conceptual bridges between what is familiar and what is new. Often, new concepts represent complex, hard-to-visualize systems with interacting parts (Glynn, 2007).
8. Clarity of using concepts of chemistry in EE: This category looked at how concepts of chemistry such as different types of reactions are utilised in EE lessons. Generally, reactions considered in this study fall under 11 categories namely: combustion, synthesis, acid-base, decomposition, single displacement, double displacement, substitution, dissociation, addition and redox reactions, and reactions of coordinated ligands.
9. Cross linking with other chemistry concepts in the context of EE: This last category looked at how EE lessons builds upon the earlier learned concepts to show interrelations and how application of earlier concepts are used in the context of EE lessons.

Figure 7 shows the results of the analysis of the approved grade 12 chemistry textbook (written by Mukuma, Swazi & Chirwa, 1997) for Zambian schools. The results show that the content is rich in illustrations of pollution issues on a global scale. Prominent examples example include: the famous 1900 fogs of London; that in the 1970s North America emitted 250 000 tonnes of lead into the atmosphere every year and children in some US cities had blood levels as high as 300 $\mu g/dm^3$; that droughts will be worse in lower altitudes due to climate change; water supplies in Rwanda and Somalia are already dangerously low; that some scientists fear that man's destruction of the rain forests (for example in Brazil) may lead to increased activity of these microorganism and to an increased concentration of dinitrogen oxide; that westerly winds have carried polluted air from Europe and the acids, washed out in the high rainfall, have killed large tracts of forest and destroyed fish stocks.

These examples show how the content excludes Zambia as a country at rick of pollution. Inevitably, the notion that pollution exist elsewhere can be inadvertently implanted in the pupils with such representation of the reality.

A close inspection of Figure 7 further shows that the EE content is poorly linked to other concepts of chemistry. It is as if the EE knowledge exists as a separate branch of science. Some of the concepts of chemistry are misrepresented or at least not a complete picture is presented as will be explained in the subsequent sections.

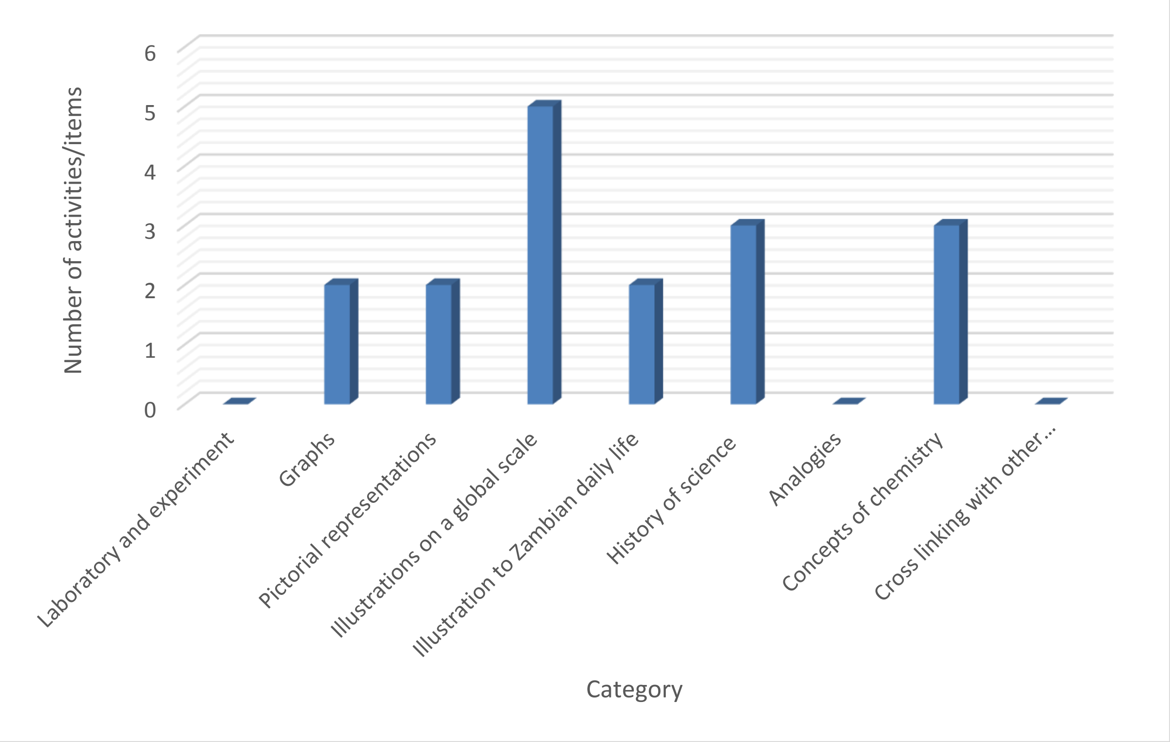

**Figure 7.** Results of the textbook analysis of EE content

Four units from the 12th grade chemistry textbook are presented to give a critical review of how the content is covered and their inadequacies and how it falls short of an ideal EE content.

**Ozone layer depletion:** This unit attempted to compare how ozone depletion is presented in the approved textbooks compared to other generally acceptable scientific ways of presenting the same issue.

The chemically very stable CFCs diffuse up into the stratosphere and decompose when hit by ultraviolet light (*uv*) to produce free radicals, including free chlorine atoms, which themselves are highly reactive free radicals.

In the approved grade 12 chemistry (Mukuma, Swazi & Chirwa, 1996, p. 168) textbook, the ozone depletion is presented as:

> …However in the upper atmosphere ultraviolet light splits the CFC to give free chlorine radicals
>
> $CFCl_3 + uv \longrightarrow CFCl_2\cdot + Cl\cdot$
>
> The chlorine radical then reacts with ozone:
>
> $Cl\cdot + O_3 \longrightarrow ClO\cdot + O_2$: The chlorine atom changes an ozone molecule to ordinary oxygen
>
> The chlorine radical is then re-formed
>
> $ClO \longrightarrow Cl\cdot + O\cdot$

The last equation is a misrepresentation of what is generally accepted as the mechanism under which ClO is split. ClO· is believed to undergo a cleavage which is initiated by ozone molecule or oxygen radical as shown below.

$ClO\cdot + O_3 \longrightarrow Cl\cdot + 2O_2$: The ClO· radical from the previous reaction destroys a second ozone molecule and regenerates the original chlorine atom, which can repeat the first reaction and continue to destroy ozone.

Or

$ClO\cdot + O\cdot \longrightarrow Cl\cdot + O_2$, which means the 'destructive' $Cl\cdot$ atom free radical is still around as explained by Rowland (2006).

Furthermore, there is no deliberate effort to link the concept which is covered under the organic chemistry subtopic of substitution reactions and the mechanism under which ozone is depleted; the reaction depicted below proceeds by formation of radicals:

Substitution reaction in organic chemistry as presented in the approved textbooks

$$CH_4 + Cl_2 \longrightarrow CH_3Cl + HCl$$
$$CH_3Cl + Cl_2 \longrightarrow CH_2Cl_2 + HCl$$
$$CH_2Cl_2 + Cl_2 \longrightarrow CHCl_3 + HCl$$

$$CHCl_3 + Cl_2 \longrightarrow CCl_4 + HCl$$

The two concepts seem to exist in isolation because there is no link that is deliberated established.

The issue of ozone depletion deserves an in-depth coverage because it is proved to be a misunderstood topic not only by pupils (Boyes & Stanisstreet, 1997) but by pre-service teachers (Khalid, 2001). Khalid found that major misconceptions amongst pre-service teachers such as: the increased greenhouse effect may cause skin cancer, ozone depletion may cause global warming, and ozone is a multifunctional layer. The content as presented in the chemistry 12 textbook does little to resolve any misconception that the pupils might have but the factual presentation of the issues seems to be of prime importance. In the absence of suitable experiment to demonstrate ozone layer depletion, analogies can be included in a textbook or module.

**Acid Rains by $H_2SO_4$: T**his unit explores how acid rain formation is covered with reference to other related concepts of chemistry taught elsewhere in the curriculum.

The cause of sulphuric acid rains, as explained in the approved chemistry textbook, and its polluting effects is known to proceed as:

$$SO_2(g) + O_3(g) + H_2O(l) \longrightarrow 2H_2SO_4(aq) + O_2(g)$$

The acid dissolves in the rain and can result in a pH of 2.0.

There is no deliberate effort to explain further that the laboratory preparation of sulphuric acid is similar to the natural formation of acid rains. The reaction, which is effectively a two stage process, involves ozone splitting into nascent oxygen and an oxygen molecule, which is responsible for the oxidation. The nascent oxygen oxidises $SO_2$ to $SO_3$ which then combines with $H_2O$ to form $H_2S_2O_3$ and subsequent formation of $H_2SO_4$ upon further dilution.

The concept of pollution due to acid rain caused by $H_2SO_4$ and preparation of $H_2SO_4$ are not explicitly explained and the link between them not well established.

Preparation of sulphuric acid as presented in the approved grade 12 chemistry textbook proceeds as:

$$S(s) + O_2(g) \longrightarrow SO_2(g)$$
$$2SO_2(g) + O_2(g) \longrightarrow 2SO_3(g)$$
$$H_2O(l) + 2SO_3(g) \longrightarrow H_2S_2O_7(l)$$
$$H_2S_2O_7(l) + H_2O(l) \longrightarrow 2H_2SO_4(l)$$

**Acid Rains by $HNO_3$:** This unit presents the pollution caused by acid rains due to nitric acid.

The cause of acid rains in form of nitric acid as explained in the approved chemistry textbooks and its polluting effects occurs via a number of steps as shown:

Preparation of Nitric acid

$4NH_3(g) + 5O_2(g) \longrightarrow 4NO(g) + 6H_2O(g)$

$NO(g) + O_2(g) \longrightarrow 2NO_2(g)$

$3NO_2(g) + H_2O(l) \longrightarrow 2HNO_3(aq) + NO(g)$

The acid dissolves in the rain and can result in a pH of 2.0. The same observation as discussed for sulphuric acid applies for the case of nitric acid.

In addition, the pupils are asked the following question: "What concentration of nitric acid ($mol/dm^3$) has a pH of 2.0?" The relevance of the activity is weak. The question lacks any meaningful context and how answering such a question is environmentally useful. It is more useful to ask the question in terms of a narrative of a town or real location where there was water pollution from acid spills, for example the mining town of Mufulira had its drinking water polluted due to acid spillages caused by an accident (as reported in the press by "Zambia: MCM Acid Spillage" (2008)). From a background of a real life situation, then the student can be asked to calculate the concentration of the acid and produce a research report about the impact on the marine species, the environment and citizens of Mufulira town. Relevance can come from the way something is taught; it does not have to come from the content itself (Keller, 1987). This study endeavoured to produce relevance in EE by appropriate teaching methods and content supported by sound theory.

Negative effect(s) of acid rains as explained in the 12th grade chemistry textbook are that many buildings or even marble in cities are attacked by acidic rains. The acid attacks them readily according to the reaction:

$CaCO_3(s) + H_2SO_4(aq) \longrightarrow CaSO_4(s) + CO_2(g) + H_2O(l)$

This reaction demonstrates a typical acid-base reaction and generally how a salt can be prepared by neutralising an acid with excess base. The topic should have been linked to other broader concepts of chemistry covered in the 11th grade. This process can be explained both in terms of destructive effects of pollution and also how a useful salt can be prepared from an acid. This reaction is also useful because it depicts how acidic soils can be neutralised to make them more suitable for crops which cannot tolerate lower pH. A balanced view should be presented in science.

**Nitrate Pollution:** This unit explains how the nitrate can cause water pollution as explained in the approved chemistry 12 textbook.

> The nitrates act to fertilize the growth of green matter – plants and algae – in the water. The extra growth is called eutrophication. When the plants or algae die they rot and use up the oxygen in the water faster than it can be replaced from the air. The water becomes anoxic

> (without oxygen) and nothing can live in it. If the water receives extra phosphate – for example from detergents washed into the water or phosphate rich earth. In these circumstances nitrate and phosphate fertilisers can be pollutants.

In the grade 11 textbook (Mukuma, Swazi & Chirwa, 1996), the pupils are required to learn about testing for the presence of various ions, and among then $NO_3^-$ detection, as explained in Table 11. It is explained that "the reagent reduces the nitrate ions to ammonia. The ammonia is not very soluble in hot liquid and comes off as a gas. Ammonia is the only alkaline gas. Devarda's alloy contains aluminium (45%), Zinc (5%) and copper (50%). This test is safer than the **brown ring test**, which needs concentrated sulphuric acid" (p. 149).

However, the teaching of nitrates pollution is not linked to the chemistry concept of how to test for nitrates in the water contaminated with nitrates. It is not clear what present and future application of the concept of testing for nitrates and indeed other ions that pupils are required to learn. No well-established link between the two concepts, nitrate pollution and testing for nitrates.

**Table 11.** Test for nitrate ($NO_3^-$) as presented in the Grade 11 Chemistry Textbook

| Conditions for the test | Reagent | Positive observation |
|---|---|---|
| To solid salt add sodium hydroxide solution and heat gently | Devarda's alloy (or aluminium powder) | Colourless gas which turns damp red litmus paper blue (the gas is ammonia) |

**Pesticide pollution:** This unit presents the issue of pesticides as a local problem. The idea presented under this section is not fully representative of the effects of DDT. It explains that DDT was particularly problematic to birds because the eggs they laid after exposure to the chemical failed to hatch and bird population began to fall subsequently affecting the food to animals up the food chain.

However the following account, and of equal importance, about DDT pollution is not explained or taught in the chemistry. The other scenario which is not mentioned, to give a more comprehensive picture, is that DDT is water insoluble and lipid (fat) soluble. This means that DDT will not dissolve in water, but will in the fats of organisms. Being insoluble in water makes it difficult to wash away in the environment (pupils can inspect a beaker smeared with oil and check if they can easily wash it with water). Cooking oil, like DDT, is also insoluble in water (the pupils can acknowledge how difficult it to wash cooking oil with water only). DDT is fat soluble implying that once they eat food (either vegetables or meat products contaminated with DDT) it will dissolve in their body fat. Once DDT gets in there, it lingers on. Because DDT dissolves in the body, it can build up in the body if the organism continues consuming food with DDT. This build-up of DDT is referred to as accumulation until saturation is attained (just as continuously pouring sugar in a fixed amount of water cause saturation). At the point of saturation, any more DDT will not dissolve in the animal fats (lipids). Accumulation, inevitably leads to another problem with DDT known as biomagnification. Biomagnification occurs when DDT becomes more concentrated as you go up the food chain as smaller animals are eaten by bigger animals (Metcalf, 1977). This means that animals (like human beings who feed on both plants and animals of all sizes) on top of the chain can potentially have the highest concentrations of DDT. The next section will endeavour to analyse the visual images that accompany the teaching and learning of EE.

## 3.6 An in-depth visual image analysis of the environmental educational content

One of the means by which the techno-scientific texts for non-specialists accomplish the re-contextualisation is the discursive interplay of a variety of available modes as potential resources for meaning making in them. Among such modes a significant one is the visual mode and despite the fact that we believe that it is exactly the inter-play of the visual images with the written text that contributes to the expansion of the meaning making potential of the texts (Dimopoulos, Koulaidis & Sklaveniti, 2003).

Dimopoulos Koulaidis and Sklaveniti adopt the position that visual images are autonomous systems of communication that do not simply reproduce reality but produce images of reality which are bound up with the interests of the social institutions (school and mass media) within which the pictures are produced, circulated and read.

The concept of framing will be partly used in the textbook analysis. According to Bernstein (2003, p. 36) “Framing refers to the principle regulating the communication practices of the social relations within the reproduction of discursive resources, that is, between transmitters and acquirers.” Bernstein distinguishes between into strong and weak framing. In strong framing the transmitter controls the selection, organisation, pacing, criteria of communication and the position, posture, and dress of the communicants, together with the arrangement of the physical location. In weak framing, the acquirer has more control over the selection, organisation, and pacing, criteria of communication and over the position, posture, and dress, together with the statement of the physical location.

In the education context, Dimopoulos, Koulaidis and Sklaveniti contend that strong framing means that the control belongs clearly to the teacher while weak framing means that there is some apparent space left to the student so as to exert his/her own control over this process. The issue of the pedagogic control is heavily influenced by the social hierarchies established as well as the degree that the pedagogic message can be negotiated by its addressees. Therefore the notion of framing can be conceptually further elaborated by referring to the dimensions of: a) the imposition of the teacher (textbook writer(s)) over the pupil, and b) the teacher's control of the conditions for the pupil's involvement. Strong framing, as far as the imposition relationships are concerned, means that the pupil is found in a powerless social position during the pedagogic process while weak framing means that he/she becomes empowered so as to exert his/her own control over the communication process that takes place in the science classes. Furthermore, strong framing as far as the conditions for the pupil's involvement is concerned, means that these conditions are fully predetermined without the student having any control over them while weak framing means that the pupil has the potential for negotiating them.

The visual images analysed are those of the grade 12 chemistry textbook approved for use in Zambian schools. The whole textbook was not analysed but the topic dealing with pollution and pollution control.

Five images extracted from the grade 12 chemistry textbook were the focus of the visual image analysis. These images were analysed using three dimensions. The first dimension concerns all the elements involved in their syntactic construction that denote the degree of their content specialisation (classification).

The second dimension corresponds to the social-pedagogic relationships that tend to be established between the message of the images and their viewers (framing). This second dimension is further subdivided into two finer dimensions, one addressing the issue of the imposition relationships established by the reading of each image and another corresponding to the degree an image prompts its viewers to actively participate in the processing of the visual meaning (e.g. thorough observation, imaginary handling, etc.).

The third dimension corresponds to the degree of abstraction characterising the images used in techno-science (i.e., formality of the visual code). These three dimensions consist of variables that become operational applying a specific socio-semiotic analysis of the grammar of their visual design as explained by Kress and Leeuwen (2006).

## Classification


(a) (b)

**Figure 8.** Industrial pollution in Zambia (a) and (b)
Source: Mukuma, Swazi and Chirwa (1997, p. 164 & 165)

**Figure 9.** Pesticides used in Zambia
Source: Mukuma, Swazi and Chirwa (1997, p. 168)

The content specialisation (classification) of the visual images is assessed using the variables of their type and function. With regard to their type, the visual images, can be characterised as realistic, conventional and hybrids. All the visual images that represent reality according to human visual perception are considered as realistic (Figure 8 and Figure 9). In this category belong both photographs and drawings.

All the visual images that represent reality in a codified way are considered as conventional (Figure 10). These representations which are usually graphs, maps, flowcharts, molecular structures and diagrams, are constructed according to the technoscientific conventions and are important to the scientific writing.

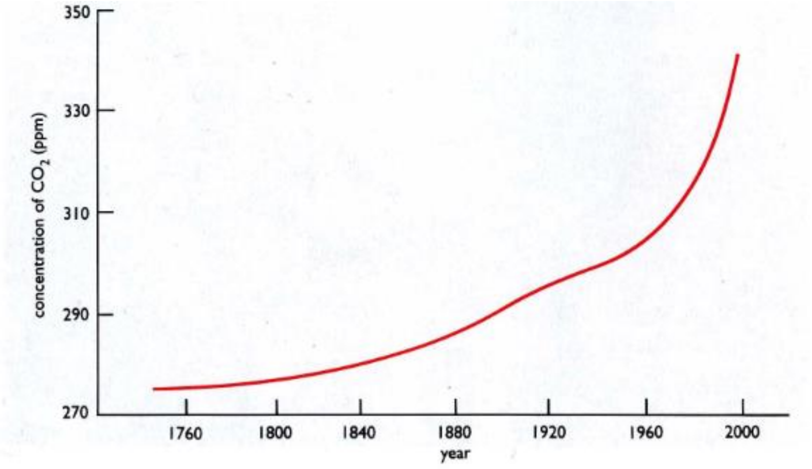

**Figure 10.** Concentration of carbon dioxide in the atmosphere (parts per million – ppm)
Source: Mukuma, Swazi and Chirwa (1997, p. 166)

The final category is the hybrid category. Hybrids include all the images in which elements from both the above two types (realistic and conventional) co-exist. These are usually conventional representations with added on realistic features. In this way the conventional nature of these representations is moderated by the appearance in them of naturalistic figures. According to Dimopoulos Koulaidis and Sklaveniti the conventional images correspond to strong, the hybrids to moderate and the realistic to weak classification.

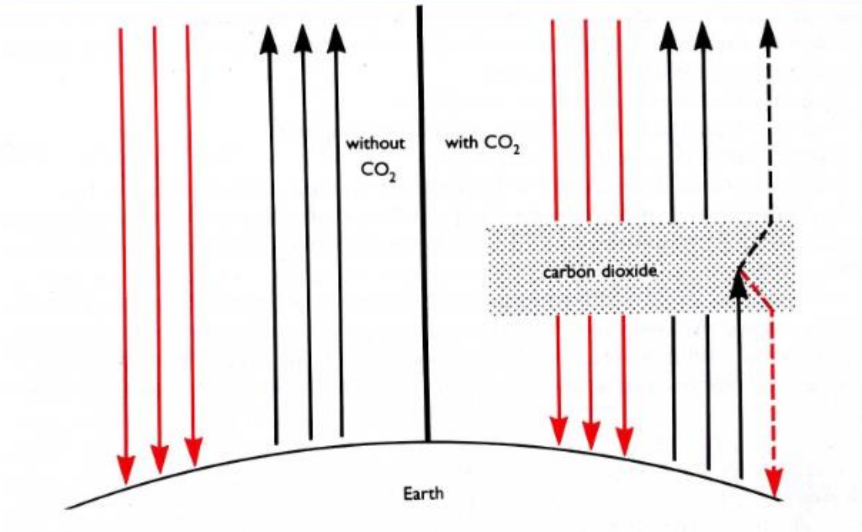

**Figure 11.** The 'greenhouse' effect of carbon dioxide in the atmosphere
Source: Mukuma, Swazi and Chirwa (1997, p.167)

Furthermore, the visual images according to their function are divided into narrative, classificational, analytical and metaphorical processes. Narrative processes (or images) are those that serve to represent “unfolding actions and events, processes of change and transitory spatial arrangements” (Kress & Leeuwen, 2006, p. 59). This category of images are represented by a vector either shown explicitly or imaginarily implied (e.g. the directionality of a man’s hand about to drink water corresponds to an imaginary vector). Narrative representations are usually used in the examined EE content in order to illustrate technical (e.g. experimental procedures) or natural processes (e.g. greenhouse effect of carbon dioxide, Figure 11). The linguistic equivalent of narrative representations is that of the action verbs.

In classificational images at least one set of participants will play the role of subordinates with respect to at least one other participant, the superordinate (Kress & Leeuwen, 2006). The super-ordinate may be either explicitly shown in the illustration, or indicated in the accompanying text or even inferred by the viewer according to his/her own experience. In other words, classificational images are those that exhibit types of relationships between places and things represented in them. Such images are used in scientific texts when the objects of the natural world are to be represented in terms of a hierarchical order and when the main concern of the text is the ranking of phenomena from the perspective of a single unifying term. The linguistic equivalents of classificational images are expressions like ‘this belongs to’ or ‘this is the kind of’ (Dimopoulos, Koulaidis & Sklaveniti, 2003).

Analytical images are those that focus on the relationships between the objects of representation in terms of a part-whole structure. They involve two kinds of participants one which is the Carrier (the whole) and any number of possessive Attributes (the parts) (Kress & Leeuwen, 2006). The parts of the whole may be labelled as in a cell structure diagram or it may be left up to the viewer to do so. As a whole, an analytical image corresponds to the linguistic equivalents “this is” or “this comprises of”. The images are about the way different attributes fit together to make up a larger whole.

Finally, metaphorical images are those that “connote or symbolise meanings and values over and above what they literally represent” (Kress & Leeuwen, 1996, p. 45). The represented participants in these images are conventionally associated with specific cultural symbols. Inbar (1996) argues that metaphorical images can be a fruitful springboard for teacher training and changing educational practice.

Both analytical and classificational images belong to the techno-scientific ways of representing things and hence they promote strong classification (Dimopoulos, Koulaidis & Sklaveniti, 2003).

Combining the results of the above two variables of type and function, one can estimate the degree of the content specialisation promoted by visual images (classification). The images promoting strong classification build up strong boundaries between the specialised techno-scientific knowledge and every day knowledge are those which are conventional or hybrids and at the same time analytical or classificational. Conversely, the images characterised by weak classification are the realistic and the narrative or metaphorical ones. All the other combinations correspond to moderate classification.

In order to operationalize states that the imposition relationships that tend to be established between images and viewers (first dimension of framing), Dimopoulos, Koulaidis and Sklaveniti use the variable of the vertical angle of shot. The vertical angle of shot represents visually exactly these imposition relationships.

**Table 12.** The grid of analysis

| | **Formality of visual images** | | |
|---|---|---|---|
| **Markers of classification** | **Strong** | **Moderate** | **Weak** |
| Type of visual image | Conventional | Hybrid | Realistic |
| | **Strong** | | **Weak** |
| Function of visual images | Classificational, Analytical | | Narrative, Metaphorical |
| **Markers of framing** | **Strong** | **Moderate** | **Weak** |
| Vertical angle of shot | Low angle | Eye-level | High angle |
| Distance of shot | Distant | Medium | Close |
| | **Strong** | | **Weak** |
| Horizontal angle of shot | oblique | | Frontal |

Source: adapted from Dimopoulos, Koulaidis & Sklaveniti (2003)

Specifically, if an image is shown from a low angle, this depicts a relationship in which the content of the image imposes over the viewer and hence the framing is strong. If an image is shown at the eye-level of the viewer, this depicts a relationship in which the content of the image has equal power with the viewer and hence the framing is moderate. Finally, if an image is shown from a high angle, this depicts a relationship in which the viewer imposes over the content of the image and hence the framing is weak (Figure 8 & 9).

The horizontal angle of shot signifies the degree of familiarity that the viewer can have with the content of an image and it takes the values of frontal and oblique angle. According to Kress and Leeuwen (2006, p. 136) “The difference between the frontal and the oblique angle is the difference between familiarity and detachment.” The message of the frontal angle is that “what you see here is part of your world, something you are familiar with” while the corresponding message of the oblique angle is that “what you see here does not belong to your world, it is something mysterious that you are not accustomed with.”

The combination of the values of the two previous variables (distance and horizontal angle of shot) determines the overall value of the framing as far as the degree of the viewer’s virtual involvement with the images is concerned. In particular, visual images characterised by frontal angle and close or medium shot are considered as corresponding to maximum level of involvement (weak framing). Those characterised by either frontal angle and distant shot or oblique angle and close shot are considered as corresponding to moderate level of involvement (moderate framing). Representations characterised by oblique and medium or distant shot are considered as corresponding to minimum involvement (strong framing). Since framing determines the social positions of students in terms of both the imposition and the degree of involvement (intimacy) they are allowed, the combination of the values for both dimensions gives an overall estimate of framing. Specifically, the combination of framing in terms of imposition relationships with framing in terms of the students’ degree of involvement (intimacy) gives an overall strong framing if both these dimensions are characterised by strong framing, weak if both are characterised by weak framing and moderate in all other cases (Dimopoulos, Koulaidis & Sklaveniti, 2003).

### 3.7 Major findings on textbook analysis of environmental education content

Analysis of the textbooks show that the content is mostly dealt with in a theoretical and abstract manner. Inevitably the teachers are forced to use mostly lecture method because, to a large extend, that is what the curriculum implicitly demands them to do.

The analysis of science textbooks can provide important information not only on trends in the construction and dissemination of scientific knowledge, but also on its teaching and learning (Souza & Porto, 2012). From the Zambian chemistry textbook analysis, which looked at how the EE topics are structured (which also provided a blueprint of how lessons are conducted), classroom activities are altogether omitted. Topics are treated from a theoretical perspective and no hands-on activities are mentioned or suggested on all aspects of the environment (water, land and air pollution). In line with the findings of the textbook analysis, MOESVTEE (2012) ironically writes that most of the teaching and learning in Zambian schools is done theoretically, even for practical and science subjects. The real curriculum is what teachers teach; in Zambia, this can be found in the approved textbooks. The topic(s) on EE is left to the creativity of the teacher. Depending on the creativity, and discretion, of the teacher the EE issues can be covered with some practical activities or purely by lecture method. It is clear that the intended learning outcomes and objectives using the current system cannot be achieved by the prevailing teaching tools and strategies. The findings of the comparison of the syllabus objectives and the textbooks found incongruity. There is a poor match of the EE related content in the syllabus and textbooks. Furthermore, Chabalengula and Mumba (2012) argue that there is incongruence in inquiry levels emphasized in textbooks and examination. The problem of mismatch of the curriculum documents (national policy, syllabus, textbooks objectives and examinations) is at several levels; syllabus to textbooks and textbook to what is examined in the national examination.

There is urgent need to device appropriate instructional strategies which carefully link all the objectives from the national policy, syllabus and textbooks; and in the process encourage of learners' creativity.

Analysis of the Zambian curriculum exposes a number of weaknesses as the content which addresses environmental related aspects is dealt with descriptively; does not require pupils to do practical work in EE and to engage and connect with the local environment; the content is more geared for rote learning and examination.

Analysis of the textbook visual images on EE reveal that of the current five images, two falls in the category of realistic images/narrative images and two are conventional images/narrative images. Using Table 12 as the grid of analysis, Figure 8 (a) and (b) and Figure 9 can be classified as Realistic, Analytical, and High angle close, oblique. On the other hand, Figure 10 is classified as conventional, and narrative. The analysis did not review any hybrid images because none are included in the textbooks. There is however a good balance between realistic and conventional images. Images that are classificational and metaphorical are altogether missing from the textbook' EE content. The images generally being realistic and conventional, narrative and analytical can be said to be portray EE as striking a balance between everyday experiences and science as belonging to the body of experts' knowledge. On the markers of framing, the realistic representations (pictures) were taken at high angle and at close range. This implies a relation in which the viewer imposes on the content of the image and hence weak framing. Weak framing implies that pedagogic practice is likely to be invisible and the acquirer, in this case the pupils, has more apparent control, the rules of regulative and instructional discourse are implicit and largely unknown to the acquirer. Constantinou and Zembylas (2003, p. 17) argue that "the distance of shot regulates the level of intimacy that is possible to be established between what is represented and the visitor and takes the values of close, medium and distant shot, which correspond to an intimate/personal, social and impersonal relationship respectively." The realistic images were taken at an oblique angle. The images taken at an oblique angle are considered as corresponding to minimum level of involvement or strong framing. The findings suggest that the realistic (corresponding to weak classification) and analytical images (corresponding to strong classification) strikes a balance. According to Dimopoulos, Koulaidis and Sklaveniti, strong classification formulates well-defined borderlines between techno-scientific knowledge and everyday knowledge. The contents of these categories are clearly segregated while weak classification results in vague or blurred borderlines between them. The images create a sense of empowerment to their viewers so as to maintain their own control in the communication-pedagogic process, because they corresponds to weak framing (high angle at close range). Strong framing (taken at an oblique angle) implies less empowerment to their readers to maintain their own control in the communication-pedagogic process. The conventional images corresponding to strong framing were also narrative, corresponding to weak framing, achieves a balance between the markers of classification. Strong classification formulates well-defined borderlines between EE knowledge and everyday knowledge, that is, the contents of these categories are clearly segregated while weak classification results in vague or blurred borderlines between them.

Criticisms of the EE visual images in the approved grade 12 textbooks (for example Figure 8) are: that there is no reference of the figures in the main text; there is no mention of the type of pollution (e.g. oil spill, failing sewer system, organic compounds, heavy metals, mine effluent etc.) problem being portrayed by the images; impact of the pollution, as described in the figure cation, on pupils and society is not cited; the site location is not identified, thus detaching the pupils from the problem (it encourages perception of the problem as not being in their backyard); does not mention concentration levels of the mentioned pollution; Does not mention if that is a daily problem or seasonal occurrence; and does not mention the solution to the identified problem.

It can be concluded that EE content is not suitable for delivering effective EE knowledge. The content fails to meet the standards set in the national policy stipulating that it will be necessary, in science as in all other subjects, for pupils to be enabled to apply their own ideas, use their own hands, and conduct their own investigations. It also fails to effectively use the local environment as an educational resource for the enlightenment of the pupils.

From the first educational policy published in 1977 to the current one enforce (MOE, 1996), emphasis has been placed on relevance of the knowledge taught to the learner. In fact the supplementary document (MOESTEE, 2012) which guides on how the policy (MOE, 1996) should be implemented clearly indicates in one of its objective that it aims at defining the basic values of the education system and help education providers to translate them into the teaching and learning experiences, taking into account the local and cultural environment. So evidence that the local and cultural environments are integrated in the teaching learning process is absent. One of the general aims of the syllabus (CDC, 2012) indicates that what is to be taught should be able to develop abilities and skills that are useful in everyday life and encourage efficient and safe practices. The textbooks fall short of this recommendation or aim. The misrepresentation of facts and concepts and failing to build on lower order skills to more complex tasks involving evaluating, analytical and creating skills, all work against its suitableness as EE content. It also goes against what is written under the assessment objectives of the syllabus (CDC, 2012, p. viii) that the candidates (or pupils) should be able to: locate, select, organise and present information from a variety of sources; translate information from one form to another; manipulate numerical data; identify patterns and draw inferences from information; give reasonable explanations for patterns and relationships; make predictions and hypotheses; solve problems. There is no evidence that these skills are overtly being promoted.

The visual images used in the textbooks convey little meaning and impact on the pupils because of lack of context in which the images are to be interpreted; in short they are meaningless visual images and does little to connect the pupils to the local environment by way of raising awareness. The syllabus (CDC, 2012), as judged by the *Content section*, *Objectives (PSBAT) section* and *Notes section*, do not suggest any inquiry activities or guidelines on how to implement inquiry-based science teaching. Some prominent words to describe the objectives include: describe, explain, discuss, relate, state and outline. The Zambian curriculum is, overall, not suitable for effective delivery of EE. All aspects presented herein have a lot of room for improvement. They can be: suitably aligned to match up with the policy objectives; and appropriate alignment of the syllabus guideline aims and objectives to match the content therein; the content of the syllabus and the approved textbooks can be improved upon. More suitable activities can be introduced as explained in Chapter 9.

For any qualitative change from the status quo, EE in Zambia must undergo a paradigm shift. Rote learning and teaching of concepts should be supplemented with proven learning techniques which encourage creating, applying, evaluating and analysing of information to arrive at a rational decision. Inquiry skills should be supported and strengthened through a number of activities. It is also cardinal that future textbooks for use in Zambia should be more streamlined to follow the syllabus guidelines to and to be more focused about local the environment. The syllabus guidelines should in turn be more streamlined to be explicit on hands-on activities and the levels of inquiry expected. Subsequently, the education system should then be responsive to the needs of society. If education is serve the needs of society, there should be mechanisms put in place to continuously identify those needs.

The next chapters (Chapter 4, 5, & 6) will endeavour to identify some of the needs with regards to water hazards found in the Zambian environment. The extent of the problems relating to water quality were clarified. Chapter 7 will then focus on how pollutants can detected at high school level so that pupils became put of the task of environmental monitoring. Pollutant detection alone is not sufficient, and so it is cardinal that pupils are equipped with skills on pollutant treatment (Chapter 8) where water is already contaminated and necessary attitudes for preservation of ecosystems by pollution prevention.

# Chapter 4

## 4. Water quality analysis of common ions, DOC and miscellaneous other parameters

### 4.1 Introduction

Surface and ground water resources are threatened by pollution from release of dissolved substances including inorganic ions and organic compounds such as oils, into rivers, wetlands and ground water from industrial activity in Zambia. Cement waste, molasses and bagasse, textile sediment sludge, petroleum, paint, pesticides, fungicides, human waste, fertilizers from farms/gardens, and lime sludge from industries in Lusaka, Kafue and the Copperbelt, all continue to find their way into water systems through direct discharge, seepage or overflow to ground and surface water courses (Chundama, 2008). To mitigate some of these problems, it is strongly recommended that there be adequate supervision on what type of sanitation is used in different areas depending on the geology and hydrology of the area; solid waste should be seen as a serious threat to water resources and the solid waste hierarchy of reduce-reuse-recycle should be followed in solid waste management activities (Nakamboa, 2005).

Many studies cite groundwater quality data as evidence of sewer-related contamination (Baird and Cann, 2008; Marquita, 2010). Common indicators cited include bacteria, nitrate, ammonium and various organic compounds (Misstear and Bishop, 1997). Furthermore, potassium and boron are also considered to be amongst the substances indicative of contamination by sewage (Whitehead, Hiscock & Dennis, 1999).

In areas without mains sewage system, runoff water from washing and flushing is conducted to pit latrines and sometimes absorber wells, so again recharges groundwater and hence a source of pollution (Khazai and Riggi, 1999). Foster, Morris and Lawrence (1993) argue that, in such a situation about 90% of the water supply will end up as recharge to groundwater. Septic tank systems are frequently reported sources of localised groundwater pollution and in some cases regional groundwater problems have also been recognised in areas of high septic tank density resulting in degradation of groundwater. One common reason for degradation of the above is that the capacity of the soil to absorb effluent from the tank has exceeded the limit, and the waste added to the system moves upwards. Many other pathogens, such as typhoid, cholera, streptococci, salmonella, poliomyelitis, and protozoans are transmitted by septic tank systems (Chandra, Kirk & Watkins, 1997). This view is further supported by Foster et al. (1999) who contends that urban [or rural] residential districts without, or with incomplete, coverage of mains sewage system, seepage from unsewered sanitation systems such as septic tanks, cesspits and latrines probably represents diffuse pollution sources. Ironically, Barret and Howard

(2002) states that despite the importance of groundwater to urban and urbanising regions in Sub-Saharan Africa, there are few published studies of urban groundwater in this region, and a detailed scenario of the urban impacts on groundwater quality does not exist.

In Lusaka, there are three major types of sanitation services namely: water borne sewer system provided by Lusaka Water and Sewerage Company (LWSC); septic tanks; and pit latrines. The coverage of water borne sewer system is about 30% of the total area which the LWSC supplies water (ECZ and LCC, 2008). With this meagre 30% coverage, and bearing in mind that an adult human being excretes around 4 kg of nitrogen per year (Barret and Howard, 2002), it is our contention that there is massive input of nitrogen into the soil, and eventually groundwater in Lusaka and other towns lacking adequate sanitation. Furthermore, urine stream is known to contain a substantial amount of nitrogen, about 8.5 mg/day and 2 mg/day of phosphorus (Green, 2003; Pickford, 1995) which is either potentially recoverable or a problem to treat. The fate of this nitrogen and phosphorus is usually in pit latrines and open ground or in stormy water runoff and subsequently combines with surface and groundwater. The consequences are obvious when it comes to health status of the general citizenry. In addition, the shallow geology and hydrogeological regime of Lusaka is of crucial importance when trying to predict the effect of urbanisation on groundwater. Furthermore, it is also important to acknowledge that nitrate contamination is the subject of extensive research because of its potential hazard resulting in Mathaemoglobinemia (Fan and Steinberg, 1996), hypertrophy of the thyroid (van Maanen et al., 1994), and diabetes (Parslow et al., 1997). Zeb et al. (2011) argues that a regular monitoring of water bodies with required number of parameters in relation to water quality prevents the outbreak of diseases and occurrence of hazards.

Lusaka is built over a karstic dolomite aquifer and ground water accounts for 61 per cent of the total water supply within Lusaka; ironically, there has been a registered increase in the amount of waste generated such that by 2006, it was estimated at 242,803 metric tons (ECZ & LCC, 2008). The fate of this waste is usually in landfills, which consequently are sources of contamination for groundwater, and may result in disease-related problems, with associated risk to the environment (Magmedov and Yakovleva, 1997; Baird and Cann, 2008). This view is reinforced by Lerner et al. (1999) who contend that urban sources of nitrogen in groundwater include leaking sewers, leaking water mains, landfills and industrial chemical spillages. Even with a developed sewer system in the UK, Lerner et al. report that sewers contribute about 13% of nitrogen loading, leaking water mains contribute about 36% and the remaining 50% of the nitrogen loading includes parks, gardens, landfills and industries. With an underdeveloped sewer system and the widespread use of illegal landfills in Lusaka and other Zambian towns, the nitrogen loadings and other pollutants from these sources can be assumed to be high and hence the need to do a comprehensive study not only in Lusaka but also in the various provinces. Zambia has an abundance of groundwater well distributed in many parts of the country of which the best known aquifer is nearly 25,000 km$^2$ in size extending from Lusaka to the Copperbelt region (ECZ, 2008). Our premise is that unplanned urban development and especially development in recharge areas have resulted in increased pollution in this aquifer, which also happens to be the most populated. It is the source of groundwater for major cities and towns like Lusaka, Kabwe and Ndola.

In Zambia, most of the waste is disposed of in un-designated places, burnt, buried in the yard or recycled and there is no separation of the various types of waste. It can be argued that leachate from the waste has resulted into ammonium and other pollutants (Mocanu, Mirca & Albu, 1997). And considering the fact that there is aged waste from old dumps and the on-going dumping or recent waste, it can be said with certainty that ground water is currently being affected by contamination from both modes, that is, from recent and aged waste leachate contamination.

The Kafue, one of the country's main rivers, is threatened by industrial activity and residue from agriculture run off. Pollutant accumulation within the Kafue ecosystem has been associated with various toxicological manifestations. The disappearance of Hippopotamus amphibious from the Kafue River in Chingola, the proliferation of water hyacinth and the bioaccumulation of heavy metals within wildlife liver tissue have been associated with pollutants in the Kafue River ecosystem (Choongo, Syakalima & Mwase, 2005; Nakayama et al., 2010; von der Heyden and New, 2003).

No comprehensive research has been done in Zambia, covering a vast area, to accurately determine and compare the loadings of nitrogen and other pollutants in different areas and from different sources. The study's objective therefore was to carry out an evaluation of the portable water due to non-functioning social facilities, industries and general negative attitudes of the citizens to prudent management of their surroundings. The study further aimed at isolating areas of poor water quality and to sensitise stakeholders and interest groups and individuals on the state of the water quality in Zambia.

## 4.2 Results

The Copperbelt Province and North-western Provinces (CB/NW) were analysed as one entity because the latter did not have sufficient data to analyse separately. At face value, comparison of Table 13 and Table 14 reveals that the Copperbelt region/North-western Province had the most parameters whose average concentration exceeded the averages values obtained from the other provinces.

An in-depth discussion was done to determine if the observed mean differences for CB/NW were significantly different across the regions and to determine which parameter(s) was significantly higher compared to others. Furthermore, the result of the analysis of ground versus surface water pollution is reported in the subsequent sections.

**Table 13.** Averages, maximum, minimum values and standard deviations of the twenty-two parameters in the three provinces and their corresponding PVs

| **Copperbelt Province/North western Province** | | | | | | | **Lusaka Province** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter Analysed | PV (Drinking) | PV (Waste Water) | Max | Min | SD | Average | PV (Drinking) | PV (Waste Water) | Max | Min | SD | Average |
| **pH** | | 6-9 | 8.36 | 6.73 | 0.39 | 7.77 | | 6-9 | 8.44 | 5.75 | 0.46 | 7.63 |
| **Temp °C** | | | 27.00 | 22.00 | 0.93 | 24.23 | | | 26.30 | 20.70 | 1.40 | 23.47 |
| **$SO_4^{2-}$** | 400.00 | 1500.00 | 1659.72 | 0.47 | 396.93 | 197.12 | 400.00 | 1500.00 | 105.33 | 0.47 | 24.74 | 29.48 |
| **$Cl^-$** | 250.00 | 800.00 | 598.24 | 0.09 | 138.22 | 61.23 | 250.00 | 800.00 | 72.92 | 0.63 | 17.10 | 19.15 |
| **$NO_3^-$** | 10.00 | 50.00 | 11.54 | 0.00 | 2.76 | 1.26 | 10.00 | 50.00 | 127.56 | 0.00 | 24.22 | 19.10 |
| **$Na^+$** | 200.00 | nd | 37.13 | 2.40 | 10.96 | 12.41 | 200.00 | nd | 108.77 | 0.53 | 25.68 | 35.18 |
| **$NH_4^+$** | 1.50 | 10.00 | nd | nd | nd | nd | 1.50 | 10.00 | 6.49 | 0.17 | 2.29 | 3.09 |
| **$K^+$** | 250.00 | nd | 51.32 | 0.01 | 9.97 | 6.84 | 250.00 | nd | 43.48 | 0.01 | 7.88 | 4.54 |
| **$Mg^{2+}$** | 150.00 | 500.00 | 341.96 | 0.40 | 71.48 | 43.38 | 150.00 | 500.00 | 71.36 | 0.21 | 15.92 | 32.06 |
| **$Ca^{2+}$** | 200.00 | nd | 93.21 | 4.45 | 25.57 | 54.21 | 200.00 | nd | 108.98 | 0.83 | 22.75 | 54.63 |
| **DOC** | nd | nd | 2.44 | 0.19 | 0.59 | 1.26 | nd | nd | 5.77 | 0.05 | 1.62 | 1.51 |
| **$PO_4^{2-}$** | 0.02 | 0.03 | 1.00 | 0.16 | 0.26 | 0.39 | 0.02 | 0.03 | 3.20 | 0.10 | 0.74 | 0.46 |
| **$ClO^-$** | nd | nd | 0.32 | 0.32 | 0.00 | 0.32 | nd | nd | 0.53 | 0.14 | 0.10 | 0.26 |
| **$O_3$** | nd | nd | 0.70 | 0.32 | 0.17 | 0.46 | nd | nd | 0.39 | 0.27 | 0.05 | 0.35 |
| **$H_2O_2$** | nd | nd | 0.25 | 0.25 | 0.00 | 0.25 | nd | nd | 0.22 | 0.11 | 0.04 | 0.18 |
| **$CN^-$** | 0.10 | 0.20 | nd | nd | nd | nd | 0.10 | 0.20 | 0.06 | 0.03 | 0.01 | 0.03 |
| **Phenol** | 0.00 | 0.20 | 2.18 | 0.77 | 0.39 | 1.36 | 0.00 | 0.20 | 1.03 | 0.21 | 0.30 | 0.52 |
| **TH** | 200.00 | nd | 2080.00 | 26.00 | 530.89 | 495.91 | 200.00 | nd | 410.00 | 68.00 | 79.50 | 188.39 |
| **$CH_2O$** | nd | nd | nd | nd | nd | nd | md | nd | 0.23 | 0.19 | 0.01 | 0.21 |
| **$NO_2^-$** | 1.00 | 2.00 | 0.28 | 0.02 | 0.08 | 0.06 | 1.00 | 2.00 | 1.92 | 0.02 | 0.44 | 0.24 |
| **B** | nd | 0.50 | nd | nd | nd | nd | nd | 0.50 | 1.57 | 0.72 | 0.37 | 1.23 |
| **$SiO_2$** | nd | nd | nd | nd | nd | nd | nd | nd | 41.20 | 3.30 | 7.37 | 15.17 |

nd, not determined; all concentration values are in ppm

**Table 14.** The averages, maximum, minimum values and standard deviations (SDs) of the twenty-two parameters in the two provinces and their corresponding Permissible Values (PVs)

| **Central Province** | | | | | | | **Southern Province** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter Analysed | PV (Drinking) | PV (Waste Water) | Max | Min | SD | Average | PV (Drinking) | PV (Waste Water) | Max | Min | SD | Average |
| **pH** | | 6-9 | 7.74 | 7.63 | 0.06 | 7.69 | | 6-9 | 8.13 | 7.63 | 0.21 | 7.93 |
| **Temp °C** | | | 21.30 | 20.80 | 0.25 | 21.05 | | | 20.90 | 20.50 | 0.16 | 20.70 |
| **$SO_4^{2-}$** | 400.00 | 1500.00 | 11.01 | 4.14 | 3.43 | 7.58 | 400.00 | 1500.00 | 62.08 | 21.50 | 17.80 | 46.39 |
| **$Cl^-$** | 250.00 | 800.00 | 2.78 | 0.70 | 1.04 | 1.74 | 250.00 | 800.00 | 12.44 | 2.57 | 4.12 | 6.91 |
| **$NO_3^-$** | 10.00 | 50.00 | 10.16 | 4.46 | 2.85 | 7.31 | 10.00 | 50.00 | 48.41 | 0.00 | 19.86 | 25.58 |
| **$Na^+$** | 200.00 | nd | 5.92 | 3.55 | 1.18 | 4.73 | 200.00 | nd | 81.02 | 10.64 | 28.79 | 47.10 |
| **$NH_4^+$** | 1.50 | 10.00 | nd | nd | nd | nd | 1.50 | 10.00 | nd | nd | nd | nd |
| **$K^+$** | 250.00 | | 0.01 | 0.01 | 0.00 | 0.01 | 250.00 | | 9.66 | 2.90 | 2.77 | 6.14 |
| **$Mg^{2+}$** | 150.00 | 500.00 | 50.23 | 45.65 | 2.29 | 47.94 | 150.00 | 500.00 | 49.08 | 16.93 | 13.34 | 34.68 |
| **$Ca^{2+}$** | 200.00 | nd | 66.65 | 43.62 | 11.51 | 55.14 | 200.00 | nd | 58.19 | 31.00 | 12.31 | 48.35 |
| **DOC** | nd | nd | 0.39 | 0.27 | 0.06 | 0.33 | nd | nd | 5.39 | 0.36 | 2.06 | 3.00 |
| **$PO_4^{2-}$** | 0.02 | 0.03 | nd | nd | nd | nd | 0.02 | 0.03 | 0.25 | 0.10 | 0.08 | 0.18 |
| **$ClO^-$** | nd | nd | nd | nd | nd | nd | nd | nd | 0.15 | 0.15 | 0.00 | 0.15 |
| **$O_3$** | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| **$H_2O_2$** | nd | nd | nd | nd | nd | nd | nd | nd | 0.36 | 0.36 | 0.00 | 0.36 |
| **$CN^-$** | 0.10 | 0.20 | nd | nd | nd | nd | 0.10 | 0.20 | nd | nd | | nd |
| **Phenol** | 0.00 | 0.20 | nd | nd | nd | nd | 0.00 | 0.20 | 0.44 | 0.21 | 0.12 | 0.33 |
| **TH** | 200.00 | nd | 94.00 | 66.00 | 14.00 | 80.00 | 200.00 | nd | 200.00 | 74.00 | 51.55 | 134.67 |
| **$CH_2O$** | nd | nd | nd | nd | nd | nd | nd | nd | 0.41 | 0.41 | 0.00 | 0.41 |
| **$NO_2^-$** | 1.00 | 2.00 | nd | nd | nd | nd | 1.00 | 2.00 | 6.00 | 0.02 | 2.99 | 3.01 |
| **B** | nd | 0.50 | nd | nd | nd | nd | nd | 0.50 | nd | nd | nd | nd |
| **$SIO_2$** | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd |

nd, not determined; concentration values are in ppm

### 4.3 Statistical treatment of the results

### 4.3.1 Results across all the provinces

A one-way between-groups analysis of variance was conducted to explore the impact of location on pollution as measured by different methods. There was a statistically significant difference at the $p < 0.05$ level in nitrate levels: F (3, 68) = 5.2, p = 0.02. Despite reaching statistical significance, the actual difference in mean scores between the locations was not very big. The effect size, calculated using eta squared, was 0.2. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for Lusaka (M= 19.5, SD=24.7) was significantly different from CB/NW (M = 1.21, SD = 2.78), Central Province (M = 7.31, SD = 4.03), Southern Province (M = 25.6, SD = 24.3).

Furthermore, there was a statistically significant difference at the $p < 0.05$ level in sodium levels: F (3, 68) = 8.6, p = 0.00. The effect size, calculated using eta squared, was 0.3. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for Lusaka (M= 36.7, SD=25.7) was significantly different from CB/NW (M = 12.0, SD = 11.2), Central Province (M = 4.7, SD = 1.7), Southern Province (M = 47.1, SD = 35.3). Furthermore it was found that Southern Province differed significantly from CB/NW.

In addition, there was a statistically significant difference at the $p < .05$ level in total hardness: F (3, 68) = 8.6, p = 0.00. The effect size, calculated using eta squared, was 0.2. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for Lusaka (M= 187.9, SD=80.9) was significantly different from CB/NW (M = 496.0, SD = 543.4).

An independent-samples t-test was conducted to compare the pollution levels of ground and surface water. With reference to nitrate there was a significant difference in mean scores for ground water (M=25.9, SD = 26.9) and surface water (M =4.1, SD = 9.0); t (30.1) = 4.149, p= 0.000 (two tailed). The magnitude of the differences in the means was 21.8.

And with reference to sodium, there was a significant difference between ground water (M= 39.3, SD= 28.6) and surface water (M= 18.6, SD= 17.8); t (42.6) = 3.5, p= 0.01.

Furthermore, there was a significant difference in DOC levels between the water obtained from the ground (M= .90, SD = 1.2) and surface water (M= 1.8, SD= 1.5); t (67.5) = -3.0, p= 0.004.

### 4.3.2 Results for parameters obtained from Lusaka and Copperbelt Provinces

Independent-samples t-test was conducted to compare the pollution levels of the water obtained from the Lusaka and Copperbelt/North-western Provinces only, these include (Phenol, $NO_2^-$, $H_2O_2$, $O_3$, $ClO^-$, and $PO_4^{3-}$). With reference to phenol, there was a significant difference in scores for Lusaka (M=0.54, SD = 0.30) and Copperbelt/North-western Province (M =1.36, SD = 0.41); t (17) = -5.574, p= 0.000 (two tailed). The magnitude of the differences in the means was 0.81. The remaining parameters were not significantly different across the two provinces.

An independent-samples t-test was conducted to compare the pollution levels of the water obtained from the ground and surface water. With reference to the parameters listed above, there was no significant difference between ground and surface water.

### 4.4 Principal component analysis (PCA)

Principal Component Analysis (PCA) was performed only on the parameters that were analysed in all the five provinces (some parameters were not analysed in some provinces as shown in

**Table 15.** The averages, maximum, minimum values and standard deviations (SDs) of the twenty-two parameters in the two provinces and their corresponding Permissible Values (PVs)

| **Copperbelt Province/North western Province** | | | | | | | **Lusaka Province** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter Analysed | PV (Drinking) | PV (Waste Water) | Max | Min | SD | Average | PV (Drinking) | PV (Waste Water) | Max | Min | SD | Average |
| **pH** | | 6-9 | 8.36 | 6.73 | 0.39 | 7.77 | | 6-9 | 8.44 | 5.75 | 0.46 | 7.63 |
| **Temp °C** | | | 27.00 | 22.00 | 0.93 | 24.23 | | | 26.30 | 20.70 | 1.40 | 23.47 |
| **$SO_4^{2-}$** | 400.00 | 1500.00 | 1659.72 | 0.47 | 396.93 | 197.12 | 400.00 | 1500.00 | 105.33 | 0.47 | 24.74 | 29.48 |
| **$Cl^-$** | 250.00 | 800.00 | 598.24 | 0.09 | 138.22 | 61.23 | 250.00 | 800.00 | 72.92 | 0.63 | 17.10 | 19.15 |
| **$NO_3^-$** | 10.00 | 50.00 | 11.54 | 0.00 | 2.76 | 1.26 | 10.00 | 50.00 | 127.56 | 0.00 | 24.22 | 19.10 |
| **$Na^+$** | 200.00 | nd | 37.13 | 2.40 | 10.96 | 12.41 | 200.00 | nd | 108.77 | 0.53 | 25.68 | 35.18 |
| **$NH_4^+$** | 1.50 | 10.00 | nd | nd | nd | nd | 1.50 | 10.00 | 6.49 | 0.17 | 2.29 | 3.09 |
| **$K^+$** | 250.00 | nd | 51.32 | 0.01 | 9.97 | 6.84 | 250.00 | nd | 43.48 | 0.01 | 7.88 | 4.54 |
| **$Mg^{2+}$** | 150.00 | 500.00 | 341.96 | 0.40 | 71.48 | 43.38 | 150.00 | 500.00 | 71.36 | 0.21 | 15.92 | 32.06 |
| **$Ca^{2+}$** | 200.00 | nd | 93.21 | 4.45 | 25.57 | 54.21 | 200.00 | nd | 108.98 | 0.83 | 22.75 | 54.63 |
| **DOC** | nd | nd | 2.44 | 0.19 | 0.59 | 1.26 | nd | nd | 5.77 | 0.05 | 1.62 | 1.51 |
| **$PO_4^{2-}$** | 0.02 | 0.03 | 1.00 | 0.16 | 0.26 | 0.39 | 0.02 | 0.03 | 3.20 | 0.10 | 0.74 | 0.46 |
| **$ClO^-$** | nd | nd | 0.32 | 0.32 | 0.00 | 0.32 | nd | nd | 0.53 | 0.14 | 0.10 | 0.26 |
| **$O_3$** | nd | nd | 0.70 | 0.32 | 0.17 | 0.46 | nd | nd | 0.39 | 0.27 | 0.05 | 0.35 |
| **$H_2O_2$** | nd | nd | 0.25 | 0.25 | 0.00 | 0.25 | nd | nd | 0.22 | 0.11 | 0.04 | 0.18 |
| **$CN^-$** | 0.10 | 0.20 | nd | nd | nd | nd | 0.10 | 0.20 | 0.06 | 0.03 | 0.01 | 0.03 |
| **Phenol** | 0.00 | 0.20 | 2.18 | 0.77 | 0.39 | 1.36 | 0.00 | 0.20 | 1.03 | 0.21 | 0.30 | 0.52 |
| **TH** | 200.00 | nd | 2080.00 | 26.00 | 530.89 | 495.91 | 200.00 | nd | 410.00 | 68.00 | 79.50 | 188.39 |
| **$CH_2O$** | nd | nd | nd | nd | nd | nd | md | nd | 0.23 | 0.19 | 0.01 | 0.21 |
| **$NO_2^-$** | 1.00 | 2.00 | 0.28 | 0.02 | 0.08 | 0.06 | 1.00 | 2.00 | 1.92 | 0.02 | 0.44 | 0.24 |
| **B** | nd | 0.50 | nd | nd | nd | nd | nd | 0.50 | 1.57 | 0.72 | 0.37 | 1.23 |
| **$SIO_2$** | nd | nd | nd | nd | nd | nd | nd | nd | 41.20 | 3.30 | 7.37 | 15.17 |

The results show that there was no ambiguity in the component matrix. After analysing the rotated matrix, it was even clearer that four components emerged. As shown in Table 17, component 1 (F1) was comprised of $Cl^-$, Mg, TH and K. Component 2 (F2) constituted of $NO_3^-$ and Na. The third component (F3) was made up of $SO_4^{2-}$ and $Ca^{2+}$. DOC constituted the last component (F4). Table 16 shows that the four parameters explained 82.9% of the variance.

**Table 16.** Total variance explained

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings |
|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total |
| 1 | 3.41 | 37.84 | 37.84 | 3.41 | 37.84 | 37.84 | 3.34 |
| 2 | 1.67 | 18.57 | 56.41 | 1.67 | 18.57 | 56.41 | 1.65 |
| 3 | 1.23 | 13.63 | 70.04 | 1.23 | 13.63 | 70.04 | 1.53 |
| 4 | 1.16 | 12.89 | 82.93 | 1.16 | 12.89 | 82.93 | 1.19 |
| 5 | .82 | 9.09 | 92.02 | | | | |
| 6 | .34 | 3.81 | 95.83 | | | | |
| 7 | .31 | 3.49 | 99.32 | | | | |
| 8 | .05 | .53 | 99.85 | | | | |
| 9 | .01 | .15 | 100.00 | | | | |

**Table 17.** Pattern and structure matrix

| | **Pattern Matrix** | | | | | **Structure Matrix** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Component | | | | | Component | | | |
| | 1 | 2 | 3 | 4 | | 1 | 2 | 3 | 4 |
| $Cl^-$ | .976 | | | | Mg | .967 | | | |
| $Mg^{2+}$ | .961 | | | | Cl | .937 | | | |
| TH | .873 | | | | TH | .911 | | | |
| $K^+$ | .756 | | | | K | .776 | | | |
| $NO_3^-$ | | .903 | | | $NO_3^-$ | | .889 | | |
| $Na^+$ | | .868 | | | Na | | .882 | | |
| $SO_4^{2-}$ | | | .827 | | $SO_4^{2-}$ | | | .831 | |
| $Ca^{2+}$ | | | .737 | | Ca | | | .739 | |
| DOC | | | | .959 | DOC | | | | .957 |

**Table 18.** Pearson correlation of the pollution data

| | $SO_4^{2-}$ | $Cl^-$ | $NO_3^-$ | $Na^+$ | $K^{2+}$ | $Mg^{2+}$ | $Ca^{2+}$ | DOC | $PO_4^{3-}$ | $ClO^-$ | $O_3$ | $H_2O_2$ | PNL | TH | $NO_2^-$ | $SiO_2$ | Location |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $Cl^-$ | -.108 | 1 | | | | | | | | | | | | | | | |
| $NO_3^-$ | -.106 | -.015 | 1 | | | | | | | | | | | | | | |
| $Na^+$ | -.063 | .190 | **.588**$^{**}$ | 1 | | | | | | | | | | | | | |
| $K^{2+}$ | .174 | **.573**$^{**}$ | -.050 | .248$^{*}$ | 1 | | | | | | | | | | | | |
| $Mg^{2+}$ | .156 | **.925**$^{**}$ | .048 | .179 | **.658**$^{**}$ | 1 | | | | | | | | | | | |
| $Ca^{2+}$ | .243 | .092 | .036 | .026 | .040 | .204 | 1 | | | | | | | | | | |
| DOC | -.058 | -.022 | -.230 | .074 | .212 | .006 | .174 | 1 | | | | | | | | | |
| $PO_4^{3-}$ | -.113 | .033 | .027 | .356 | **.509**$^{**}$ | -.049 | **.651**$^{**}$ | .461$^{*}$ | 1 | | | | | | | | |
| $ClO^-$ | .132 | .241 | -.089 | .062 | -.065 | -.268 | .088 | -.263 | -.003 | 1 | | | | | | | |
| $O_3$ | -.242 | -.124 | -.460 | -.426 | -.001 | -.650 | -.750 | -.111 | -.651 | .490 | 1 | | | | | | |
| $H_2O_2$ | .287 | -.191 | .436 | .482 | **.852**$^{*}$ | .024 | .118 | **.825**$^{*}$ | -.941 | -.114 | -1.000$^{**}$ | 1 | | | | | |
| PNL | .045 | .113 | -.563$^{**}$ | -.549$^{*}$ | -.197 | -.593$^{*}$ | -.038 | -.366 | .409 | **.887**$^{**}$ | **1.000**$^{**}$ | .121 | 1 | | | | |
| TH | .435$^{**}$ | **.813**$^{**}$ | -.124 | .046 | **.609**$^{**}$ | **.892**$^{**}$ | .320$^{*}$ | -.014 | .063 | .155 | -.040 | -.148 | .162 | 1 | | | |
| $NO_2^-$ | -.018 | -.056 | .197 | .163 | -.031 | -.022 | .045 | **.679**$^{**}$ | -.745$^{*}$ | -.281 | -1.000$^{**}$ | .920 | -.507 | -.054 | 1 | | |
| $SiO_2$ | -.292 | -.234 | -.129 | -.012 | -.083 | -.204 | -.318 | .052 | .022 | .029 | -.038 | -.849 | -.293 | -.163 | -.256 | 1 | |
| Location | .148 | .072 | -.189 | -.237$^{*}$ | .049 | .063 | -.065 | .038 | -.136 | -.152 | .437 | **.810**$^{*}$ | .049 | .146 | **.488**$^{**}$ | – | 1 |
| Water Source | .086 | .112 | -.511$^{**}$ | -.412$^{**}$ | .097 | -.077 | .154 | **.319**$^{**}$ | .299 | .137 | .437 | -.153 | .374 | .194 | -.145 | -.030 | .298$^{*}$ |

** Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed)

Correlations, as shown in Table 18, were observed between several parameters and the significant ones were between $Na^+$ and $NO_3^-$ (*r* = .588); between $K^+$ and $Cl^-$ (*r* = .573); between $PO_4^{3-}$ and $Ca^{2+}$(*r* = .651) and between $Mg^{2+}$ and $Cl^-$ (*r* = .925) among others. In addition, location (province) was correlated positively with $H_2O_2$ and $NO_2^-$ at .810 and .488 respectively. Water source (either obtained from the ground or rivers/streams) correlated significantly with DOC (*r* = .319). Using Tukey HSD test, PCA and the correlation coefficients, it was found that $NO_3^-$ and $Na^+$ are indeed closely associated suggesting that they may have the same origin; the increase or decrease of either parameter will affect the other in a predictable manner. In addition, significant correlations of $Cl^-$, TH, $K^+$, $Mg^{2+}$ reinforces component 1 (F1) extracted by PCA. However, component 3 (F3) was not supported by correlation coefficient; there was no evidence supporting a close relation that an increase or decrease of $SO_4^{2-}$ leads to corresponding changes in levels of $Ca^{2+}$ even though they fall under one component, F3. Furthermore, DOC analysis correlates significantly and positively with location, this finding confers addition insight to t-test results which showed that DOC levels were significantly high in surface water compared to ground water. However, there are several other parameters which correlated significantly but no rational explanation was given for their correlations because they were not supported by other analyses methods and they also proved not to be statistically significant in other regions compared to others; they did not either prove higher when compared to ground and surface water.

### 4.5 The Water Pollution Index (WPI)

The findings of the Zambian water quality using the *WPI* are summarised in Table 19, Table 20 and Table 21. The results are arranged in ascending order with water samples that met the benchmark ($0.0 \leq WPI \leq 1.0$) to the water samples that were highly polluted ($WPI > 10$).

It is apparent from the *WPI* tables, that the Zambian water is compromised in one way or another, apart from the nitrate issue. The *WPI* reveals that out of all the water collected from Lusaka Province, 39.1% were not compromised (the water was safe for household consumption with reference to the analysed parameters); out of the water samples collected from the Copperbelt/North-western Provinces, 20.9% were safe for household consumption and 28.6% of the samples collected from Central and Southern Provinces were not polluted. Further analysis of the water shows that water treatment is reasonably effective in Mufulira as the water derived from the tap CB22T is suitable for human consumption despite its source being the highly polluted Kafue River (CB40R). However, the other water samples obtained directly from the mine ground aquifer and supplied to the former mine residential area proved to be unsuitable for human consumption, despite whatever treatment procedure is performed on the water, as shown by sample CB20T and according to the *WPI* of 1.63, is moderately polluted.

**Table 19.** Water quality in Lusaka Province using the Water pollution Index

| Code | Site name | WPI |
|---|---|---|
| LSK47G | Chainama Lusaka General Hospital | 0.19 |
| LSK16R | Roma/Garden Township Stream | 0.24 |
| LSK1D | Mutendere Dam | 0.29 |
| ND43R | Kafubu Upstream | 0.32 |
| LSK15T | Matero Petroda Station Tap Water (LWSC) | 0.44 |
| LSK56G | Mutendere Near Chainama Golf Club Well Water | 0.44 |
| LSK4R | Mumana Pleasure Resort (stream) | 0.46 |
| LSK51G | UNZA Tap Water - Groundwater | 0.51 |
| LSK65G | Zeko Camp Borehole | 0.87 |
| LSK17D | Blue Water Dam | 1.05 |
| LSK7R | Mutendere/Maplot midstream | 1.36 |
| LSK52G | Femag Garden John Laing Tap Water from the Ground | 1.56 |
| LSK58G | Entrance of Chunga - Ground Water | 1.60 |
| LSK50G | Vera Chiluba Basic School Tap from tap ground | 2.17 |
| LSK14G | John Laing Tap (ground water) | 2.19 |
| LSK9R | Ngombe Basic School Stream | 2.31 |
| LSK8R | Malimba Ngwerere Stream | 2.43 |
| LSK57G | Chunga, Africa Methodist Episcopal Church Ground Water Borehole | 2.60 |
| LSK49T | Libala Basic School Tap from the Ground | 2.75 |
| LSK63G | Ndeke Village | 3.09 |
| LSK13T | Chawama Compound Tap Water (LWSC) | 3.15 |
| LSK54G | Gospel Outreach Tap Water-ground | 3.19 |
| LSK53G | Kanyama Ground Water-Borehole-Filling Station | 3.56 |
| LSK68G | Thornpark Construction Centre Borehole | 3.68 |
| LSK60G | Avondale River Side Street Tap Water from the Ground | 4.19 |
| LSK10G | New N'gombe Basic Tap (underground) | 4.50 |
| LSK55G | Zingalume Police Tap Water from the Ground | 4.72 |
| LSK67G | Villa Elizabetha | 4.73 |
| LSK62G | George Compound Borehole | 5.02 |
| LSK64G | Chisengalumbwe Basic School | 5.25 |
| LSK61G | Ngome tap Water from Ground Aquifer | 5.56 |
| LSK59G | Twikatane Area Ground Water | 5.65 |
| ND46R | Kafubu Downstream | 7.24 |
| LSK3R | Mutendere River upstream | 7.41 |
| LSK48G | Kamwala Remand Prison Borehole Water | 8.34 |
| LSK72G | Zingalume borehole water | 8.60 |
| LSK2R | Chipata/Marapodi at Garden Park (stream) | 9.05 |
| LSK66G | NRDC Borehole Tap | 9.22 |
| LSK6R | Ngwerere Stream (near Kasisi) | 9.28 |
| LSK12R | Lumumba/Great North Road Junction (stream) | 10.19 |
| LSK70D | Goma Lakes | 10.47 |
| ND31R | Kafubu River | 10.93 |
| ND45T | Laka Petroleum Filling Station Tap Water - Ndola | 11.26 |

**Table 20.** Water quality in Copperbelt and North-western Province using the Water pollution Index

| Code | Site name | WPI |
|---|---|---|
| CB30R | Malembeka Stream into Kafue (1st site) | 0.02 |
| SL73G | Solwezi well water | 0.08 |
| CB23R | Boating Club Dam (Mufulira) | 0.16 |
| CB28R | Chingola/Chililabobwe Road Kafue River | 0.20 |
| CB22T | Tap Water - Mufulira Town Centre (Mulonga Water) | 0.22 |
| CB19R | Kafue River Mufulira/Kitwe Road | 0.25 |
| CB24R | Kafue River, Nkana East Waterworks | 0.47 |
| CB25R | River Near Sabina | 0.62 |
| CB26R | Before Tailings Damp (Butondo Stream) | 0.67 |
| CB20T | Mine Water Mulonga Tap (Entebbe) | 1.63 |
| CB27R | Tailings Damp Effluent) | 2.10 |
| CB21R | West Shaft Effluent Water | 2.54 |
| CB29R | Chingola Mine Effluent | 4.77 |
| CB34R | Ndola Kitwe Dual Carriage Kafue River | 10.00 |
| CB39R | Kawama stream - Mufulira | 10.17 |
| CB36R | Chingola River Upstream | 10.55 |
| CB33R | Butondo Stream at Road Near Butondo High | 10.58 |
| CB32R | West Mine Shaft - Butondo Stream (at Bridge) | 10.70 |
| CB40R | Kafue Water Treatment Plant - Mulonga WSC | 10.77 |
| CB44R | Kansuswa Stream (at Mufulira/Kitwe Road) | 10.92 |
| CB37R | Tailings Damp (TD 11) | 11.09 |
| CB38G | Eagle High School Tap Water (Groundwater) | 11.17 |
| CB35R | Malembeka Stream into Kafue (2nd site) | 11.57 |

**Table 21.** Water quality in central and southern province using the Water pollution Index

| Code | Site name | WPI |
|---|---|---|
| KB41T | Kabwe City Council Tap Water (Lukanga WSC) | 0.33 |
| KB42T | Jack & Jill School - Lukanga WSC | 0.75 |
| MG74G | Magoye borehole water- school | 2.34 |
| KF11R | Kafue River at Motor Bridge | 5.07 |
| MZ69T | Mazabuka Tap water | 8.04 |
| KF18R | Train Bridge (Kafue River) | 8.85 |
| MG71G | Magoye borehole water - main compound | 9.21 |

LSK-Lusaka city; CB-Copperbelt; SL-Solwezi town; ND-Ndola city; KB-Kabwe town; KF-Kafue town; MG-Magoye town; MZ-Mazabuka town; G-groundwater; T-tap water; R-river water; D-dam/water reservoir

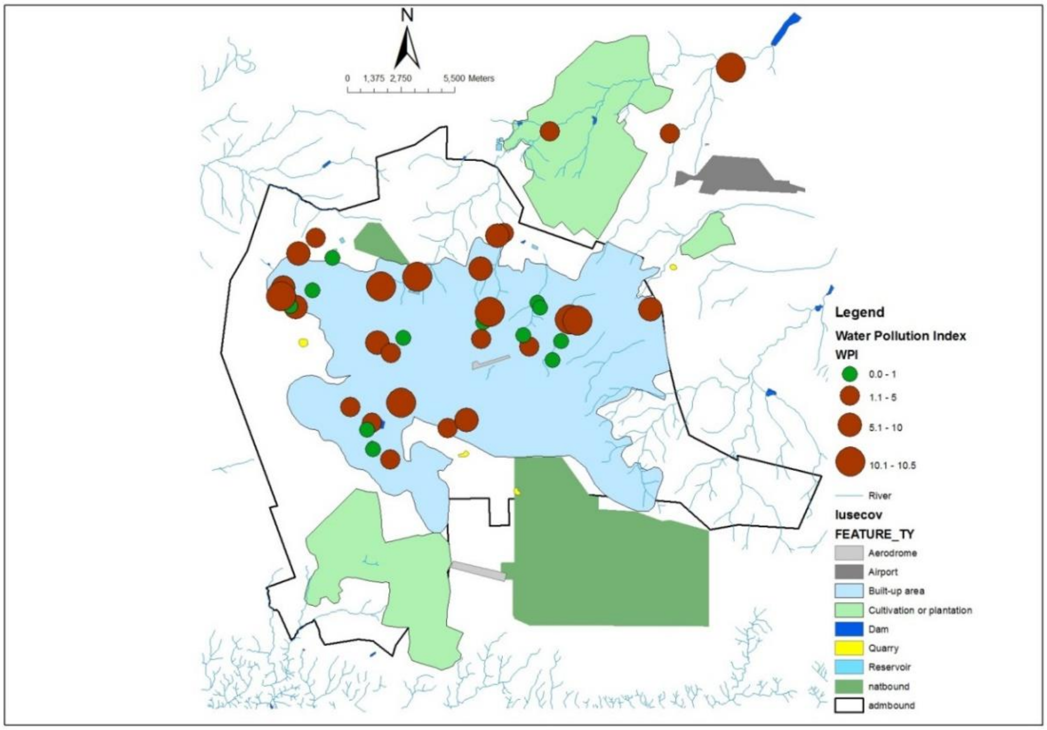

**Figure 12.** Lusaka Region data using the Water Pollution Index

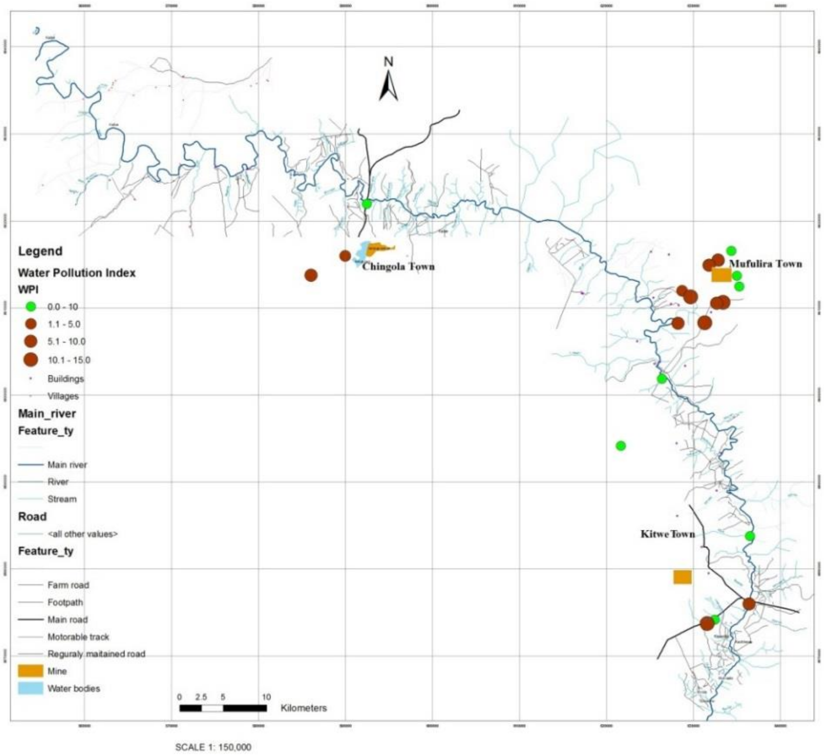

**Figure 13.** Copperbelt Region’s water quality using Water Pollution Index

The Lusaka city (Figure 12) and Copperbelt region (Figure 13) data is further presented on maps, using ArcGIS, showing spatial distribution of water quality across the two regions. There was a general tendency of the groundwater to degrade on the outskirts (commonly referred to as the peri-urban) of the Lusaka city boundary; most of the unplanned settlements in Lusaka are also built on the outskirts of the city. As for surface water, it was expected that more pollutants would be observed towards the north east as it is generally the flow of all surface water in Lusaka, but there is no general observable trend. However, there is a general observable trend that the surface water which meets *WPI* clean water criteria is at or near the centre (e.g. LSK16R) of the city and but also intermingled with some of the worst polluted groundwater (e.g. LSK68G).

## 4.6 Discussion

The water in Lusaka city revealed mixed results, that is, both acceptable chemical loadings and unacceptably high chemical loadings (to pollution levels) with nitrate being more widespread and predominant in high-density residential areas, like sites; LSK2R, LSK8R, LSK13T, LSK14G, LSK48G, LSK49T, LSK54G, LSK55G, LSK57G, LSK59G, LSK63G, among others. The locations that revealed high levels of nitrates in tap water derive their water from boreholes and wells. A similar trend is observed in Magoye (site MG71G and MG74G), a typical rural area with a very low population density and no industrial activities; the sampled water was extracted from a borehole. The source of nitrate is mostly from decaying organic matter, sewage, fertilizers, manure, and nitrate in the soil or natural deposits, animal waste and septic tanks. The areas which tested for high nitrate have also been a source of perpetual cholera outbreaks; relentless cholera outbreaks have been reported over the past years with the first reported cases being in 1977 (Sasaki et al., 2009; WHO, 2011).

Analysis of the data shows that nitrate pollution is a major problem in Lusaka city in contrast to the CB/NW- and Central Provinces, where none of the samples tested for nitrates beyond what is naturally expected. The low levels of nitrates prevailing in the CB/NW and Central Provinces can be attributed to the well organised and planned settlements which are serviced by sewer pipelines. This fact is quite opposite to Lusaka which is comprised of a large number of unplanned settlements (shanty townships, slums etc.), which are not serviced by a sewer system and garbage collection by the city council is way beyond their capacity. This has resulted in many illegal/backyard dumpsites. The situation in Lusaka is also found in most rural areas like Magoye, where there has never existed any sewer system (except for in-situ sanitation), or any garbage collection system.

The high sulphate content (as Table 15) is restricted to the Copperbelt region especially, near the effluent water discharged from the copper mines in Chingola and Mufulira towns.

The mining activities are a probable explanation of the high levels of sulphates in the drinking water (e.g. Site CB20T). The water in the Butondo River (CB21R, receiving drainage water from the mines) equally revealed high sulphate, an indication of how negatively the mine has affected the environment. "Zambia: MCM Acid Spillage" (2008) reports that Mopani Copper Mines (MCM) in Mufulira has disclosed that part of its groundwater table has been contaminated following an acid spillage into the main domestic water supply system that pumps water to households in former mine townships.

Part of the tap water used in Lusaka is obtained from the Kafue River at Kafue town. Nevertheless, groundwater abstraction in the city has increased because of the construction of public and private boreholes. LWSC has approximately 50 boreholes around the city which draw water from the Lusaka and Cheta aquifers. For surface water derived from the Kafue River, there is a conventional treatment facility at the Ioland Water Treatment Plant. As for LWSC groundwater obtained from public boreholes, there are simple on-site chlorination facilities at borehole sites (LWSC, Personal Communication, January 11, 2013). And for private boreholes, the onus is on the individual to treat or not to. Inevitably these uncontrolled, unmonitored and untreated shallow and deeper boreholes can pose serious health hazards.

Nitrate concentrations are similar in urban and rural areas and frequently exceed the drinking water limits set by the Zambia bureau of standards and environment council of Zambia. There is unequivocal evidence of pollution by sewer system as this problem was more predominant in the sites with a rudimentary sewer system, both urban and rural. Rural areas may have an addition loading from fertilizer application from the nearby farms but there is no strong evidence linking the two. For example site SL73G, found in a typical farming area did not test for nitrates beyond what is expected in nature.

It can be deduced from the locations sampled that the main source of nitrate is from human excrement (pit latrines) and biomass decay (garbage). This fact is further supported by the presence of ammonia, and nitrite (intermediate products in the nitrogen cycle) in both the rural (MZ69T, MG71G, MG74G) water and Lusaka city water.

Groundwater protection is best achieved by defining "standards of practice" which, for example would exclude certain types of development and land use activity in areas specified as hygrogeologically sensitive. Recent hydrogeological and hydrochemical studies at the University of Toronto confirm that urbanization represents a serious threat to local groundwater quality (Howard, 1997). Because of its vulnerability, groundwater use may be restricted to certain areas where geology is favourable or where the supply infrastructure has not been installed, or it may only be certain types of users. In Birmingham, UK, virtually all of the public supply is surface water, with groundwater restricted to industries (Howard, 1997), but this is not the case in Zambian (and many other developing countries) where, for example, 58 per cent (130,000m$^3$/d) of water supplied by LWSC is from ground sources, excluding the sources from satellite systems and private boreholes estimated at 80,000m$^3$/d (ECZ, 2008). Data from the Zambian Ministry of Health (MOH) indicates that diarrhoea was one of the cause of hospital visitation, an average of 75 persons per 1,000 population from 2006 to 2008, ranking only third from malaria and respiratory infections (Ministry of Health and European Development Fund, 2010). Ironically, one of the interventions by the MOH, acting with other stakeholders, is to advocate sinking of more boreholes on top of the existing ones and promote the use of pit latrines. However, it is important to note that when groundwater is used as a source of drinking water, it is vital that sanitation methods and garbage collection and its disposal are of the highest efficiency to eliminate threats to human safety (Khalid et al., 2011; Zaadnoordijk et al., 2004), which is not the case in Zambia and numerous other developing countries. A risk assessment into the potential for sewer-related pollution should be carried when locating a new borehole site, especially if this is within or close to an urban area (Misstear and Bishop, 1997).

Some of the factors associated with environmental problems in Zambia is that there are no clear promulgated standards for the minimum or maximum groundwater depths, making evaluation of drainage situation difficult and although for some chemicals, quality standards are present, but the picture is not complete (for example DOC, TOC, pH, $ClO^-$, TH, B and $PO_4^{3-}$). Currently, there is no systematic priority list available on which pollutants are most serious in Zambia and what should be emphasized at household, industry and/or government level. Furthermore, there is a lack of an integral approach, by this we mean, ground water, storm water, surface water, sewers and drinking water supply, all represents different dimensions of the same water system within a given locality. Nonetheless, these activities have been studied and planned separately. Hardly is the issue of groundwater given the gravity that it deserves and how it relates to human settlements and town planning. It was the purpose of this study to highlight some of the important water related aspects that would be worth giving a serious consideration.

One parameter worth noting is the amount of water TH in Lusaka city and Copperbelt region; it is important to note that guidelines for hardness are based on aesthetic, rather than health concerns. Safe

Drinking Water Foundation (2006) states that levels greater than 200 ppm are considered poor but can be tolerated and levels in excess of 500 ppm are normally considered unacceptable. Of the Lusaka water samples, 33% were beyond 200 ppm, but all were below 500 ppm. This is in contrast to the Copperbelt region water (especially near the mining towns), where 13.6% of the samples' TH concentrations were greater than 200 ppm; 31.8% with concentrations well beyond 500 ppm. The other sites assessed from miscellaneous regions around Zambia revealed normal TH with occasional undetectable levels of TH below 20 ppm.

The other parameters ($Cl^-$, $H_2O_2$, $CH_2O$, pH, DOC, $O_3$ $SiO_2$), even though lack agreed upon standards, tested positive in some of the water samples and hence it would be appropriate to embark on research to establish the effects on human health from such chemicals as is common in the Zambian water. For instance, $SiO_2$ was detectable in all the samples tested from Lusaka city and 38% of all the samples tested positive for $ClO^-$; further discussion was not done for lack of Zambian *PV* standards to warrant an in-depth discussion. Another parameter highly considered in public discourse but with widely varying standards is pH; the ZBS/ECZ has not set any guidelines for drinking water. By and large, the pH values were within range of 6.5 to 8.5 (USEPA standards) except for one sample (LSK13T) from Chawama compound in the capital city of Zambia, Lusaka, which was slightly acidic at 5.75. However, it is important to use the unregulated contaminant monitoring program where data is collected for contaminants that were present in water samples, but do not have health-based standards set under the Safe Drinking Water regulations. If safety of water is to be sustained, surface and groundwater protection process must be an integral part of the ministry in charge of environmental issues (Ministry of Tourism, Environment and Natural Resources in case of Zambia).

### 4.7 Major findings

After analysing water from the five Zambian provinces with different characteristics, it is indisputable that the pollution is anthropogenic in nature and is a consequence of mining on the Copperbelt, as revealed by TH levels, and the rampart unplanned residential areas in Lusaka Province as revealed by PCA, Tukey HSD test and correlation coefficients which show $NO_3^-$ and $Na^+$ to be significantly higher in Lusaka compared to other regions. These parameters, among others, are a typical signature of human induced (human excrement) pollution. Furthermore, the levels of $NO_3^-$ and $Na^+$ in ground water were significantly higher than in surface water. On the other hand, DOC levels were significantly higher in surface water compared to ground water and were not specific to any province. The users of the water in Zambia should pay particular attention when using ground water because of $NO_3^-$ and $Na^+$ (i.e., especially for Lusaka and Southern Provinces), and DOC pollution when using surface water irrespective of province. The residents of the Copperbelt Province should however be cautious of sulphate, phenolic compounds and excessive water TH especially when using the water obtained from the mine ground aquifers.

It is clear from this study that living in Lusaka (or any location heavily dependent on in-situ sanitation and backyard dumpsites like Magoye town) is particularly hazardous, given the high prevalence of nitrate pollution in tap water derived from the ground aquifers. Because many people obtain their drinking water from ground sources, it is important to set regulatory standards for more parameters and to monitor supplies regularly to ensure that potential health risk to humans are avoided. In Zambia, it is popular advice (through private and public media and MOH) to tell the general public to either chlorinate and/or boil their drinking water, but merely boiling water will increase rather than decrease the contaminant concentrations. It is correct to argue that by boiling their drinking water, most Zambians are exposed to elevated pollutant concentrations than what was elucidated in this study. This study, therefore, suggests that water especially in Lusaka should not be boiled as a way of disinfecting it, but rather chlorinate because boiling will not remove the nitrates and other pollutants but instead increase their concentration.

# Chapter 5

## 5. Heavy metal analysis

### 5.1 Introduction

Zambia is a landlocked Southern African country with an area of 752,614 square kilometres. In 2010, it had an estimated population of 13,046,508 million (Central Statistical Office [CSO], 2010). There is a well-developed mining sector which is the backbone of the economy. The mining sector is dominated by Cu and Co production. The country ranks among top eight producers of Cu (The world Copper Factbook, 2010). The country is also among the major producers of gem-quality emerald, a variety of mineral commodities for the construction industry and, other gemstones (primarily amethyst, beryl, aquamarine and tourmaline) and has a high potential of coal production (Mobbs, 2004).

There is an effort to decrease to a minimum or eliminate penetration of the most serious contaminants into the food chain and therefore also into the human body. One of the tool in this struggle is to target the monitoring of relevant contaminants in raw materials and foods of animal origin and water which is the main component utilised by plants. In order to do this, the study concentrated on a very wide area of Zambia spanning five provinces and analysing water samples from 74 sites. Dissolved metal analysis was the focus of the study because the concentrations of metals in dissolved form are also readily available for absorption by plants, and direct intake by animals.

Heavy metals (Ag, As, Cd, Cu, Cr, Hg, Ni, Pb and Zn) can be present in the aquatic system in both dissolved forms, which can cause toxic effects on a wide diversity of organisms, including vertebrates, and particulated ones (including adsorbed on sediments, suspended particulate matter or colloids, in transitional metal complexes, and Fe/Mn hydroxides nets, linked to organic matter and carbonates…) (Marcovecchio, Botte & Freije, 2007). Many researchers have tried to analyse the heavy metals in Zambia. Several studies like that of von der Heyden and New (2004) focused on groundwater pollution on the Zambian Copperbelt and deciphering the sources and the risk. Holden and Malamud (2006) researched on quantifying health hazards from heavy-metal contaminated food crops at three Zambian locations. The focus of their study was to investigate preliminary values of Target Hazard Quotients (THQ) for urban agriculture crops irrigated by industrial wastewater in Zambia. By and large, most of the research in this area has been confined to study of heavy metals in food, soils and sediments (Choongo, Syakalima & Mwase, 2010; Holden, 2010; Sherameti & Varma, 2009; Tembo, Sichilongo & Cernak, 2006). There are high incidences of pathogens, such as typhoid, cholera, streptococci, salmonella, poliomyelitis, and protozoans; in fact many cholera outbreaks have been reported over the previous years (Sasaki et al., 2009), as a result, heavy metal contamination has largely been ignored in the Zambian media. However, the scientific community makes occasional effort to determine heavy metal loadings in different environments (soil, water, sediments, soil).

### 5.1.1 Description of the study areas by province

#### *5.1.1.1 Kabwe town (Central Province)*

Kabwe, in central Zambia, is located about 150 kilometres north of the nation's capital, Lusaka, and is one of six towns in close proximity to the Copperbelt, once Zambia's thriving industrial base. In 1902, rich deposits of Zn and Pb were discovered there. Mining and smelting commenced thereafter and continued until 1994 without addressing the potential dangers of Pb contamination. Cd and Ag were also produced as by-products. The mine and smelter are no longer operating but have left a city poisoned and scared by debilitating concentrations of Pb dust in the soil and by metals in the water (Musonda & Tembo, 2004; Yabe et al., 2011). In one study conducted in Kabwe, the dispersal in soils of Pb, Cd, Cu, and Zn extended over a 20 km radius at levels much higher than those recommended by the World Health Organization (Tembo, Sichilongo & Cernak, 2006).

Mining is Zambia’s economic lifeblood, but Kabwe’s mineral riches dried up in 1994, when heavy financial losses forced the state-run Zambia Consolidated Copper Mines (ZCCM) company to shut down operations. Once one of Africa’s largest and richest mining towns, Kabwe was left with a legacy of toxic waste.

#### *4.1.1.2 Solwezi (North Western Province)*

Solwezi is the capital of the North Western Province of Zambia. The district had approximately 239,051 inhabitants as of 2010 census (CSO, 2011). The main industry in Solwezi is Cu mining at Kansanshi Mine (located about 10 km north) and Lumwana Mine (located about 65 km west), out of the town centre, run by First Quantum Minerals and Equinox Minerals respectively. “Coastal and Environmental Services” (2011) reports that:

> Kansanshi Mine exploits Cu-Au ore from Kansanshi Anticlinal. The mining site has been in operation since 19th century for Cu and Au successively. Lumwana on the other hand was discovered in 1961, no serious work was carried out there until Equinox Minerals Ltd became involved in 1999. First Quantum Mining Ltd (FQM) intends to develop the Trident Cu, Ni Project through Kalumbila Minerals Ltd. The Trident Project, located 140km west of Solwezi,

> has three distinct areas of mineralisation named Sentinel, Enterprise and Intrepid. Geological drilling and evaluation continues at each of these targets and it is proposed that Sentinel will be developed initially followed by Enterprise and finally Intrepid. Each target is individually seen as a significant mine development which will likely extend over a period in excess of 22 years.

The water from this region was sampled and analysed for dissolved heavy metal pollution. It is our proposition that it will be in the best interest of the Zambian government to carry out a similar, independent, study in the same area after some years of sustained mineral exploration because Solwezi is home to some of the newest mines in the country and negative environmental effects may not have reached their climax yet.

#### *4.1.1.3 Mazabuka District and its Satellite District of Magoye (Southern Province)*

Mazabuka and Magoye are predominantly agricultural districts. In Zambia, fertilizer application primarily follows a blanket recommendation. Historical evident suggests that continued fertilizer use without guided recommendation and lack of proper soil management resulted in declining soil productivity (Phiri, 2008). A soil fertility survey was carried in 2001 in Eastern, Central and Southern Provinces of Zambia. The objective of the survey was to prepare fertilizer recommendations based on soil analysis for use by farmers in Eastern, Central and Southern Provinces of Zambia. A total of 651 composite soil samples were collected from small-scale farmers in several districts and among them Mazabuka district. Ninety per cent (90%) of the total soil samples from the districts sampled were found to have low to very low exchangeable magnesium and 49% very low exchangeable calcium. Soil samples from Eastern, Southern and Central Provinces were found to have medium to very high exchangeable potassium. It was strongly recommended that lime be considered as one of the major inputs in the farming system of the surveyed provinces. Inorganic fertilizer recommendations based on soil analysis were also given particularly for Central, Southern and some parts of Eastern Districts of Zambia (ibid). Published research on heavy metals is lacking in these predominantly rural districts of Zambia. Most studies as described above focus on agriculture related elements; the common anions and cations. Research on dissolved heavy metal contamination in water is lacking.

#### *4.1.1.4 Lusaka city (Lusaka Province)*

With mushrooming of new residential areas which has not kept pace with expansion in the piped water supplied by Lusaka Water and Sewerage Company, groundwater has increasingly become a relatively cheap source of water supply for domestic and other uses in Zambia. However, the Lusaka aquifer is known to be vulnerable and fragile because it is shallow and hosted by an open karst system (Nkhuwa, Kafula & Ahmed, 2008).

Sanitation provision in Lusaka has also not kept pace with the construction of new residential areas and the expanding informal settlements. There are many issues related to threats of water resources, one contentious issue being the sanitation provision in Lusaka which is insufficient, as in most cities in sub-Saharan Africa (United Nations Human Settlements Programme, 2012). Most people do not have access to a hygienic toilet; large amounts of faecal waste are discharged into the environment without adequate treatment. Some of the major sanitation issues include cross contamination from pit latrines to shallow wells (ECZ & LCC, 2008). There are also large amounts of backyard dumpsites; this is likely to have major impacts on groundwater (and streams/rivers) considering the shallow geology of Lusaka. A wide array of industries are concentrated in Lusaka city and disposal of the waste they generate is questionable. The Environmental Council of Zambia (ECZ) has no capacity to effectively monitor all the industries. On the other hand, abstraction of ground and surface water for human consumption is common in Lusaka city; it was imperative to investigate the anthropogenic pollution due to dissolved heavy metal pollution on the vast Lusaka water resources.

#### *4.1.1.5 Copperbelt (Copperbelt Province)*

Streams and rivers are a major source of fresh water in Zambia. The Kafue River, for example, is a major supplier of fresh water to most residential areas in the Copperbelt region including the mining and chemical industries where large quantities of water is used to wash mineral ores in order to extract metals such as Cu and Co. In the process, they generate effluents, which have potential to pollute the environment. The effluents are discharged into streams and rivers as a way of disposing them. The wastewaters are pre-treated before discharging to the surface waters of streams and underground waters through percolation and to the atmosphere by evaporation. Acid mine drainage, a condition created by effluents when disposed into stream and river waters, impacts the water quality (Ntengwe & Maseka, 2006). Water samples from three mining towns (Kitwe, Ndola, Mufulira & Chingola), their network of streams and tributaries were collected and analysed for dissolved heavy metals.

## 5.2 Data Analysis

### 5.2.1 Preliminary analysis of the raw data

Table 22 shows the parameters relative to their permissible values (*PVs*). Arsenic is one of the parameters that exceeded its recommended value in drinking water. Cd on the other hand was undetectable in all the samples assessed in this study. In all the parameters assessed, the average values were far below their *PVs* except for Mn and Ni. The other parameters whose maximum recordable value exceeded their recommended values are Mn, As, Cr, Ni, and Pb.

**Table 22.** Summary of the pollution data obtained from 74 locations around Zambia

| Parameter | Min | Average | Max | PV | SD |
|---|---|---|---|---|---|
| **pH** | 5.750 | 7.680 | 8.440 | 6.0-8.5 | 0.429 |
| **Temperature $^{o}$C** | 20.50 | 23.59 | 27.00 | | 1.42 |
| **As (ppm)** | 0.000 | 0.009 | 0.506 | 0.050 | 0.058 |
| **Cd (ppm)** | 0.000 | 0.000 | 0.000 | 0.005 | 0.000 |
| **Cr (ppm)** | 0.000 | 0.010 | 0.089 | 0.050 | 0.028 |
| **Cu (ppm)** | 0.000 | 0.012 | 0.270 | 1.000 | 0.037 |
| **Mn (ppm)** | 0.000 | 0.369 | 10.389 | 0.100 | 1.618 |
| **Ni (ppm)** | 0.000 | 0.015 | 0.698 | 0.010 | 0.083 |
| **Pb (ppm)** | 0.000 | 0.003 | 0.094 | 0.050 | 0.015 |
| **Zn (ppm)** | 0.000 | 0.075 | 1.210 | 5.000 | 0.206 |

### 5.2.2 PCA and correlations

The communalities ranged from 88.7% for Mn to 25.8% for Pb. Three factors were extracted by PCA. Analysis of the rotated matrix showed that Mn had the greatest influence in this category (F1) and was associated with Ni and Cu as shown in Table 24. The second factor (F2) was dominated by Zn and associated with Cr and Pb.

**Table 23.** Total variance explained

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 2.1 | 30.4 | 30.4 | 2.1 | 30.4 | 30.4 | 2.1 | 29.6 | 29.6 |
| 2 | 1.1 | 16.1 | 46.4 | 1.1 | 16.1 | 46.4 | 1.2 | 16.7 | 46.3 |
| 3 | 1.0 | 14.7 | 61.1 | 1.0 | 14.7 | 61.1 | 1.0 | 14.8 | 61.1 |
| 4 | 1.0 | 14.0 | 75.1 | | | | | | |
| 5 | .9 | 13.0 | 88.1 | | | | | | |
| 6 | .7 | 9.9 | 98.0 | | | | | | |
| 7 | .1 | 2.0 | 100.0 | | | | | | |

The third factor (F3) only comprised of As. The factors extracted suggest that Cu, Ni and Mn may have the same origin. This fact is further reinforced by the Pearson correlation (Table 25) which shows that Mn correlates strongly with Cu and Ni. Cd, though analysed, was not included in the data analysis because it was undetectable in all the 74 samples. Table 23 shows that pollution due to three metals (Mn, Ni, & Cu) explains 61.1% of the variance.

**Table 24.** Component and rotated matrix

| | **Component Matrix** | | | **Rotated Matrix** | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 |
| Mn | .925 | | | .941 | | |
| Ni | .780 | | | .749 | | |
| Cu | .670 | | | .731 | | |
| Zn | | .581 | | | -.687 | |
| Cr | .427 | -.572 | | | .564 | |
| Pb | | .506 | | | .489 | |
| As | | | .885 | | | .901 |

**Table 25.** Pearson Correlation (r)

| | As | Cr | Cu | Mn | Ni | Pb | Zn | Location | Water-source |
|---|---|---|---|---|---|---|---|---|---|
| As | 1 | | | | | | | | |
| Cr | -.052 | 1 | | | | | | | |
| Cu | -.036 | .073 | 1 | | | | | | |
| Mn | -.012 | .186 | **.632**$^{**}$ | 1 | | | | | |
| Ni | -.021 | **.305**$^{*}$ | .165 | **.676**$^{**}$ | 1 | | | | |
| Pb | -.018 | -.062 | .059 | -.031 | .059 | 1 | | | |
| Zn | -.047 | -.128 | -.041 | -.065 | -.058 | .022 | 1 | | |
| Location | -.092 | **.275**$^{*}$ | .199 | .097 | .122 | .004 | -.047 | 1 | |
| Water-source | -.086 | **-.276**$^{*}$ | -.176 | -.157 | -.115 | .223 | **.236**$^{*}$ | **-.366**$^{**}$ | 1 |

* $p<0.05$ (2tailed); **$p<0.01$ (2tailed)

### 5.2.3 ANOVA and t-test

A one-way between-groups analysis of variance was conducted to explore the impact of location on pollution as measured by different methods. There was a statistically significant difference at the $p < 0.05$ level in chromium levels: F (2, 67) = 9.36, p = 0.00. Despite reaching statistical significance, the actual difference in mean scores between the locations was not very big. The effect size, calculated using eta squared, was 0.2. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for CB/NW (M = 0.027, SD = 0.42), differed significantly from Lusaka province (M= 0.00, SD=0.00).

A one-way between-groups analysis of variance was conducted to explore the impact of location on pollution as measured by different methods. There was a statistically significant difference at the $p < 0.05$ level in copper levels: F (2, 71) = 6.09, p = 0.04. Despite reaching statistical significance, the actual difference in mean scores between the locations was not very big. The effect size, calculated using eta squared, was 0.1. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for CB/NW (M = 0.031, SD = 0.058), differed significantly from Lusaka province (M= 0.011, SD=0.018).

The other parameters (As, Mn, Ni, Pb and Zn) were not significant amount in certain provinces compared to others.

An independent-samples t-test was conducted to compare the pollution levels of ground and surface water. With reference to Cr there was a significant difference in mean scores for ground water (M=0.00, SD = 0.00) and surface water (M =.016, SD = 0.35); t (43) = 3.091, p= 0.003 (two tailed). The magnitude of the differences in the means was 0.0162.

Furthermore, an independent-samples t-test was conducted to compare the pollution levels of ground and surface water. With reference to Zn there was a significant difference in mean scores for ground water (M=0.136, SD = 0.271) and surface water (M =.0363, SD = 0.144); t (38.2) = -1.823, p= 0.076 (two tailed). The magnitude of the differences in the means was 0.0998.

The other parameters (As, Cu, Mn, Ni and Pb) did not register any difference between ground and surface water.

Table 26 summaries the findings of the Zambian water quality using the *WPI*. The Data is arranged in ascending order with water samples that meets the benchmark ($0.0 \leq WPI \leq 1.0$) down to the water samples that are highly polluted ($WPI > 10$). It is apparent from the *WPI,* Table 26, that some the Zambian water samples are compromised in one way or another. The *WPI* reveals that out of all the water collected from Lusaka city (as shown in Table 26), 72.5% is not compromised (it's safe for human consumption); out of the water samples collected from the Copperbelt region, 36.4% is safe for direct human consumption and 91.75% of the samples collected from miscellaneous regions around Zambia are not polluted.

**Table 26.** Coding system, site names and the Water Quality Using the Water Pollution Index (WPI)

**Lusaka City (LSK)**

| Code | Site Name | WPI |
|---|---|---|
| LSK47G | Chainama Lusaka General Hospital | 0.00 |
| LSK67G | Chisengalumbwe Basic School | 0.01 |
| LSK64G | Villa Elizabetha | 0.01 |
| LSK59G | Twikatane Area Ground Water | 0.02 |
| LSK62G | George Compound Borehole | 0.02 |
| LSK70D | Roma/Garden Township Stream | 0.03 |
| LSK49T | Libala Basic School Tap from the Ground | 0.03 |
| LSK16R | Goma lakes | 0.03 |
| LSK50G | Vera Chiluba Basic School Tap from tap ground | 0.04 |
| LSK66G | Avondale River Side Street Tap Water from the Ground | 0.04 |
| LSK60G | NRDC Borehole Tap | 0.04 |
| LSK10G | New N'gombe Basic Tap (underground) | 0.05 |
| LSK57G | Kamwala Remand Prison Borehole Water | 0.06 |
| LSK53G | UNZA Tap Water - Groundwater | 0.06 |
| LSK51G | Kanyama Ground Water-Borehole-Filling Station | 0.06 |
| LSK48G | Chunga, Africa Methodist Episcopal Church Ground Water Borehole | 0.06 |
| LSK55G | Zingalume Police Tap Water from the Ground | 0.08 |
| LSK15T | Matero Petroda Station Tap Water (LWSC) | 0.09 |
| LSK65G | Zeko Camp Borehole | 0.09 |
| LSK63G | Ndeke Village | 0.10 |
| LSK17D | Blue Water Dam | 0.12 |
| LSK72G | Zingalume borehole water | 0.15 |
| LSK13T | Chawama Compound Tap Water (LWSC) | 0.20 |
| LSK58G | Entrance of Chunga - Ground Water | 0.39 |
| LSK9R | Ngombe Basic School Stream | 0.65 |
| LSK4R | Mumana Pleasure Resort (stream) | 0.71 |
| LSK68G | Thornpark Construction Centre Borehole | 0.73 |
| LSK52G | Femag Garden John Laing Tap Water from the Ground | 0.75 |
| LSK54G | Gospel Outreach Tap Water-ground | 0.81 |
| LSK8R | Malimba Ngwerere Stream | 1.60 |
| LSK14G | John Laing Tap (ground water) | 1.77 |
| LSK61G | Ngome tap Water from Ground Aquifer | 1.84 |
| LSK6R | Ngwerere Stream (near Kasisi) | 1.92 |
| LSK7R | Mutendere/Maplot midstream | 2.62 |
| LSK5R | Ngombe East Stream | 3.06 |
| LSK12R | Lumumba/Great North Road Junction (stream) | 3.49 |
| LSK3R | Mutendere River upstream | 3.73 |
| LSK56G | Mutendere Near Chainama Golf Club Well Water | 3.90 |
| LSK1D | Mutendere Dam | 5.17 |
| LSK2R | Chipata/Marapodi at Garden Park (stream) | 6.25 |

**Copperbelt Region (CB)**

| Code | Site Name | WPI |
|---|---|---|
| CB36R | Chingola River Upstream | 0.00 |
| CB44R | Kansuswa Stream (at Mufulira/Kitwe Road) | 0.00 |
| CB23R | Boating Club Dam (Mufulira) | 0.01 |
| CB30R | Malembeka Stream into Kafue (1st site) | 0.01 |
| CB22T | Tap Water - Mufulira Town Centre (Mulonga Water) | 0.02 |
| CB24R | Kafue River, Nkana East Waterworks | 0.05 |
| CB38G | Eagle High School Tap Water (Groundwater) | 0.19 |
| CB40R | Kafue Water Treatment Plant - Mulonga WSC | 0.82 |
| CB34R | Ndola Kitwe Dual Carriage Kafue River | 1.65 |
| CB32R | West Mine Shaft - Butondo Stream (at Bridge) | 1.68 |
| CB25R | River Near Sabina | 1.69 |
| CB19R | Kafue River Mufulira/Kitwe Road | 1.71 |
| CB35R | Malembeka Stream into Kafue (2nd site) | 1.78 |
| CB39R | Kawama stream - Mufulira | 1.78 |
| CB28R | Chingola/Chililabobwe Road Kafue River | 1.90 |
| CB26R | Before Tailings Damp (Butondo Stream) | 2.26 |
| CB33R | Butondo Stream at Road Near Butondo High | 4.04 |
| CB20T | Mine Water Mulonga Tap (Entebbe) | 4.26 |
| CB21R | West Shaft Effluent Water | 4.80 |
| CB37R | Tailings Damp (TD 11) | 5.21 |
| CB29R | Chingola Mine Effluent | 8.09 |
| CB27R | Tailings Damp Effluent) | 8.39 |

**Other Regions**

| Site Name | | WPI |
|---|---|---|
| KF11R | Kafue River at Motor Bridge | 0.00 |
| KF18R | Train Bridge (Kafue River) | 0.00 |
| MZ69T | Mazabuka Tap water | 0.00 |
| ND43R | Kafubu Upstream | 0.04 |
| ND31R | Kafubu River | 0.05 |
| KB42T | Jack & Jill School - Lukanga WSC | 0.05 |
| ND46R | Kafubu Downstream | 0.06 |
| KB41T | Kabwe City Council Tap Water (Lukanga WSC) | 0.07 |
| MG71G | Magoye borehole water - main compound | 0.07 |
| MG74G | Magoye borehole water- school | 0.08 |
| ND45T | Laka Petroleum Filling Station Tap Water - Ndola | 0.13 |
| SL73G | Solwezi well water | 1.15 |

LSK-Lusaka city; CB-Copperbelt; SL-Solwezi town; ND-Ndola city; KB-Kabwe town; KF-Kafue town; MG-Magoye town; MZ-Mazabuka town; G-groundwater; T-tap water; R-river water; D-dam/water reservoir

Further analysis of the water shows that water treatment is fairly effective in Mufulira as the water derived from the tap CB22T is suitable for human consumption despite deriving the water from the Kafue River CB40R, which is the major recipient of waste water drainage from different mines. However, the groundwater derived from the mine aquifer and supplied for drinking to former mine residential areas is polluted as deduced from the data evidenced by site CB20T. It is clear that mining activities have had a negative impact on the environment. The water in other regions of Zambia was the least polluted followed by the water from Lusaka city. Overall, the Copperbelt region had the worst polluted water (by per cent of the water which meet the clean water criteria).

### 5.3 Analysis of data using spatial maps

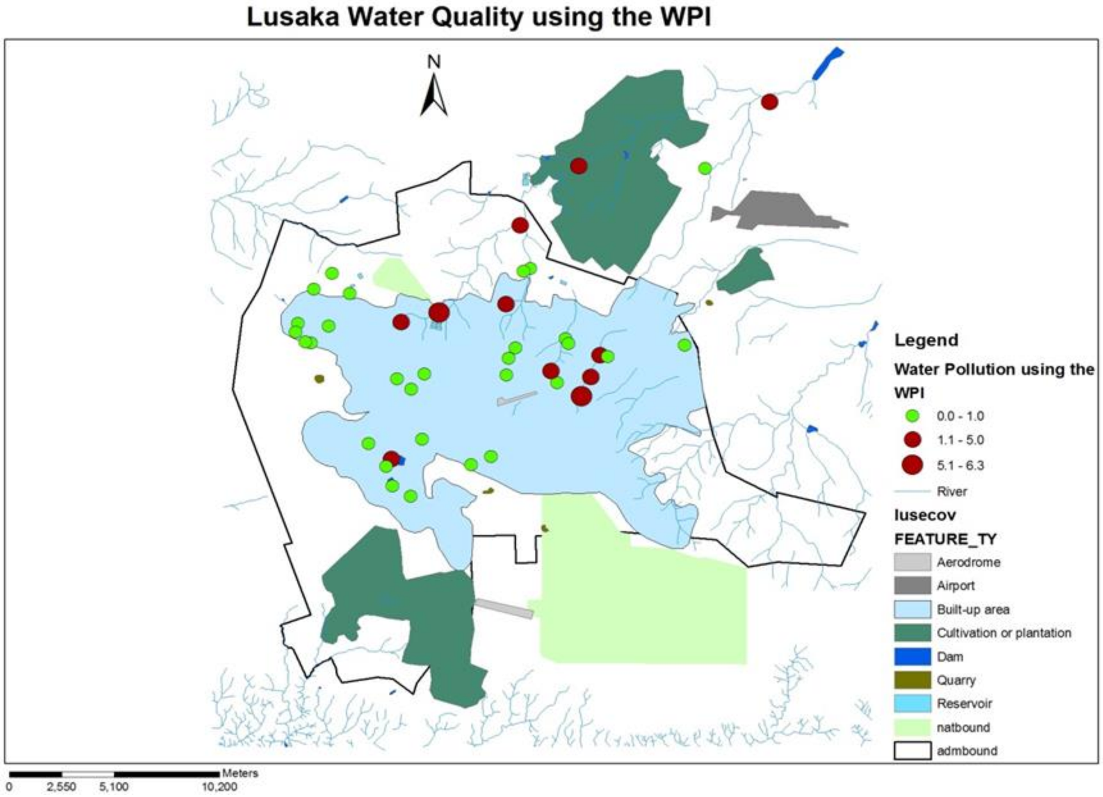

**Figure 14.** Water quality in Lusaka Region using the WPI

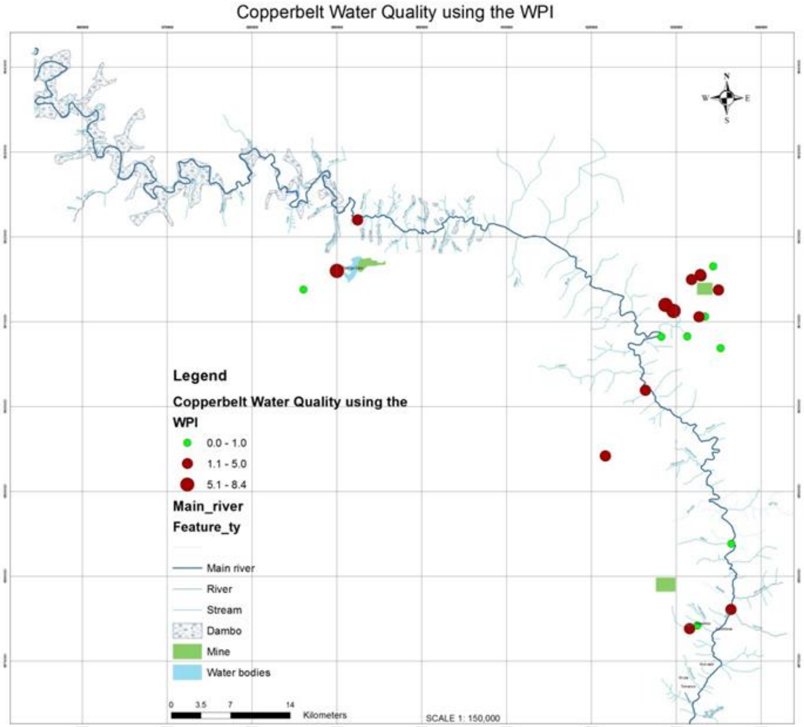

**Figure 15.** Water quality in the Copperbelt Region using the WPI

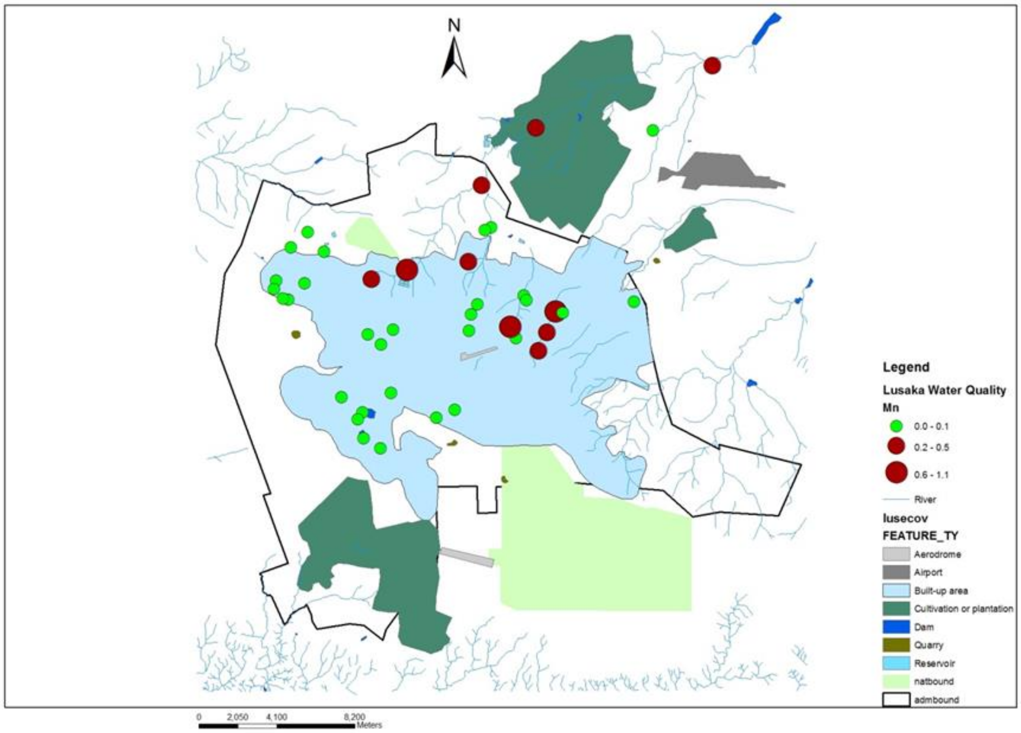

**Figure 16.** Lusaka manganese levels

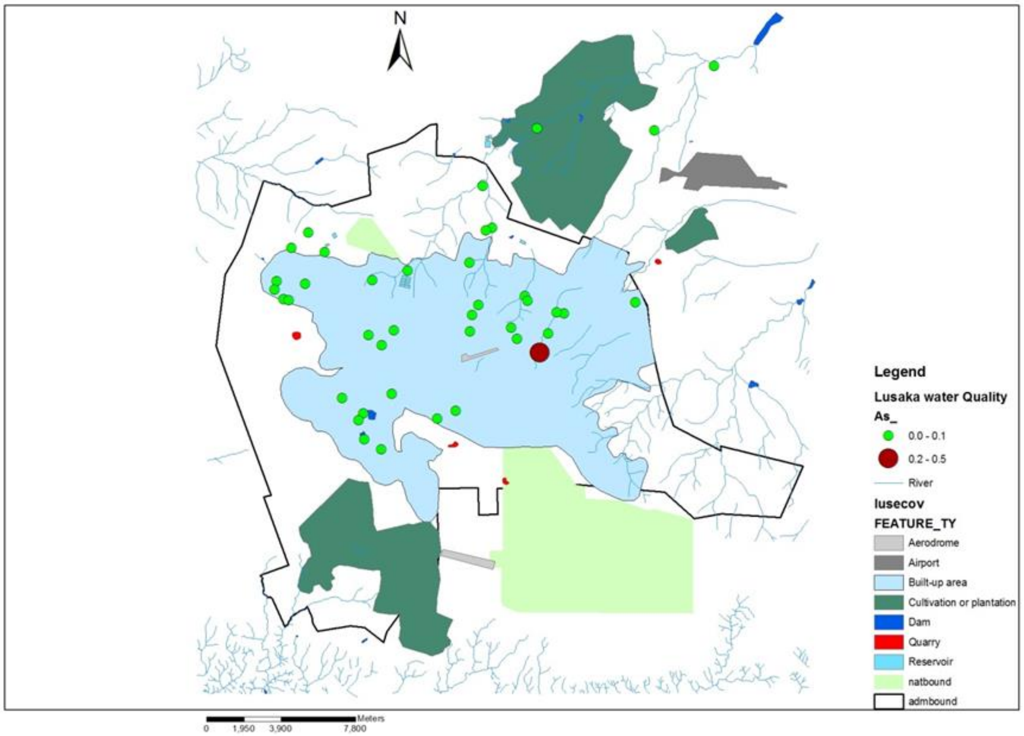

**Figure 17.** Portable and river water arsenic levels in Lusaka

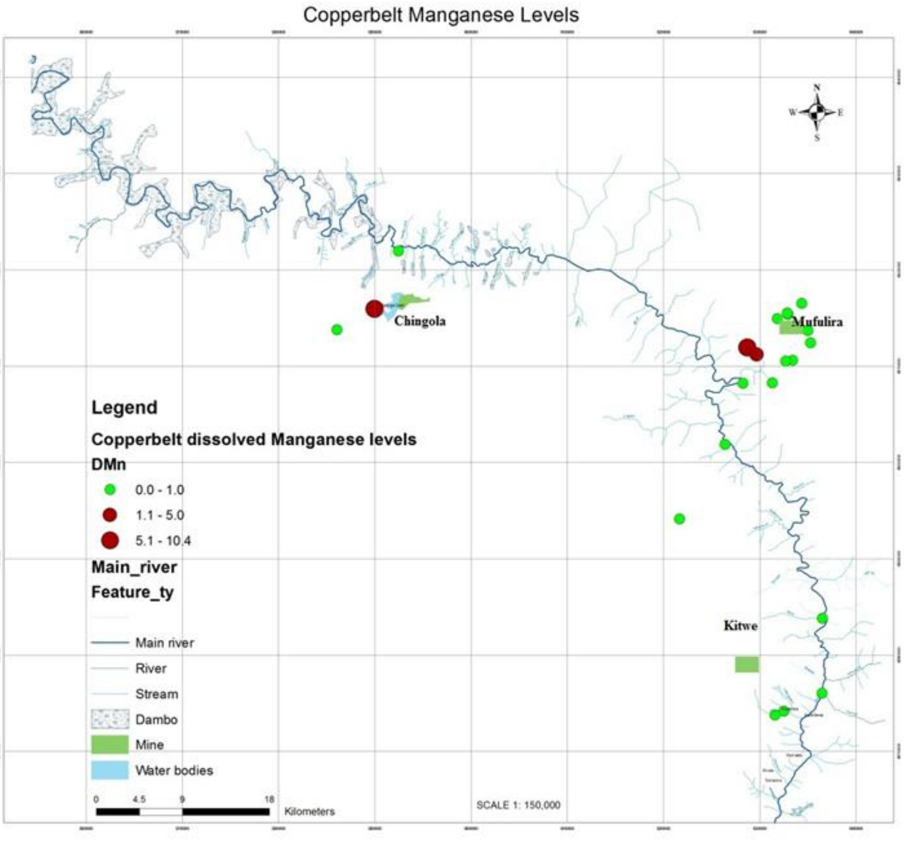

**Figure 18.** Portable and river water manganese levels in the Copperbelt

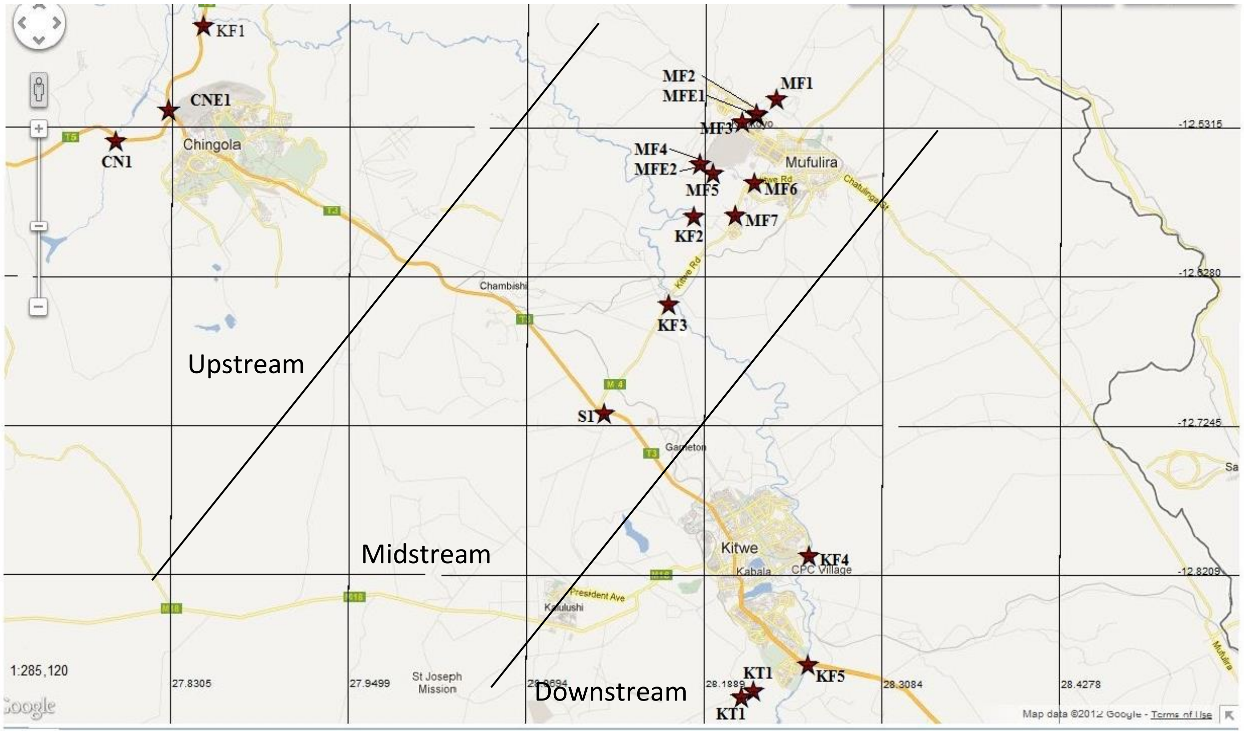

**Figure 19.** Sampling sites along the Kafue River and its network of tributaries

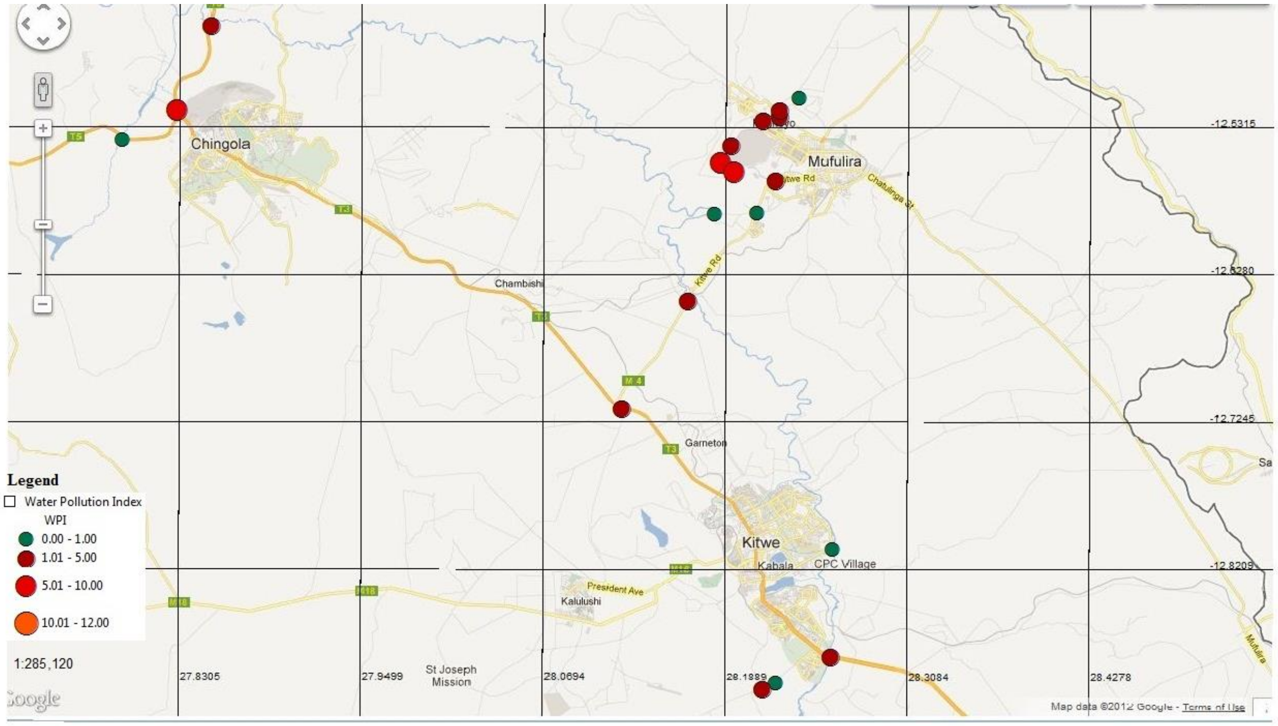

**Figure 20.** Kafue River Water Quality using the Water Pollution Index

**Table 27.** Pollutant flow in the Kafue watershed – Copperbelt

| Parameter | Upstream Kafue River | | | Midstream Kafue River (ppm) | | | | | | | | | | | | Downstream Kafue River (ppm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CN1 | CNE1 | KF1 | MF1 | MF2 | MFE1 | MF3 | MF4 | MFE2 | MF5 | MF6 | MF7 | KF2 | KF3 | S1 | KF4 | KF5 | KT1 | KT2 |
| **pH** | 7.970 | 7.630 | 8.140 | 7.790 | 7.910 | 8.360 | 7.850 | 7.930 | 7.310 | 7.890 | 7.400 | 6.760 | 7.900 | 7.920 | 7.950 | 8.020 | 7.990 | 6.730 | 7.560 |
| **Temp. °C** | 23.100 | 24.600 | 23.800 | 24.900 | 23.400 | 23.600 | 23.700 | 23.700 | 23.500 | 24.300 | 24.100 | 25.900 | 23.800 | 24.100 | 24.100 | 25.000 | 24.900 | 24.700 | 23.800 |
| **As(ppm)** | 0.000 | **0.004** | 0.000 | 0.000 | **0.001** | **0.005** | **0.005** | **0.000** | **0.001** | **0.005** | 0.000 | **0.000** | 0.000 | 0.000 | **0.003** | 0.003 | 0.001 | 0.000 | 0.000 |
| **Cd(ppm)** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **Cr(ppm)** | 0.000 | 0.000 | 0.089 | 0.000 | **0.089** | 0.000 | 0.000 | **0.089** | **0.089** | 0.000 | **0.089** | 0.000 | 0.000 | 0.000 | **0.089** | 0.000 | 0.089 | 0.000 | **0.089** |
| **Cu(ppm)** | **0.004** | **0.270** | 0.095 | **0.007** | **0.006** | **0.145** | **0.023** | **0.008** | **0.026** | **0.008** | **0.006** | **0.003** | 0.056 | 0.035 | **0.004** | 0.016 | 0.013 | **0.007** | **0.004** |
| **Mn(ppm)** | 0.000 | **10.389** | 0.163 | 0.000 | 0.000 | **0.251** | 0.000 | **0.249** | **9.545** | **1.369** | 0.000 | 0.000 | 0.105 | 0.181 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **Ni(ppm)** | 0.000 | **0.028** | 0.000 | 0.000 | 0.000 | **0.126** | **0.076** | **0.005** | **0.698** | **0.083** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **Pb(ppm)** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **Zn(ppm)** | 0.000 | **0.021** | 0.000 | 0.000 | 0.000 | **0.003** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.017 | 0.000 | 0.000 |

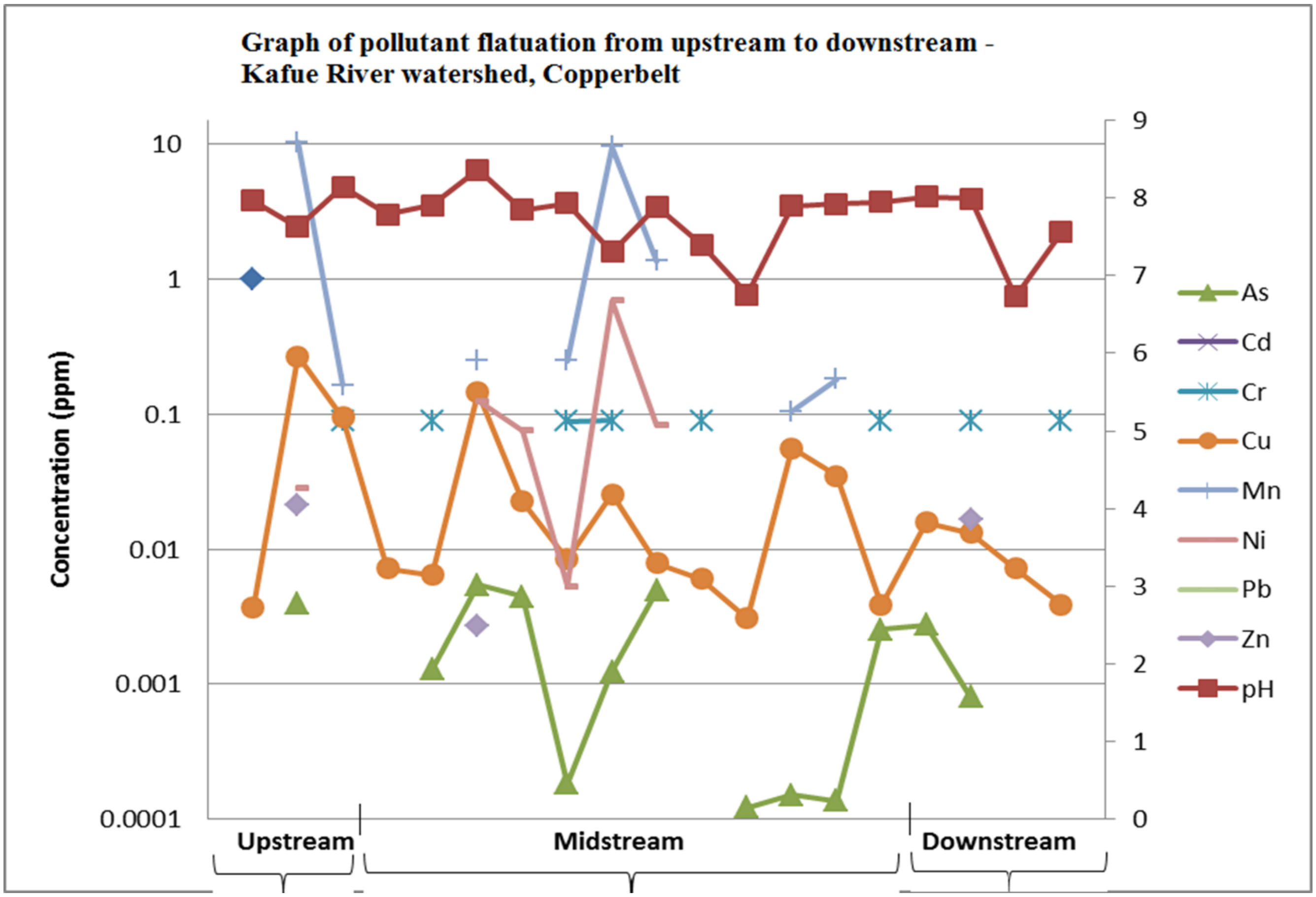

**Figure 21.** Pollutant flow in the Kafue Watershed - Copperbelt

## 5.4 Pattern of the pollution

Zambia is predominantly a mining country whose economy is heavily dependent on Cu mining. Despite the widespread mining activities, there were no significant levels of dissolved Cu in all the regions that were sampled (Table 22). However, there is significant pollution due to Mn as shown in Figure 16 and Figure 18. Mn pollution is also a major pollution factor in Lusaka which is not a mining city, with surface water resources being more polluted compared to groundwater. However, the water collected near high density residential areas with a rudimentary sewer system and with widespread use of on-site sanitation and an abundance of backyard dumpsites did not prove to have any serious heavy metal loadings beyond what is permissible in drinking water. Kabwe is reported as one of the most polluted towns in Zambia (Cohen, 2011) but the water collected from the tap KB41T and KB42T met the drinking water criteria at 0.07 ppm and 0.05 ppm respectively.  The pollution in the former mining giant may exist in form of dust and pollution in soils and sediments, and near the former mine as explained by Tembo, Sichilongo and Cernak (2006). Dissolved heavy metal pollution was not a huge factor in the former mining town even though it ranks amongst the top ten most polluted areas in the world. Analysis of the Kafue watershed as shown by Table 27 and Figure 21, in the Copperbelt area, from upstream to downstream reveal that there was no continuous pollution of one pollutant across the Kafue watershed in the Copperbelt from upstream to downstream. High levels of heavy metals, particularly Mn and Ni were observed at point sources of pollution but accompanied by a drastic drop in the levels of the pollutant further downstream. Figure 20 using the WPI further reveals that water from the watershed is generally free of heavy metal pollution to moderate pollution. The high polluted site as depicted on the map on the point sources of pollution.

## 5.5. Discussion

Analysis of the water from the Copperbelt revealed that surface or river/stream water was polluted the most as judged by the *WPI,* Table 26. As expected there was more pollution near the mine effluent (point source of the pollution) and a progressive reduction downstream. The previous study by von der Heyden and New (2004) of ground water pollution on the geological and geochemical investigation strongly suggests an upslope tailings impoundment as the source of contaminants with the edge of the pollution plume lying 500–700 m downstream of the impoundment. Similar water samples were collected, in this study, near tailings impoundments, sample CB37R and CB29R which had pollution indexes of 5.21 and 8.09 respectively.  Furthermore, von der Heyden and New (2004) found that there was attenuation of heavy metals as linked to tailings dam and aquifer pH, with the high buffering capacity of each implying that these processes of attenuation are likely to continue removing harmful metals from the aquifer. However, this study found that dissolved metal concentration was particularly high near the effluent water from the tailings dump. Mulonga water and sewerage company-Mufulira town obtains its water from site CB40R with *WPI* 0.82 and after treatment, the *WPI* is 0.02. This shows that water treatment is effective and the water supplied to former council residential areas is safe. However, the scenario is different with the water supplied to the former mine residential areas (CB20T), the *WPI* is 4.26 as revealed by Table 26. This water is obtained from the mine ground aquifer. Its *WPI* is classified as slightly polluted water under the scale chosen in this study and may not be suitable for long term use for human consumption.

### 5.5.1 Description of the pollution by parameter

#### 5.5.1.1 Arsenic (As) pollution

Arsenic is listed as a known human carcinogen by the department of health and human services; it occurs naturally in ground water, often reaching high concentrations (Wright, 2005). Drinking water especially that derived from groundwater is a major source of As for many people. Although anthropogenic uses of As can result in its contamination of water, by far the greatest problems occur with that produced by natural process (Baird & Cann, 2008). One sample as shown in Figure 17, LSK1D, of the 74 samples, tested for As loadings to pollution levels; the pollution index was 5.17. The water that was sampled from this site is in a vicinity of a large illegal dumpsite. However, all the ground and surface water samples were free of any As loadings to pollution levels.

#### 5.5.1.2 Copper (Cu) pollution

Copper is necessary for good health. However, very large single or daily intakes of Cu can harm human health. Long-term exposure to Cu dust can irritate the nose, mouth, eyes and cause headaches, dizziness, nausea and diarrhoea. Drinking water that contains higher than normal levels of Cu may cause vomiting, diarrhoea, stomach cramps and nausea. Chronic high intakes of Cu can cause liver and kidney damage and even death (OhioEPA, 2002a). The study did not find significant amounts of dissolved Cu in water, notwithstanding the limitation of the study that it did not concentrate on total heavy metal pollution. The study did not equally look at the Cu pollution in soils, plant tissue or as suspended Cu dust in air. All the samples met the clean water criteria both in the Copperbelt province, Lusaka city and the other regions assessed in this study.

### 5.5.1.3 Cadmium (Cd) pollution

Cadmium is a relatively volatile element not essential to plants, animals and humans. Its presence in living organisms is unwanted and harmful. An increased level of Cd in the air, water and soil increases its uptake by live organisms. It is taken up by plants and animals (Smirjakova et al., 2005) or it can be ingested by eating the contaminated animals and plants or through direct consumption of the untreated ground or surface water such as is common in Zambia. When excessive amounts of $Cd^{2+}$ are ingested, it replaces $Zn^{2+}$ at major enzymatic sites and thus, causes metabolic disorders (Ahluwalia & Malhotra, 2007). Cadmium is commonly found in rechargeable Ni-Cd batteries. The batteries' popularities are growing due to their rechargeable nature (Theodore, 1996). However, the water samples collected from across Zambia passed the clean water criteria including the effluent water despite the indiscriminate disposal of Cd based products.

### 5.5.1.4 Zinc (Zn) pollution

Zinc compounds also have a great range of useful properties and applications, and consequently are used in a very wide range of products. Some common examples of the use of zinc compounds in Zambia include: zinc oxide used as a white pigment, zinc chromate used as a rust inhibitor; zinc oxide used in ointments for burns and skin protection, zinc pyrithione used in anti-dandruff shampoos; zinc chloride used as an electrolyte in dry-cell batteries; rubber and plastic compositions (these are usually discarded in illegal dumpsites/landfills after their useful lifespan); zinc oxide and zinc chloride used for vulcanising rubber and as pigments and fillers, especially in vehicle tyres; zinc oxide, zinc acetate and zinc carbonate used for making glazes; zinc sulphate used in paper bleaching; insecticides and fungicides as zinc naphthenate, zinc octoate, zinc versatate used to preserve wood against fungal rot and insects; zinc phosphide used in rodent bait. However, despite its versatility, the highest Zn load determined was 1.20 ppm site CB38G.The site with highest Zn loads is in the mining town but not any closer to obvious sources of pollution. However, it was still within safe drinking levels of 5 ppm as determined by Zambia Bureau of standards.

### 5.5.1.5 Chromium (Cr) pollution

The Cr(III) and Cr(VI) ions present in various environmental media are of relevance to biology, ecology, and health; the trivalent form being relatively benign while the hexavalent form is relatively toxic (Adriano, 2001).

Its various compounds have a wide range of uses: major ones include electroplating, drug manufacture and textile dyes (Si, 2011). In regions like India hexavalent Cr, among other pollutants, is a major source of aquatic pollution from tannery effluent (Yadav, Shukla & Rai, 2005). However, there are no documented pollution issues from the Zambian tannery industries.

Hexavalent chromium [Cr (VI)] compounds used in a wide variety of commercial processes and unregulated disposal of the Cr containing effluent can lead to serious contamination of soil, sediment, surface and ground waters. In trace amounts, Cr is considered an essential nutrient for numerous organisms (Mertz, 1981; Pechova & Pavlata, 2007), but at higher level, it is toxic and mutagenic (Cieslak-Golonka, 1996). Chrome tanning processes are popular at industrial scale and discharge of untreated wastewater into the environment a commonplace. In such aqueous waste, Cr (VI) is present as either dichromate ($Cr_2O_7^{2-}$) in acidic environments or as chromate ($CrO^{4-}$) in alkaline environments (Yadav Shukla & Rai, 2005). In this study, Cr was strongly associated with Zn and Pb in the PCA and significantly correlated with Ni (Table 25). However, the average concentration (0.01 ppm) of Cr was far below its PV of 0.05 ppm. Cr was not deemed a serious pollution problem in the Zambian water systems.

#### 5.5.1.6 Manganese (Mn) pollution

Kondakis et al. (1989) reported that progressive increases of Mn concentration in drinking water are associated with progressively higher prevalence of neurological signs of chronic manganese poisoning (CMnP) and Mn concentration in hair of older persons. Master, in a research reported by Motluk (1997), also found that environmental pollution seems to have an independent effect on the rate of violent crimes - defined as homicide, aggravated assault, sexual assault and robbery. He argued that counties with the highest levels of Pb and Mn pollution typically have crime rates three times the national average. Mn was the biggest pollution problem determined in the Copperbelt region and Lusaka city. The average Mn pollution was 0.369 ppm well beyond the *PV* of 0.1 ppm. The site (CB29R) with the highest Mn level was 100 times the *PV* for drinking water.

#### 5.5.1.7 Nickel (Ni) pollution

Ni is an essential element for healthy animals and probably for humans. The most common adverse health effect of Ni in humans is an allergic reaction. People can become sensitive to Ni when jewellery or other items containing Ni touch the skin. Once a person is sensitized to Ni, further contact with the metal will produce a reaction. The most common reaction is a skin rash at the site of contact. In some sensitized people, dermatitis may develop at a site away from the area of contact. Some sensitized individuals react when they eat Ni in food or water, or breathe dust containing Ni. Kidney and lung damage have been observed for large doses of Ni (OhioEPA, 2002b). From the PCA analysis and Pearson correlation product moment analysis, results show that Ni was strongly associated with Mn, which is also the single most significant pollution problem in Zambia. It was detectable in Zambian water samples beyond the recommendable value of 0.01 ppm; the maximum value registered was 0.698 ppm.

### 5.5.1.8 Lead (Pb) pollution

Lead is a nonspecific toxin that acts at the molecular levels and inhibits many enzymatic activities that regulates normal biological activities (Adriano, 2001). The Pb salts are attributed to water hazards and consequently are harmful. Lead poisoning has been recognised as a cause of mental retardation, learning disabilities in children. Furthermore, high blood pressure in adults correlates with high levels of Pb in blood (Wright, 2005). The same applies to Pb compounds such as lead acetate, lead oxide, lead nitrate, and lead carbonate. In the absence of any recycling of Pb-acid batteries and other Pb containing products in Zambia, it can be postulated that Pb-acid batteries contributes to the high percentage of Pb pollution in the municipal solid waste. Pb in petrol was only phased out in March 2008 (ERB, 2008). Because of the persistent nature of heavy metal in the soil, it was expected that groundwater would test for Pb.

Pb limits plant chlorophyll synthesis (Sharma & Dubey, 2005). Higher concentrations negatively influence plant growth and through plant uptake, Pb enters food chains. Ahluwalia and Malhotra (2007) argues that Pb, being similar to $Ca^{2+}$, gets accumulated in the bones and is subsequently remobilised along with phosphates from bones which exert a toxic effect. As a consequence, Pb pesticide application is prohibited in most countries. Pb accumulates in organisms, sediments and sludge. Analysis of correlation coefficient revealed that levels of Pb did not correlate with any other heavy metal. The average concentration was 0.003 ppm well below the *PV* value of 0.05 ppm. The highest concentration recorded being 0.094 ppm. Despite the numerous reports documenting the historical negative effects of the obsolete Kabwe mine on the environment, dissolved Pb pollution was not beyond the recommended *PV* in all the samples except two sites (far from Kabwe town), CB20T and LSK14G. The samples from the former, and only Pb mining town (Kabwe), were free of any Pb contamination.

### 5.6 Major Findings

Contrary to popular belief and what other researchers may have reported about Zambia that soil sediments are contaminated with heavy metals. There were no apparent serious problems (involving all heavy metals) which can be considered as being beyond remediation. There were no significant metal loadings in high density informal settlements and near illegal or backyard dumpsites. The heavy metal pollution problems are to a large extent confined to the Cu mining towns and are mostly due to Mn. Even though Zambia is a Cu mining country and the seventh producer of refined Cu as of 2010 data (British Geology Survey, 2012), the pollution due to dissolved Cu is insignificant even from the effluent water discharged by the mines in Mufulira and Chingola towns. The high levels of heavy metal (especially Mn) loads in the Copperbelt are a probable consequence of the lack of control and remediation measures during and after mining operations. Factor 1, using PCA, showed that Mn was the most influential factor explaining 30.4 per cent of variance observed in the analysis. The statistical analysis further reveals that Mn is the controlling element; it both correlates positively and significantly with Cu and Ni. However, there is no correlation between Cu and Ni as revealed by Table 25. Despite environmental protection legislation and monitoring by ECZ and other controlling bodies being in existence, the mining industry is the main source of severe water pollution. Nchanga Tailings leach plant in Chingola Zambia manages a Cu tailings leach plant. The processes range from reclamation, concentrator tails, thickening/dewatering, filtration, leaching, concentration in counter current decantation thickeners, purification in solvent extraction/electro winning and neutralization of final tails with lime from the lime plant. Despite all these processes the pH did not show any anomalies not only from the Nchanga mine or the Mufulira mine effluent with similar operations, but all samples across Zambia except for one sample from Lusaka city (LSK13T) which was slightly acidic at pH 5.75.

# Chapter 6

## 6. Seasonal variation of water quality along the Kariba Lake, Zambezi River and its tributaries

### 6.1 Introduction

The Zambezi is the fourth-longest river in Africa, and the largest flowing into the Indian Ocean. The area of its basin is 1,570,000 square kilometres. The 2,574 kilometres-long river has its source in Zambia and flows through Angola, along the border of Namibia, Botswana, Zambia, and Zimbabwe, to Mozambique, where it empties into the Indian Ocean (Zambezi River, 2008). Dangerous levels of bacteria have been found in the backwaters of the Zambezi River, where fish have been recently found suffering from an unknown and apparently fatal disease (Zambezi river pollution warning, 2007; Magadza, 2006). Pollution of surface and groundwater resources and the atmosphere have become major environmental problems for the Zambezi River Basin. The increase in pollution discharges is largely attributed to urbanisation, increased industrial and agricultural activities, mining and soil erosion. The urban centres produce sewage effluent, industries emit greenhouse gases and other industrial wastes, and the agricultural sector uses fertilisers and other pesticides which all contribute to the pollution of the surface and groundwater resources. In the Zambezi River Basin, gold panning is prevalent resulting in soil erosion and water resources pollution. Mine wastes, if not disposed and managed properly, result in heavy metal pollution (Tumbare, 2004).

There is an act which mainly deals with the management of the Zambezi River water for economic, industrial and social development with particular emphasis on water usage for energy purposes governed by an inter-state Act (with Zimbabwe) called the Zambezi River Authority Act Chapter 467 (Nwasco, 2010b). Much of the basin's waters are used to generate hydroelectric power (HEP) primarily from the two largest human-made lakes, Kariba, 5,250 km$^2$ holding 156 km$^3$; and Cabora Basa, 2,739 km$^2$ holding 56 km$^3$ (Mpande & Tawanda, 1998). With the river flowing through five countries there is a likelihood of interstate conflict resulting from mismanagement of the river. Although pollution of water resources has not yet created regional conflicts, the likelihood of such conflict exists in the future. The issue, however, has the potential of becoming a regional problem, particularly regarding pollution from heavy metals, as evidenced by the existence of DDT and heavy metals in Lake Kariba (ibid). The riparian countries, therefore, need to cooperate in formulating and monitoring legislation to prevent such contamination. Furthermore, Mpande and Tawanda (1998) suggest that legislation should include the establishment of limits on effluent as well as punitive measures for offenders. The world over, four principle theories or doctrines have been maintained by riparian states regarding the rights on international waters. 1) The theory of absolute territorial sovereignty maintains that a watercourse states enjoys exclusive authority over the waters of an international watercourse within its territory. 2) According to the theory of absolute territory integrity a watercourse state has a right to the natural flow of water into its territory. 3) The theory of limited territory sovereignty of a state over its territory is limited by obligation to use the territory in a way that does not cause significant harm to other nations. And lastly 4) according to the theory of community of interests the physical unity of the watercourse creates a community of interests in the water (Dombrowsky, 2007). However, it is not very apparent as which theory guide the management of the Zambezi River amongst the riparian countries. However, the theory of community of interests seems to be at play as evidenced by the recent reference to 'shared water courses' in the protocol on Shared Watercourse Systems in the Southern African Development Community (SADDC) of 1995 (ibid).

The Upper Zambezi River is thinly populated by pastoralist farmers and fishermen, and with no history of industrial activities. However, with the coming of new mines near the source of the river in Kabompo, there is a possibility of new sources of pollution. The pollution in the Kabompo River, which feeds into the Zambezi River, would affect hundreds of thousands of people further downstream. It is the purpose of this study to provide current information (in 2011) about the seasonal variations of the water quality along the Zambezi River. This study therefore is intended to analyse and disseminate hydrological and environmental data and environmental conditions of the Zambezi River, its tributaries and Lake Kariba.

## 6.2 Data Analysis

### 6.2.1 Analysis of the boxplots of the nine parameters

The individual parameters were analysed using descriptive statistics, where the boxplots were used as a convenient way of graphically depicting the parameters by the seasonal numerical data through the five-number summaries: the smallest observation (sample minimum), lower quartile (Q1), median (Q2), upper quartile (Q3), and largest observation (sample maximum). The boxplots were used to indicate which parameter in a given season, if any, might be considered outliers of the Zambezi River data.

The boxplots display differences between populations without making any assumptions of the underlying statistical distribution as they are non-parametric. The spacing between the different parts of the box help to indicate the degree of dispersion (spread) and skewness in the data, and identify outliers.

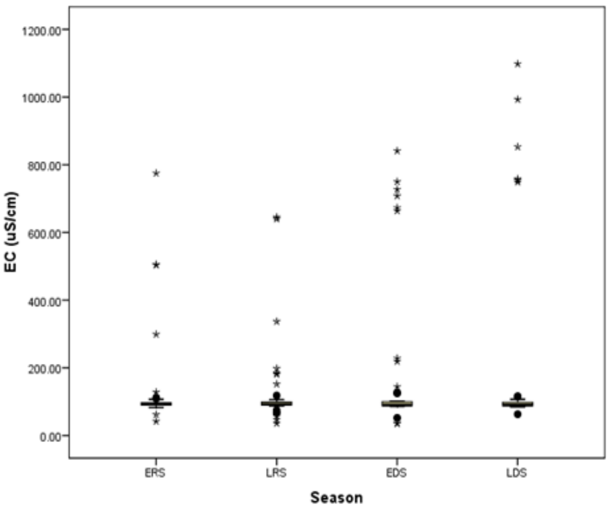

**Figure 22.** Boxplot for Electroconductivity

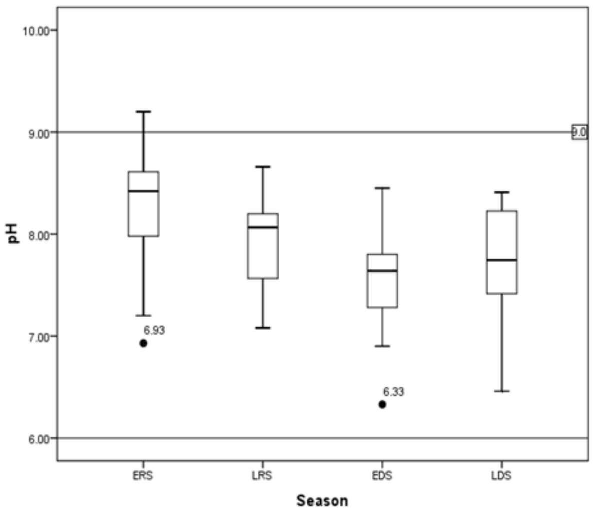

**Figure 23.** Boxplot for pH

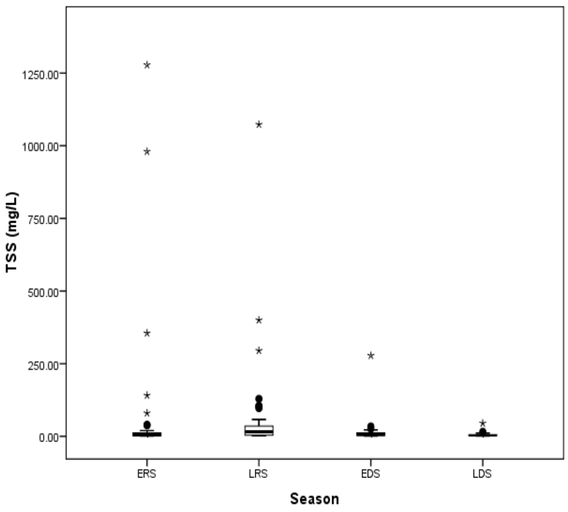

**Figure 24.** Boxplot for Total Suspended Solids

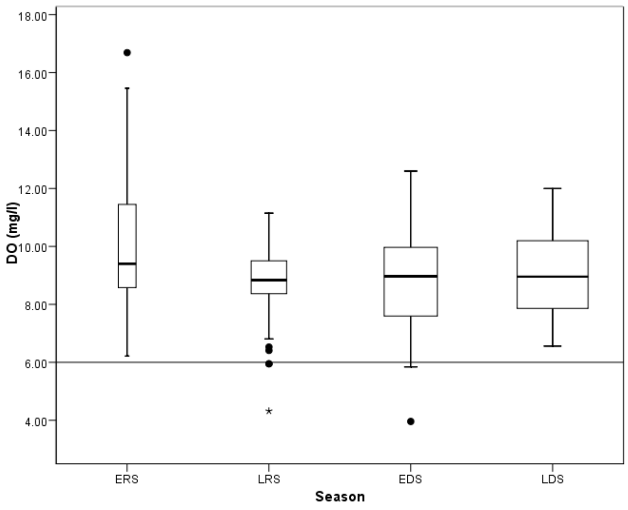

**Figure 25.** Boxplot for Dissolved Oxygen

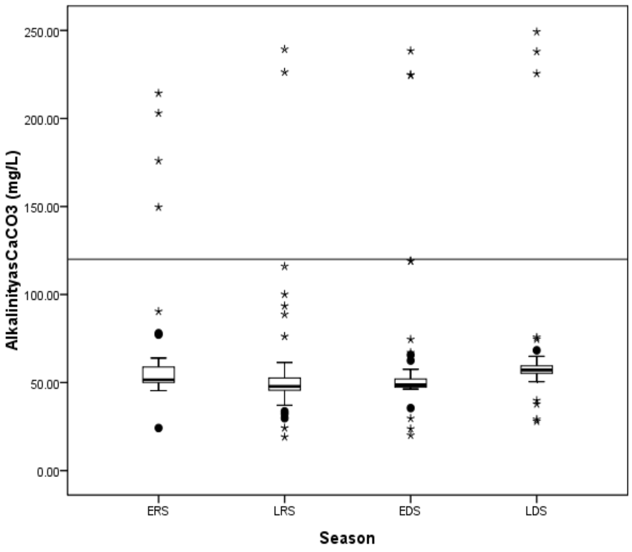

**Figure 26.** Boxplot for Alkalinity as $CaCO_3$

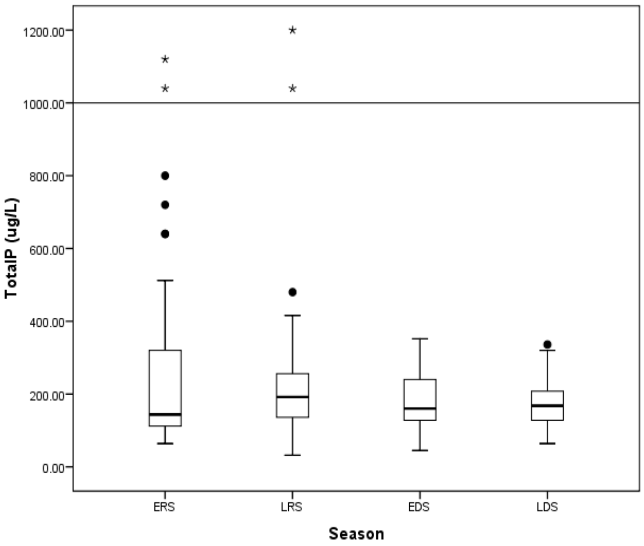

**Figure 28.** Boxplot for Total Phosphorus

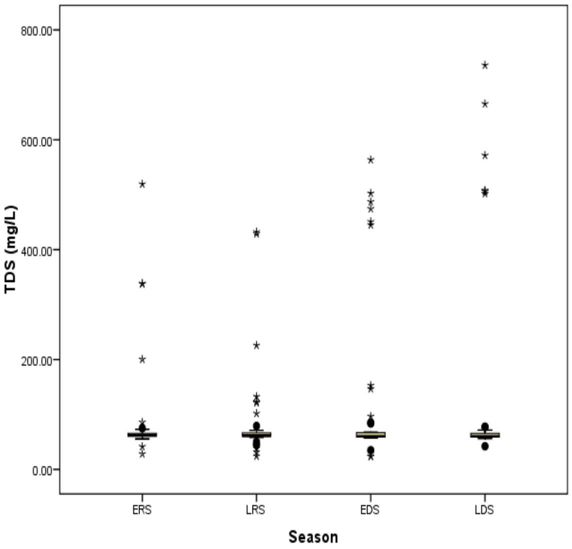

**Figure 27.** Boxplot for Total Dissolved Solids

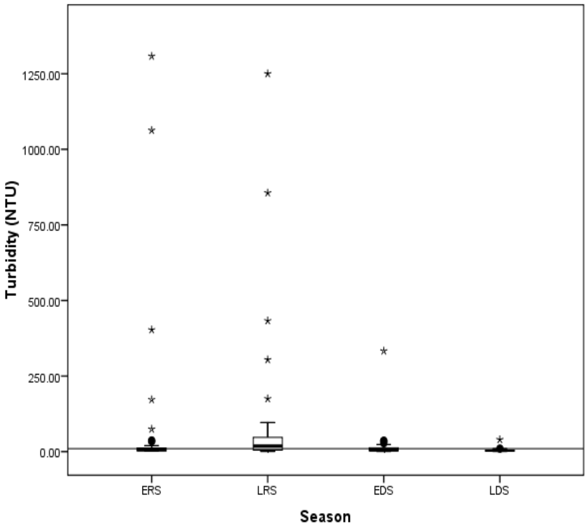

**Figure 29.** Boxplot for Turbidity

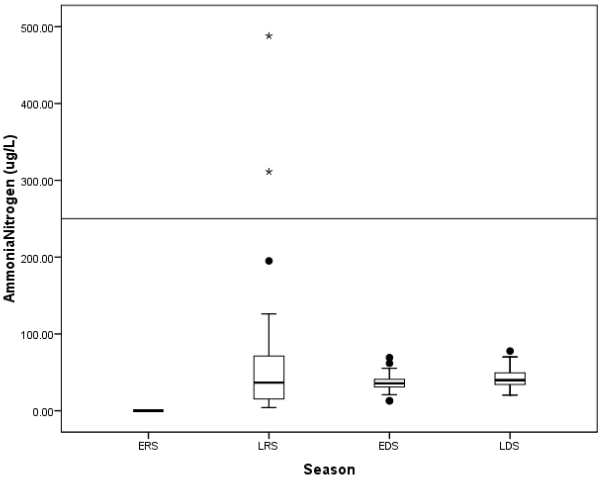

**Figure 30.** Boxplot for Ammonia Nitrogen

Boxplots of the individual parameters in the four seasons were examined. Figures 22 to 30 show an example of boxplots for some meaningful variables related to the water quality of the Zambezi River, Lake Kariba and its tributaries such as ammonia-nitrogen, DO, and total phosphorus. The line across the box represents the median, whereas the bottom and top of the box show locations of the first and third quartiles (Q1 and Q3). The whiskers are the lines that extend from the bottom and top of the box to the lowest and highest observations inside the region defined by Q1-1.5(Q3-Q1) and Q3+1.5(Q3-Q1), individual points with values outside these limits (outliers) are plotted with asterisks (Vega et al., 1998). Boxplots provide a visual impression and shape of the underlying distributions. For example, box plots (such as that for turbidity) indicate that the underlying distribution skewed towards higher levels. Boxplots with large spread indicate large seasonal variations of the water compositions (see pH boxplots). By inspecting these plots it was possible to perceive differences among the four seasons. For example, pH is higher in the ERS (exceeding the effluent water standards of pH 9 in some locations) and lowest in EDS. The high pH in the ERS would probably be an indicator of stormy water with high levels of organic material and inorganic nutrients which tend to increase the water pH.

### 6.2.2 Principal component analysis (PCA)

Principal Component Analysis (PCA) did not find any ambiguity in the component matrix. After analysing the rotated matrix, it was even clearer that four components emerged. Component 1 (F1) was comprised of Turbidity, TSS, TP and $NH_3$-N. Component 2 (F2) constituted of EC, TDS and Alkalinity as $CaCO_3$ and the third component (F3) was made up of DO and pH (Table 28). Temperature constituted the last component (F4). Table 29 shows that the four parameters explained 81.37% of the variance.

**Table 28.** Pattern and structure matrix

| | Component | | | | | Component | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | | 1 | 2 | 3 | 4 |
| Turbidity | .958 | | | | Turbidity | .954 | | | |
| TSS | .918 | | | | TSS | .915 | | | |
| TP | .813 | | | | TP | .813 | | | |
| Ammonia-Nitrogen | .550 | | | | Ammonia-Nitrogen | .557 | | | |
| EC | | .963 | | | TDS | | .966 | | |
| TDS | | .963 | | | EC | | .966 | | |
| Alkalinity as $CaCO_3$ | | .812 | | | Alkalinity as $CaCO_3$ | | .810 | | |
| DO | | | .918 | | DO | | | .888 | |
| pH | | | .788 | | pH | | | .841 | |
| T | | | | .965 | T | | | | .962 |

**Table 29.** Total variance explained

| | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings |
|---|---|---|---|---|---|---|---|
| Component | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total |
| 1 | 2.916 | 29.160 | 29.160 | 2.916 | 29.160 | 29.160 | 2.756 |
| 2 | 2.479 | 24.788 | 53.947 | 2.479 | 24.788 | 53.947 | 2.590 |
| 3 | 1.674 | 16.737 | 70.684 | 1.674 | 16.737 | 70.684 | 1.694 |
| 4 | 1.069 | 10.690 | 81.374 | 1.069 | 10.690 | 81.374 | 1.273 |
| 5 | .712 | 7.125 | 88.499 | | | | |
| 6 | .428 | 4.280 | 92.779 | | | | |
| 7 | .382 | 3.820 | 96.599 | | | | |
| 8 | .281 | 2.812 | 99.411 | | | | |
| 9 | .059 | .589 | 100.000 | | | | |
| 10 | .000 | .000 | 100.000 | | | | |

### 6.2.3 Pearson correlation

Correlations (Table 30) were observed between several parameters and among them the significant ones were between: TDS and EC ($r$ = 1.0); between turbidity and TSS ($r$ = .93); between total phosphorus and turbidity ($r$ = .71) and between alkalinity as $CaCO_3$ and both EC and TDS ($r$ = .635). In addition, location [site] was correlated positively with almost all the parameters except ammonia-nitrogen and temperature. The turbidity and TSS of the water is likely made up of phosphorus containing constituents as there was a strong correlation between these parameters.

**Table 30.** Pearson Correlation

| | **T** | **pH** | **EC** | **DO** | **TSS** | **TDS** | **Alkalinity as CaCO$_3$** | **Turbidity** | **TP** | **Ammonia-Nitrogen** | **Season** | **Location** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T | 1 | | | | | | | | | | | |
| pH | **.337**$^{**}$ | 1 | | | | | | | | | | |
| EC | -.143 | .050 | 1 | | | | | | | | | |
| DO | -.071 | **.577**$^{**}$ | **.172**$^{*}$ | 1 | | | | | | | | |
| TSS | .060 | .043 | .024 | **.167**$^{*}$ | 1 | | | | | | | |
| TDS | -.143 | .050 | **1.000**$^{**}$ | **.172**$^{*}$ | .025 | 1 | | | | | | |
| Alkalinity as CaCO$_3$ | **.144**$^{*}$ | **.214**$^{**}$ | **.635**$^{**}$ | **.184**$^{*}$ | .091 | **.635**$^{**}$ | 1 | | | | | |
| Turbidity | .060 | .016 | .014 | .140 | **.930**$^{**}$ | .015 | .077 | 1 | | | | |
| TP | .089 | .068 | .045 | **.190**$^{**}$ | **.618**$^{**}$ | .045 | .094 | **.710**$^{**}$ | 1 | | | |
| Ammonia-Nitrogen | -.074 | **-.146**$^{*}$ | .063 | -.101 | **.343**$^{**}$ | .063 | .064 | **.390**$^{**}$ | **.298**$^{**}$ | 1 | | |
| Season | **-.571**$^{**}$ | **-.414**$^{**}$ | .142 | **-.180**$^{*}$ | **-.180**$^{*}$ | .142 | .032 | **-.179**$^{*}$ | **-.216**$^{**}$ | **.220**$^{**}$ | 1 | |
| Location | .037 | **.172**$^{*}$ | **.497**$^{**}$ | **.198**$^{**}$ | **.202**$^{**}$ | **.497**$^{**}$ | **.345**$^{**}$ | **.232**$^{**}$ | **.242**$^{**}$ | .139 | .000 | 1 |

** Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed)

Equally, there is a strong correlation between TDS and EC. The findings suggest that high TDS brings the onset of high EC in certain locations. The findings further suggest that changes in season bring about turbidity and high TSS as there was a very strong correlation between them.

### 6.3. Multiple comparison of water parameters

One-way analysis of variance was used to compare the mean scores (*M*) of the ten pollution parameters. The study was intended to uncover the impact of season (the independent variable) on the water quality parameters (dependent variable). ANOVA only uncovered information on whether the water quality across the seasons differed significantly, but did not reveal any significant difference. An *F* (degrees of freedom between groups, degrees of freedom within groups) ratio was also calculated, which represented the variance between the groups, divided by the variance within the groups. A large *F* ratio indicates that there is more variability between the groups (caused by the independent variable or season) than there is within each group (referred to as the error term). A significant *F* test indicates that we can reject the null hypothesis, which states that the population means are equal. It does not, however, tell us which of the groups differ. To uncover where the difference was, a post-hoc test was conducted to determine which groups are significantly different from one another. Furthermore, eta squared statistics has been in reported in this study. Eta squared can range from 0 to 1 and represents the proportion of variance in the dependent variable that is explained by the independent (group) variable. Effect size statistics provide an indication of the magnitude of the differences between the groups (not just whether the difference could have occurred by chance) (Pallant, 2007). In this study, if the Sig. value and/or probability value (*p*) is less than or equal to .05, it meant there was a significant difference somewhere among the mean scores on the pollution parameter for the four seasons.

The ten parameters were compared against season and the results are reported in the proceeding sections.

### 6.3.1 Temperature

A one-way between-groups analysis of variance was conducted to explore the impact of season on temperature, as measured over a period of twelve months. The 12 months were divided into four seasons (season 1: Oct to Nov-ERS; season 2: Jan to Mar-LRS; season 3: Apr to Jun-EDS; season 4: Jul to Sep-LDS). There was a statistically significant difference at the $p < .05$ level in temperature for the four seasons: $F$ (3, 182) = 36.10, $p$ = .00. Despite reaching statistical significance, the actual difference in mean scores between the groups was quite small. The effect size, calculated using eta squared, was .37. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for ERS (*M* = 27.40, *SD* = 1.90) and LRS (*M* = 27.30, SD = 2.20) was significantly different from EDS (*M* = 25.60, *SD* = 2.80) and LDS (*M* = 23.00, *SD* = 2.20). In addition EDS differed significantly from LDS.

Thermal pollution occurs when humans change the temperature of a body of water. The most common point source of thermal pollution is cooling water, which is used to cool machines. Thermal pollution may also be caused by storm water runoff from warm surfaces such as streets and parking lots. Soil erosion is another cause, since it can cause cloudy conditions in a water body. Cloudy water absorbs the sun's rays, resulting in a rise in water temperature. Thermal pollution may even be caused by the removal of trees and vegetation which normally shade the water body. Novotny (2002) also argues that temperature and turbidity are special cases of physical pollutants that affect other pollutants and impair aquatic life. The most important impact of warm water thermal pollution is a decrease in dissolved oxygen. Less oxygen in the environment may affect aquatic organisms and the overall health of the ecosystem.

Thermal pollution can result in significant changes to the aquatic environment. Most aquatic organisms are adapted to survive within a specific temperature range. Thermal pollution may also increase the extent to which fish are vulnerable to toxic compounds, parasites, and disease. If temperatures reach extremes, very high or very low, few organisms will survive. Judging by the effluent water standards from ZBS, all the water samples were within permissible range though there were significant seasonal temperature differences. This is expected because of natural seasonal fluctuations which bring about variations in temperature.

### 6.3.2 pH

A one-way between-groups analysis of variance was conducted to explore the impact of season on pH, as measured over a period of twelve months. The yearly 12 months were divided into four categories (season 1: Oct to Nov-ERS; season 2: Jan to Mar-LRS; season 3: Apr to Jun-EDS; season 4: Jul to Sep-LDS). There was a statistically significant difference at the $p < .05$ level in pH for the four seasons: $F$ (3, 182) = 21.40, $p = .00$. Notwithstanding reaching statistical significance, the actual difference in mean scores between the groups was relatively small. The effect size, calculated using eta squared, was .26. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for ERS ($M$ = 8.30, $SD$ = .49) was significantly different from LRS ($M$ = 7.90, $SD$ = .42), EDS ($M$ = 7.60, $SD$ = .42) and LDS ($M$ = 7.80, $SD$ = .49). In addition, LRS differed significantly from EDS.

The pH of natural water depends on several factors, which include the bicarbonate buffering system, types of rocks, types of soil, and nature of discharged pollutants. The concentration of carbonates and carbon dioxide is the main influence on the pH of clean water. High concentrations of bicarbonate produce alkaline waters (high pH), while low concentrations usually produce acidic waters (low pH).

Acidic and alkaline compounds can be weathered into the stream from the different types of rock present. When limestone ($CaCO_3$) is present, carbonates can be released, affecting the pH of the water. The types of soil in the drainage area also affect the pH. Drainage water from forests and marshes is often slightly acidic, due to the presence of humic acids produced by decaying vegetation (Chiou et al., 2000).

Nitrogen oxides ($NO$, $NO_2$) and sulphur dioxide ($SO_2$) from mining activities (Hill, 2010), automobile exhaust (and machines powered by fossils fuels) are converted into nitric acid ($HNO_3$) and sulphuric acid ($H_2SO_4$) in the atmosphere. These acids can affect the pH of streams by combining with moisture in the air and falling to the earth as acid rain.

Surface waters can sometimes act as weak buffer solutions depending on the concentrations of carbonates and bicarbonates (Exploring the Environmental Water Quality, 2004).

The pH values of natural surface waters usually range from 5.5 to 8.5. Extremely high (≥9.6) or low (≤4.5) values are unsuitable for most aquatic organisms. Fledgling fish and immature stages of aquatic insects are extremely sensitive to pH levels below 5. Most aquatic species prefer pH near neutral but can withstand a pH in a range of about 6 (7 for nitrifiers) to 8.5 (Novotny, 2002).

Changes in pH can also affect aquatic life indirectly by altering other aspects of water chemistry. Low pH levels accelerate the release of heavy metals from sediments on the stream bottom. The heavy metals can reduce the chance of survival of most aquatic organisms (Exploring the Environment Water Quality, 2004). Overall the seasonal pH was in the alkaline range with ERS (September to December) registering the most alkaline water condition. There were significant differences between the seasons as revealed by the statistical analysis with EDS registering the highest pH.

### 6.3.3 Electroconductivity (EC)

A one-way between-groups analysis of variance was conducted to explore the impact of season on EC, as measured over a period of the four seasons. There was no statistically significant difference at the $p < .05$ level in EC for the four seasons: $F$ (3, 182) = 1.50, $p = .22$.

Salty water conducts electricity more readily than purer water. Therefore, electrical conductivity is routinely used to measure salinity. The types of salts (ions) causing the salinity usually are chlorides, sulphates, carbonates, sodium, magnesium, calcium and potassium.

While an appropriate concentration of salts is vital for aquatic plants and animals, salinity that is beyond the normal range for any species of organism will cause stress or even death to that organism. Salinity also affects the availability of nutrients to plant roots. Nutrient disturbances under salinity reduce plant growth by affecting the availability, transport, and partitioning of nutrients (Jouyban, 2012).

Depending on the type of salts present, salinity can increase water clarity. At very high concentrations, salts make water denser, causing salinity gradations within an unmixed water column and slightly increasing the depth necessary to reach the water table in groundwater bores.

Electrical conductivity in waterways is affected by: geology and soils; land use, such as agriculture (irrigation), urban development (removal of vegetation, sewage and effluent discharges), industrial development (industrial discharges); flow (electrical conductivity is generally lowest during high flows and increases as flows decrease, with extreme levels occurring during droughts); run-off; groundwater inflows; temperature; evaporation and dilution (Waterwatch Australia, 2002).

Contaminated discharges can change the water's electrical conductivity in various ways. For example, a failing sewage system raises the conductivity because of its chloride, phosphate, and nitrate content, but an oil spill would lower the conductivity. The discharge of heavy metals into a water body can raise the conductivity as metallic ions are introduced into the waterway (ibid). Despite the wide variations observed in the EC values and several outliers as revealed by the boxplots, there was no significant difference across the seasons.

### 6.3.4 Dissolved Oxygen (DO)

A one-way between-groups analysis of variance was conducted to explore the impact of season on DO, as measured over a period of twelve months. As in the previous cases, the 12 months were categorised into four. There was a statistically significant difference at the $p < .05$ level in DO for the four seasons: $F(3, 182) = 5.10$, $p = .00$. Despite reaching statistical significance, the actual difference in mean scores between the groups was rather minor. The effect size, calculated using eta squared, was .08. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for ERS ($M = 10.00$, $SD = 2.40$) was significantly different from LRS ($M = 8.60$, $SD = 1.40$), EDS ($M = 8.90$, $SD = 1.70$) and LDS ($M = 9.00$, $SD = 1.80$).

Adequate DO is necessary for good water quality. Its depletion in water is associated with microorganisms decomposing much of the organic matter in a water body (Hill, 2010). Oxygen is a necessary element to all forms of life. Natural stream purification processes require adequate oxygen levels in order to provide for aerobic life forms. Ahluwalia and Malhotra (2007) argue that if the amount of DO is high, the degree of self-purification of water is high; in such cases, milder water treatment is required. As DO levels in water drop below 5.0 ppm, aquatic life is put under stress; the lower the concentration, the greater the stress. Novotny (2002) contends that water quality investigations and toxicities studies indicate that the DO content is the most important parameter for protecting fish and aquatic biota. Oxygen dissolves in water at very low concentrations. The atmosphere is 20% oxygen or 200,000 ppm and can reach concentration of up to 10.0 ppm oxygen dissolved in its water (Wright, 2005). ERS differed significantly from the other seasons; it had the highest amount of DO, implying that the water is most oxygenated during this season. Despite some monthly outliers below the recommended 6 ppm, all the seasonal averages indicated healthy water conditions along the Zambezi River Watershed.

### 6.3.5 Total Suspended Solids (TSS)

A one-way between-groups analysis of variance was conducted to explore the impact of season on TSS, as measured over a period of twelve months. There was no statistically significant difference at the $p < .05$ level in TSS for the four seasons: $F(3, 182) = 2.20$, $p = .09$.

Total suspended solids (TSS) include all particles suspended in water which will not pass through a filter. Suspended solids are present in sanitary wastewater and many types of industrial wastewater. There are also nonpoint sources of suspended solids, such as soil erosion from agricultural and construction sites.

As levels of TSS increase, a water body begins to lose its ability to support a diversity of aquatic life. Suspended solids absorb heat from sunlight, which increases water temperature and subsequently decreases levels of DO (warmer water holds less oxygen than cooler water). Photosynthesis also decreases, since less light penetrates the water (Hill, 2010). As less oxygen is produced by plants and algae, there is a further drop in DO levels.

TSS can also destroy fish habitat because suspended solids settle to the bottom and can eventually blanket the river bed. Suspended solids can smother the eggs of fish and aquatic insects, and can suffocate newly-hatched insect larvae. Suspended solids can also harm fish directly by clogging gills, reducing growth rates, and lowering resistance to disease. As revealed by the HSD test, there was no significant difference in the TSS values across the seasons. The *PV* as set by ZBS was not exceeded across the four seasons.

### 6.3.6 Total Dissolved Solids (TDS)

A one-way between-groups analysis of variance was conducted to explore the impact of season on TDS, as measured over a period of twelve months. There was no statistically significant difference at the $p < .05$ level in TSS for the four seasons: $F(3, 182) = 1.50$, $p = .22$.

TDS in drinking-water originate from natural sources, sewage, urban run-off, industrial wastewater, (WHO, 1996) and chemicals used in the water treatment process, or the material from the piping or hardware used to convey the water, i.e., the plumbing. Elevated TDS can be caused by natural environmental features such as: mineral springs, carbonate deposits, salt deposits, and sea water intrusion, but other sources may include: drinking water treatment chemicals, storm water and agricultural runoff, and point/non-point wastewater discharges (Oram, 2007). As was the case with TSS, there was no significant difference in TDS across the seasons and its *PV* was not exceeded.

### 6.3.7 Alkalinity as $CaCO_3$

A one-way between-groups analysis of variance was conducted to explore the impact of season on alkalinity, as measured over a period of twelve months. There was no statistically significant difference at the $p < .05$ level in alkalinity as $CaCO_3$ for the four seasons: $F\ (3, 182) = .4, p = .74$.

The ability of surface waters to neutralize acidic inputs depends on carbonate ($CO_3^{2-}$) and bicarbonate ($HCO_3^-$) expressed as alkalinity (Novotny, 2002). In natural water, alkalinity is due to the presence of $HCO_3^-$, $SiO_3^{2-}$, $HSiO_3^-$, $CO_3^{2-}$ and $OH^-$. Sometimes, the presence of salts of weak organic acids bind $H^+$ and thus result in increasing the concentration of $OH^-$ ions (Ahluwalia & Malhotra, 2007). Most alkalinity in surface water comes from $CaCO_3$, being leached from rocks and soil. This process is enhanced if the rocks and soil have been broken up for any reason, such as mining or urban development. Limestone contains especially high levels of $CaCO_3$. Alkalinity is significant in the treatment of wastewater and drinking water because it will influence treatment processes such as anaerobic digestion. Baird and Cann (2008, p. 594) have pointed out that the alkalinity value for a lake is sometimes used by biologist as a measure of its ability to support aquatic plant life, a high value indicating a high potential fertility. Water may also be unsuitable for use in irrigation if its alkalinity level is higher than the natural level of alkalinity in the soil. An accumulation of salts in the soil can result in alkalinity or salinity, which has the potential to limit crop production (Creswell & Martin, 1998). This study did not find any significant difference across the four seasons in alkalinity as $CaCO_3$. However, the boxplots reveal that several locations exceeded the recommendable values of alkalinity; several outliers were observed as revealed by Figure 26 and Figure 31 to Figure 34.

### 6.3.8 Turbidity (TB)

A one-way between-groups analysis of variance was conducted to explore the impact of season on turbidity, as measured over a period of twelve months. There was no statistically significant difference at the $p < .05$ level in turbidity for the four seasons: $F\ (3, 182) = 2.60, p = .053$.

Unfiltered storm water runoff into streams, lakes, ponds, and oceans can have a significant impact on water quality. As storm water flows over the land surface, it picks up pollutants like sediments, nutrients, pathogens, debris, toxins and various other chemicals.

Polluted storm water runoff not only lowers water quality but can harm or kill fish and other wildlife. For example, excessive amounts of sediment in water can destroy aquatic habitats.

Nonpoint source pollution comes from rainwater which runs over lawns, parking lots, city streets, forest, and construction sites. There was no significant difference in TB across the four seasons although the box plot revealed skewed distribution and several outliers towards higher levels in the ERS and LRS.

### 6.3.9 Total Phosphorus (TP)

A one-way between-groups analysis of variance was conducted to explore the impact of season on TP, as measured over a period of twelve months. There was a statistically significant difference at the $p < .05$ level in TP for the four seasons: $F(3, 182) = 3.10$, $p = .03$. The effect size, calculated using eta squared, was .05. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for ERS ($M = 269.8$, $SD = 254.07$) was significantly different from LDS ($M = 175.10$, $SD = 62.80$). LRS ($M = 237.30$, $SD = 204.56$), and EDS ($M = 186.50$, $SD = 71.78$) did not differ significantly from any other season.

Phosphorus, a nutrient essential to the growth of organisms, and is commonly the limiting factor in the primary productivity of surface water bodies. TP includes the amount of phosphorus in solution (reactive) and in particle form. Agricultural drainage, wastewater, and certain industrial discharges are typical sources of phosphorus and can contribute to the eutrophication of surface water bodies (Baird & Cann, 2008). Phosphorus can cause population explosion of photosynthetic bacteria and blue-green algae (Ahluwalia & Malhotra, 2007).

Concentrations of phosphorus in water, air, and soil are measured to assess the present situation. With traditional measuring methods, it is only possible to determine environmental problems caused in the past. Early recognition of future loading, as well as the identification of the effective measures, enables the potential decrease of later loading. Both are possible only with measures for environmental protection on the whole system, which is the integration of water, land, and air, and will be based solely on prevention. For sustainable river basin management, there is a strong need to evaluate different option strategies. Only thus will the available resources be applied in the most advantageous, sustainable way (Drolc & Zagorc Koncan, 2002). As for TP, HSD revealed that ERS was significantly different from LDS, and all the other seasons did not differ in a statistically significant way. ERS registered the highest TP loadings followed by LRS. The results show that the water is particularly worse during the rainy season, a consequence of stormy water from farms, unsewered onsite sanitation infrastructure and industries.

### 6.3.10 Ammonia Nitrogen ($NH_3$-N)

A one-way between-groups analysis of variance was conducted to explore the impact of season on $NH_3$-N, as measured over a period of twelve months. There was a statistically significant difference at the $p < .05$ level in $NH_3$-N for the four seasons: $F(3, 179) = 14.70$, $p = .00$. Despite reaching statistical significance, the actual difference in mean scores between the groups was quite small. The effect size, calculated using eta squared, was .2. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for ERS ($M = .00$, $SD = .00$) was significantly different from LRS ($M = 60.10$, $SD = 83.64$), EDS ($M = 36.50$, $SD = 10.93$) and LDS ($M = 42.30$, $SD = 12.53$). In addition, LRS differed significantly from EDS.

At pH of 7.00 or below, most of the ammoniacal nitrogen will be ionized as ammonium. At pH levels greater than 9.00 the proportions of nonionised ammonia will increase. The nonionised ammonia is toxic to fish, while the ionized ammonia is a nutrient to algae and aquatic plants and also exerts dissolved oxygen demand (Novotny, 2002). Ammonia ($NH_3$) is mainly generated from agricultural sources, with major point sources found particularly near intensive livestock and poultry farms. Ammonia pollution causes both acidification of soils and a decrease in the richness of plant species (European Commission, 2006). $NH_3$-N is a constituent in raw domestic wastewater. The findings of this study show that ERS differed significantly from all seasons. This is partly because there was no water flow in some sampled locations (for example Kalomo and Quayi are ephemeral rivers) and hence no parameters were analysed. LRS and EDS differed significantly with the former registering higher $NH_3$-N loading compared to the latter.

## 6.4 Discussion on pollution with Water Pollution Index

### 6.4.1 Season comparison of parameters exceeding their *PV*s and *WPI*

In the proceeding section, the ten parameters considered in this study are compared relative to what is expected to be found in unpolluted water samples. The minimum, maximum and the mean values of the parameters are compared to their *PVs*. In-depth analyses of the parameters are hereby presented by season as depicted in Figure 31 to Figure 34.

**Table 31.** The averages and standard deviation (SDs) of the ten parameters in the four seasons and the corresponding PVs

| | | | Min | Max | Mean | SD | Min | Max | Mean | SD | Min | Max | Mean | SD | Min | Max | Mean | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Unit | *PVs* | ERS | ERS | ERS | | LRS | LRS | LRS | | EDS | EDS | EDS | | LDS | LDS | LDS | |
| T | °C | 40 | 23.90 | 32.10 | 27.37 | 1.86 | 22.00 | 30.90 | 27.33 | 2.19 | 17.50 | 30.80 | 25.58 | 2.80 | 15.10 | 26.60 | 23.02 | 2.17 |
| pH | | 6 - 9 | 6.93 | 9.20 | 8.29 | 0.48 | 7.08 | 8.66 | 7.91 | 0.42 | 6.33 | 8.45 | 7.57 | 0.42 | 6.46 | 8.41 | 7.76 | 0.49 |
| EC | µS/cm | 2300 | 42.00 | 775.00 | 127.96 | 129.95 | 36.00 | 645.00 | 124.56 | 118.12 | 35.00 | 841.00 | 173.08 | 212.49 | 63.00 | 1098.00 | 197.25 | 274.20 |
| DO | mg/L | >5 | 6.22 | 16.69 | 10.03 | 2.31 | 4.32 | 11.15 | 8.76 | 1.38 | 3.96 | 12.60 | 8.90 | 1.69 | 6.56 | 12.00 | 9.01 | 1.42 |
| TSS | mg/L | 100 | 1.00 | 1278.00 | 65.35 | 232.76 | 2.00 | 1073.00 | 59.72 | 165.99 | 1.00 | 278.00 | 13.82 | 39.27 | 1.00 | 45.00 | 5.16 | 6.89 |
| TDS | mg/L | 3000 | 28.14 | 519.25 | 85.76 | 87.06 | 24.12 | 432.20 | 83.46 | 79.15 | 23.45 | 563.47 | 115.96 | 142.37 | 42.21 | 735.66 | 132.16 | 183.72 |
| Alkalinity as $CaCO_3$ | mg/L | 120 | 24.20 | 214.30 | 64.53 | 38.80 | 19.10 | 239.30 | 58.73 | 40.60 | 20.10 | 238.40 | 62.56 | 46.11 | 28.00 | 249.20 | 68.40 | 47.17 |
| Turbidity | NTU | 10 | 1.70 | 1308.00 | 69.29 | 244.63 | 1.00 | 1250.00 | 84.07 | 222.09 | 1.00 | 333.00 | 15.62 | 47.13 | 0.78 | 39.80 | 4.47 | 5.97 |
| TP | µg/L | 1000 | 64.00 | 1120.00 | 259.98 | 248.87 | 32.00 | 1200.00 | 237.33 | 204.56 | 44.80 | 352.00 | 186.47 | 71.78 | 64.00 | 336.00 | 175.11 | 62.80 |
| Ammonia-Nitrogen | µg/L | 1250 | nd | nd | nd | nd | 4.05 | 488.11 | 60.06 | 83.64 | 12.85 | 69.19 | 36.52 | 10.93 | 20.43 | 77.73 | 42.26 | 12.53 |

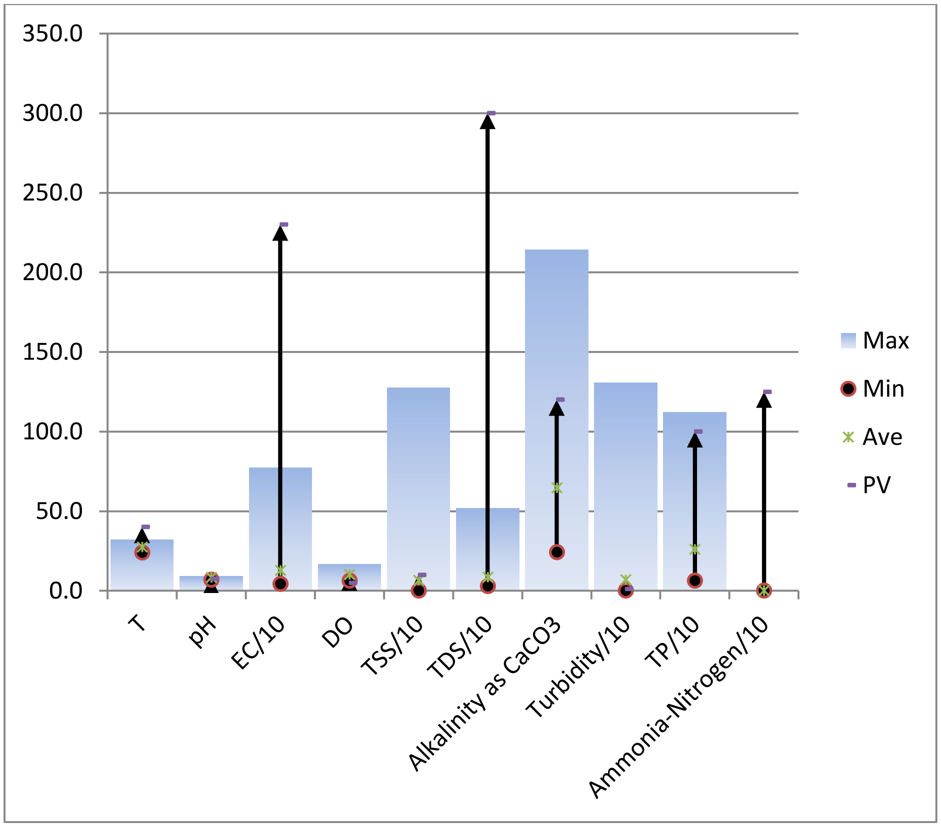

**Figure 31.** Early Rain Season (ERS) comparison of parameters exceeding their PVs

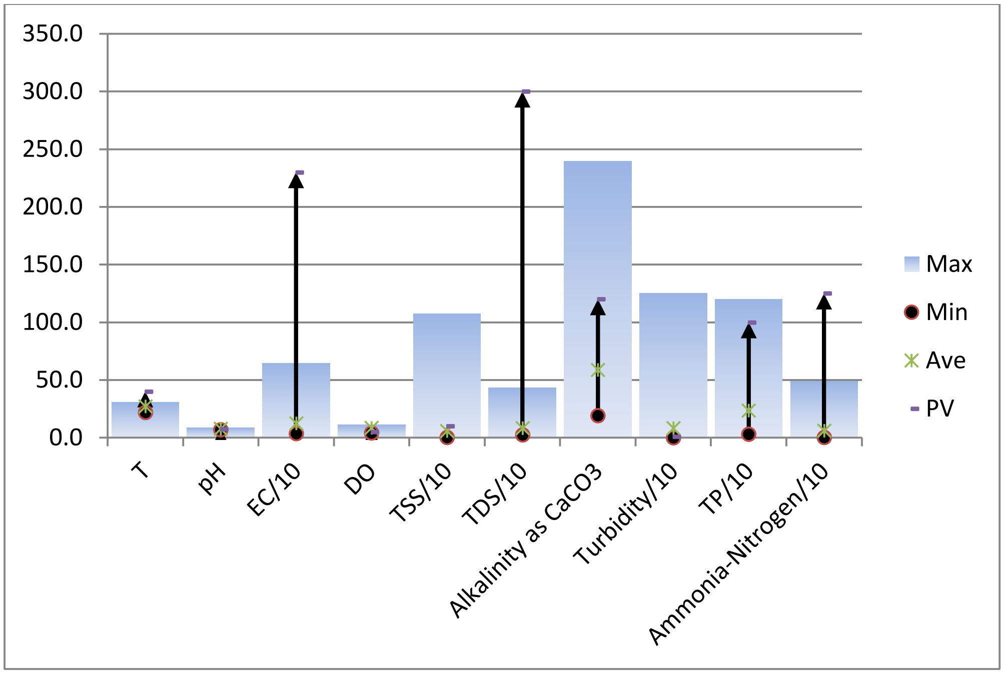

**Figure 32.** Late Rain Season (LRS) comparison of parameters exceeding their PVs

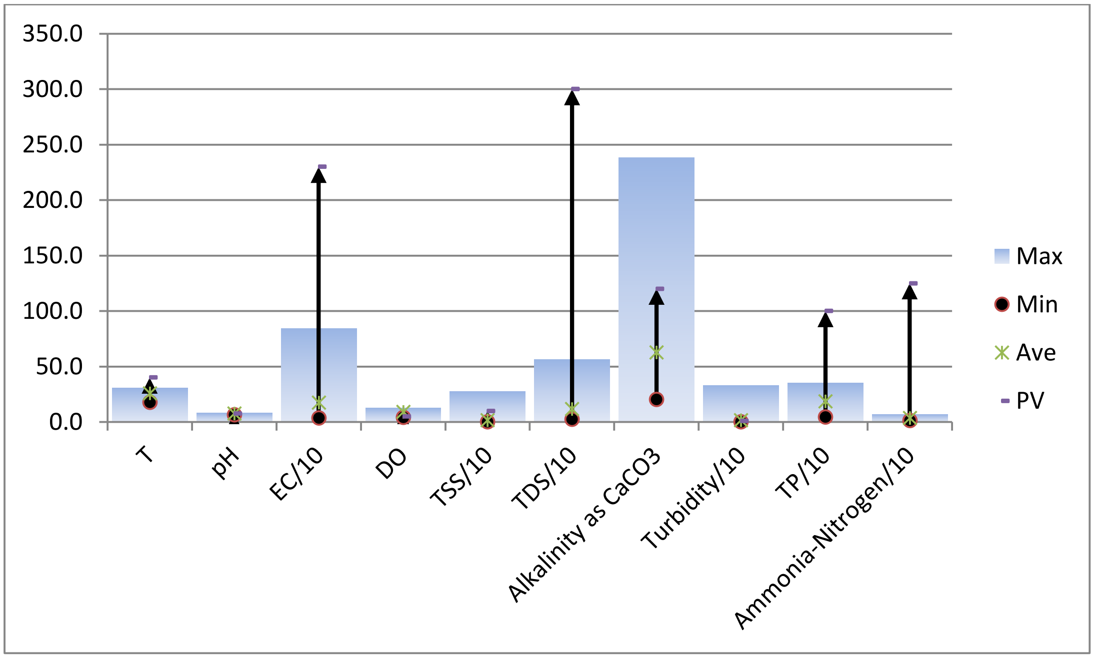

**Figure 33.** Early Dry Season (EDS) comparison of parameters exceeding their PVs

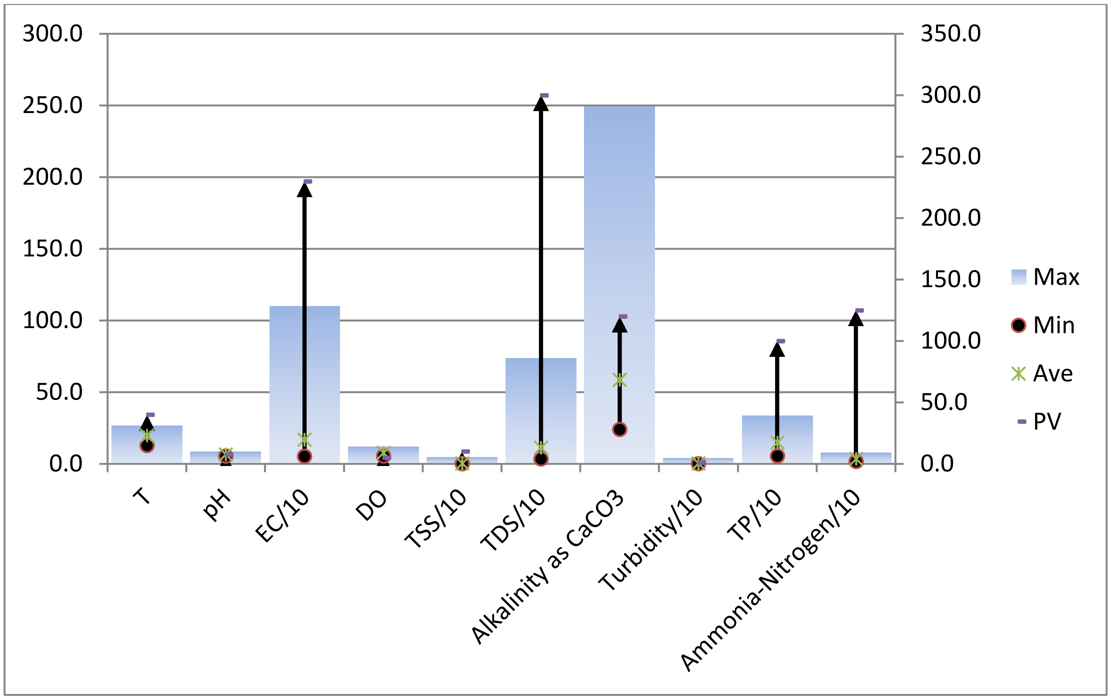

**Figure 34.** Late Dry Season (LDS) comparison of parameters exceeding their PVs

Of the ten parameters, TSS, turbidity, and TP exceeds their *PVs* in some seasons in contrast to alkalinity as $CaCO_3$ which exceeds its *PV* in all the seasons as depicted by Figure 31 to Figure 34.

### 6.4.2 Local characteristics of pollution

Figure 35 and Figure 36 (using the water pollution index) reveal an important pattern that the most compromised water samples came from tributaries that feed the Zambezi River. Amongst the outstanding locations which were most polluted are Quayi river (*WPI*= 6.40), Kariba at Sanyati-further (*WPI*= 5.28), Kalomo River (*WPI* = 4.76) and Deka river (*WPI* = 4.65), Kanzinze River (*WP* = 1.95), and Kariba at Gatche (*WPI* = 1.47).

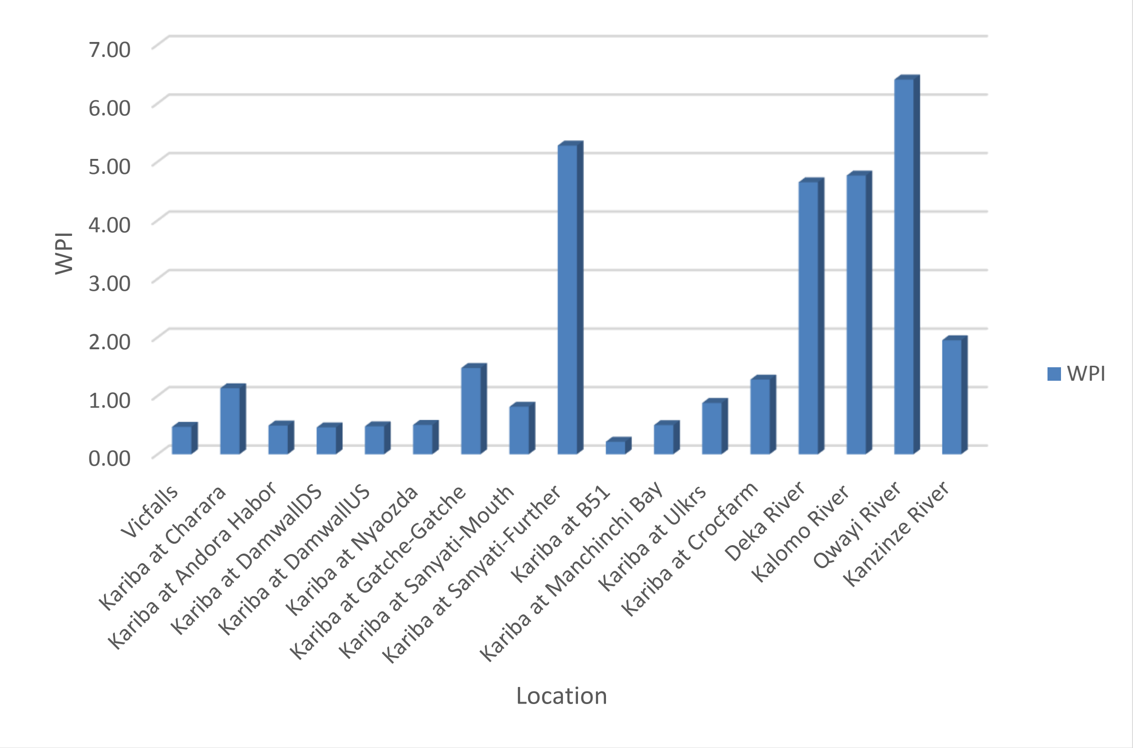

**Figure 35.** Comparison of pollution by location using the WPI

### 6.4.3 Seasonal characteristics of pollution

Furthermore, the data obtained using the *WPI* as presented in Figure 37 shows which season(s) presented notable pollution problems and the data clearly shows that LDS is characterised by very safe water with reference to the ten parameters that were the focus of this study. When the 17 locations are further compared for their overall contribution to water quality, it was found that tributaries discharging the water into the Kariba/Zambezi River had the most compromised water as shown by the *WPI* values of Quayi River, Kariba at Sanyati-further, Kalomo and Deka Rivers.

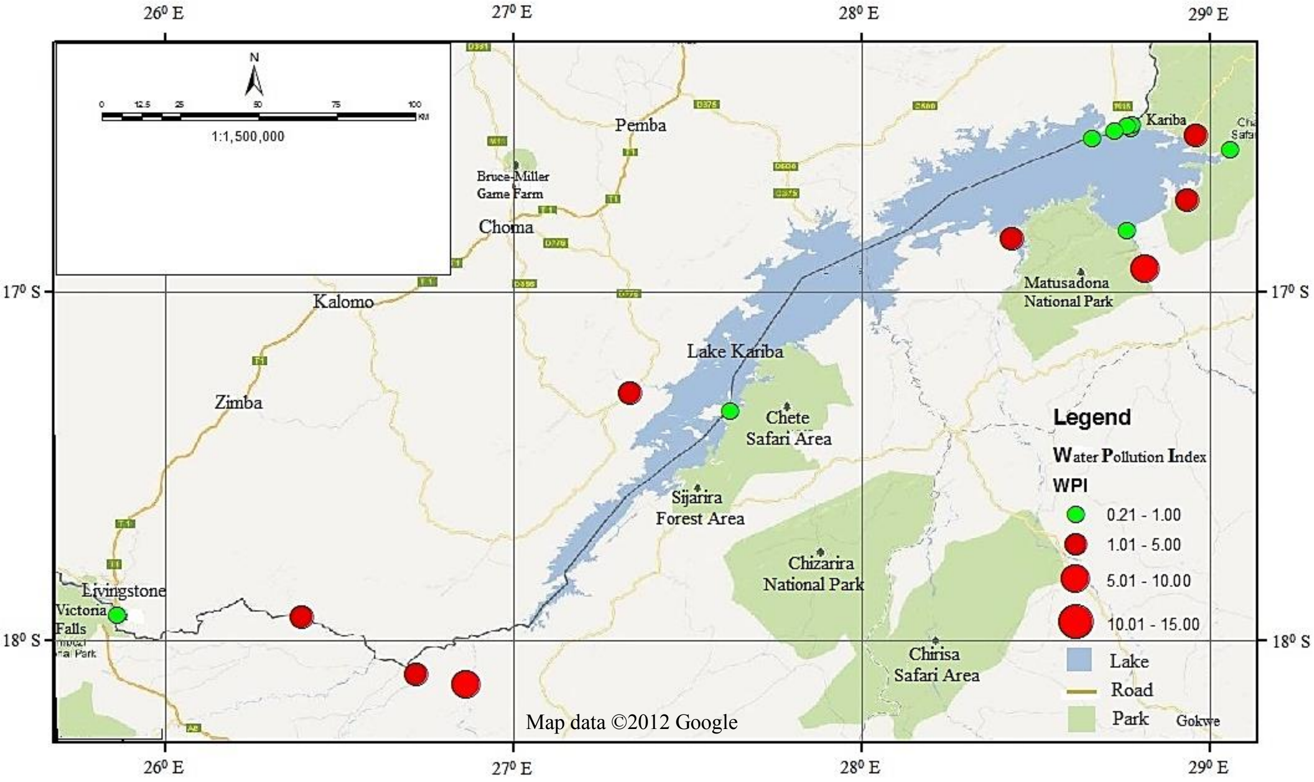

**Figure 36.** Spatial distribution of pollution by location using the WPI on the Lake Kariba, Zambezi River and its tributaries

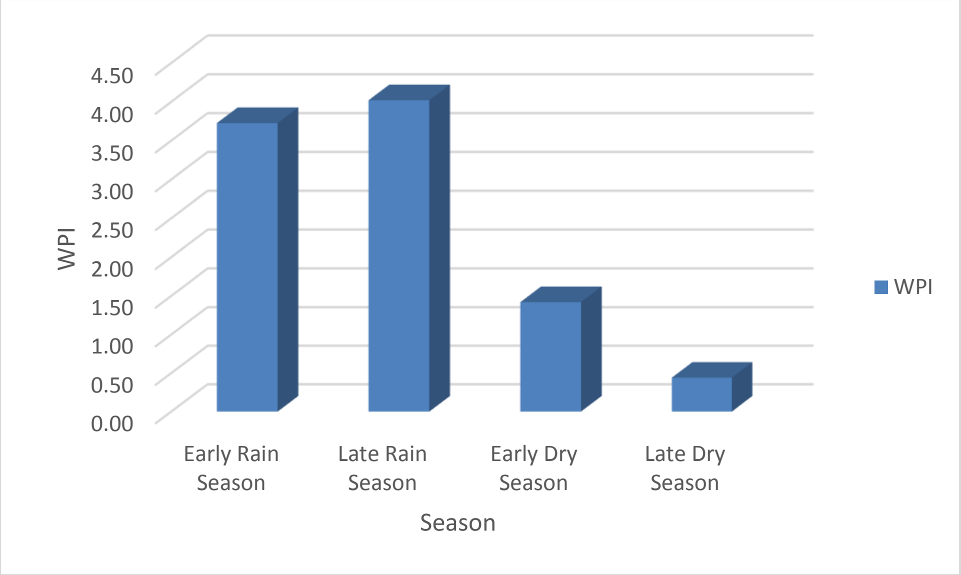

**Figure 37.** Comparison of pollution by season using the Water Pollution Index

In addition it can be argued, as shown in Figure 36, that deterioration in water quality climaxes in the LRS and quality gradually improves towards the EDS until it attain its best level in the LDS before the quality tumbles again in the ERS. The pattern is consistent with onset of the rain season in October indicating that pollutants are washed to the river banks from further inland close to and inside the human settlements.

### 6.5 Major findings

The findings of this study reveal that water quality deterioration along Lake Kariba, Zambezi River and its tributaries is particularly in a critical condition during the rainy reason. ERS had a *WPI* of 3.72 and LRS had a *WPI* of 4.02 and hence more care is particularly needed when using the water from the watershed (shown in Figure 36) during these seasons. Furthermore, using principal factor analysis, the ten parameters yielded four factors and the most predominant (as evidenced from factor loadings) of the factors controlling water quality along the Zambezi are: factor 1 dominated by turbidity, factor 2 dominated by TDS, factor 3 dominated by DO and factor 4 by temperature. These parameters were found to be very momentous, as revealed by factor loadings, in explaining water quality across the seasons. By far the biggest pollution problems (parameters exceeding their *PVs*) was caused by turbidity followed by alkalinity as $CaCO_3$, then TSS and to a less extent by total phosphorus. It is also important to note that the tributaries feeding Lake Kariba are the most polluted. Furthermore, the watershed waters (after traversing between Zambia and Zimbabwe) flows into the neighbouring Mozambique and results show that the water exiting Lake Kariba is generally free of any significant pollution, across all seasons, probably a consequence of the diluting effect of the vast water resources of the Lake. However, it is vitally important to alert the users of the water by the banks and further downstream of some of the hazards found in the water with changing seasons and especially during the late rainy season.

# Chapter 7

## 7. High school activities utilising the low-cost colorimeters

### 7.1 Introduction

Whether using simple, inexpensive field test kits, or more expensive and specialised instruments, students can gather data about water quality that will help them learn remarkably about the rivers, streams, groundwater and other water bodies of interest. Through explicit instructions and assessment of students' science process skills, it is possible to help them gain the skills to approach science as scientists do. The attributes of what scientist do may include practices such: as asking questions and defining problems; developing and using models; planning and carrying out investigations; analysing and interpreting data; using mathematics; constructing explanations and designing solutions; engaging in arguments using evidence; and obtaining, evaluating, and communicating information (Bybee, 2011). Science process skills include skills such as data interpretation, problem solving, experimental design, scientific writing, oral communication, collaborative work, and critical analysis of primary literature (Coil et al., 2010). Therefore, it can be argued that scientists possess science process skill. In the analysis of water pollution, students can use monitoring equipment and apply scientific process skills as they gather data about many parameters of water quality. By assessing the water quality in a local water body, students will understand better how human activities affect this resource, and how we can protect its quality in future.

Musar (1993, p. 5) argues that "social and technological changes require constant updating of the general population's knowledge and skills. Developments in science and technology are tangible realities affecting any member of society." Creating awareness about science and emphasizing the importance of scientific literacy is especially important for developing nations (Malik, 2012). Science education has two broad purposes: The first purpose is to promote scientific literacy among citizens on matters that affect them; and the second is to build up the technological capability by equipping the future workforce with essential science-based knowledge and skills among other things (Musar, 1993). In the development of science process skills, provision of equipment is essential. Provision of adequate science equipment is important because it can make teaching more convenient and more effective, and can increase the amount of work students do, and enable teachers to broaden the science curriculum (Lazarowitz & Tamir, 1993).

The relevance of the low-cost equipment to the curriculum can be improved by showing its versatility and how accurate it can help in making students understand the quality of the water in their surrounding and how mass production of such equipment is within the budget of even the most economically deprived school. This is also important in making schools to avoid buying, at a higher cost, from established manufacturers. Such easy to make low-cost equipment can induce a spirit of self-reliance and sense of ownership of the equipment and the process of gathering data. Relying on local resources as far as possible is crucial in moving the scientific literacy agenda forward (Jones et al., 1984).

The notion of improvisation is understood explicitly in some quarters, and understood and practiced only implicitly in others. Among those who have an explicit conception of improvisation are educators in less advanced educational systems, especially those in economically poor, developing nations and for such educators, improvisation connotes the use of apparatus constructed from locally available material resources as a means of keeping educational expenditure low (Tsuma, 1985). In relation to water analysis in EE, there is twofold benefit for designing a low-cost colorimeter (LCC), apart from keeping expenditure low, in that pollutants can be determined leading to sensitization about the local environment. Improvisation has other advantages as well. Davis (1953) argues that to provide more pupil participation in experimentation, it is recommended to furnish a wide variety of improvised and inexpensive, yet highly useful, science equipment. The situation obtaining in the Zambian Secondary Schools is that educational facilities and resources are not available for the learning process, effective teaching and learning. Most of the teaching and learning is done theoretically, even for practical and science subjects (MOESVTEE, 2012). Where apparatus are lacking, it is recommended, among other things, to use improvised materials to improve academic achievement in science (Mboto, Ndem & Stephen, 2011) and other subjects such as English can also use improvisation to improve performance (Asokhia, 2009). Improvisation is an indispensable task in the scientific enterprise to enrich the teaching and learning of science (Olagunju & Abiona, 2008). Therefore, the value of improvisation cannot be understated because science laboratory with adequate equipment is a critical variable in determining the quality of output from senior secondary school science (Olufunke, 2012).

Many and varied are the reasons which may prompt a student (teacher as well) to design and build a piece of scientific apparatus; many and diverse are the choices he may make as to what he will build and how; and, indeed, many and varied are the reactions teachers may experience upon sight of the finished products (Casimir, 1955). It is important that the value of the apparatus is clearly stated even before it is improvised. Having a clear objective is important as stated in this study. The main reason being improving of the local environment through enhanced pupil participation via the improvised teaching materials.

At one point in the history of Zambia, there was the Overseas Development Administration (ODA)-funded Action to Improve English, Mathematics and Science (AIEMS) teacher training project which was initiated in 1994. The purpose of AIEMS was to strengthen the Ministry of Education in its provision of in-service training for trainers and teachers in primary and secondary English, mathematics and science (Miti & Herriot, 1997). Projects like AIEMS gradually went into oblivion (after the end of the project cycle) due to lack of ownership and reliance of the donated equipment which in some cases was irrelevant to the local circumstances. Nonetheless, AEIMS had good objectives as reflected in one of its workshop objectives of fostering  repackaging of AIEMS materials to suit local needs and training strategies and to ensure that the 'source culture' does not clash with the 'recipient culture'. However, despite the good intentions and the heft funding which according to Miti and Herriot stood at £12.7 million for a period of seven years, all what remains of the project are only documents written about it. Long term sustainability (and lasting achievement) is not evident and was overtaken by other events (in-service programs) and the status quo, more or less, continues.

The low-cost equipment is appropriate in the light of economic deprivation and increasing water pollution not only in Zambia, but indeed in many other developing countries.  Local development of equipment is supported in accordance with the curriculum and, where feasible, also local production of the equipment. Locally designed and produced equipment has a number of additional benefits, in that teachers and pupils can handle faults arising due to everyday usage. Investigation in the local environment is also useful in keeping up the objective of the Ministry of Education of providing safe water, by cooperating with the Ministry of Environment and Community Development (MOE, 1996). For provision of safe water, it is important to know the pollution parameters that are making it unsafe and the extent of the problem; and this is where the LCC becomes expedient. On the same issue, Musar (1993) argues that supply of spare parts and repair services are ensured for a longer period.

Science is a subject with great practical importance and as much as possible equipment which encourages this objective to become a reality must be encouraged and sustained. Many students see science as abstract and irrelevant to their lives due to lack of engaging classroom laboratory equipment and activities (Thomas & Israel, 2012). The importance of practical work in science is widely accepted and it is acknowledged that good quality practical work promotes the engagement and interest of students as well as developing a range of skills, science knowledge and conceptual understanding (SCORE, 2008).

There has been some efforts made in Zambia to address the problem of lack of teaching materials, and such efforts were addressed by the establishment of the National Science Centre (NSC) in Lusaka whose aim among other things, is to enable schools across Zambia to purchase laboratory supplies and apparatus affordably. Furthermore, local materials and labour are used, so expertise and capital are developed within the country. Despite this effort, the local curriculum does not require the pupils to determine levels of pollutants in the water; it is presumed that equipment for such a task is very costly to acquire by the local schools.

Using the LCC, teachers can demonstrate numerous scientific tests using water in their community. The pupils can learn the basic need for testing their water to avoid health complications and how microorganisms can grow in their water. Furthermore, pupils in collaboration with their teachers can compare the results of their own community drinking water to the guidelines of the Zambia Bureau of Standards (and Environmental Council of Zambia) drinking water quality, and to World Health Organisation (WHO) drinking water regulations.

Furthermore, teachers can guide their students to test for the most problematic water pollutants that are common in Zambia or in each region of the country since types of pollutants are largely dependent on human activities prevalent in a given location (e.g. mineral processing or agriculture). Some of the common parameters that may be of importance to pupils in Zambia include: Cu, Mn, $NO_3^-$, $PO_4^{3-}$ and $SO_4^{2-}$. Students can compare their local water to three other samples of water, possibly from other regions (or towns) as well as to a control medium. The other water samples would include urban treated drinking water, a rural treated drinking water and raw untreated water sources, and then to compare results from these waters to their own community drinking water.

Generally, four main categories of pollutants are of prime importance and these include:

- Organic compounds that pollute the water such as detergents, pesticides, fuels, and some types of industrial wastes (organic);
- Inorganic compounds such as $SO_4^{2-}$ from industries, $PO_4^{3-}$ and $NO_3^-$ from animals and fertilizers. By-products of most primary industrial activities fall in this category too;

- Macroscopic pollutants that are usually large types of debris, for example, food waste, plastics and sediments from stormy water runoff. Sometimes trash dumped on the street can end up in the rivers and that would be a form of macroscopic pollution. Basically, this is the pollution which is easily perceivable to the pupils; and
- Thermal pollution mainly caused by industries. Usually the temperature is increased due to the reaction of some chemicals with the water. Chemicals like acid can release large amounts of heat when reacted with water.

This study explored the qualitative method, such as used in the pack test, for analysis of Mn ions using an LCC. Some water samples collected from Zambia contain high concentration of Mn beyond what is locally and internationally accepted as revealed by several studies (Nwasco, 2010a; Žaludková & Zeman, 2011). The analytical principle was based on allowing a beam of light to pass through a solution containing a coloured analyte initiated by the reaction of potassium periodate which is embedded inside the pack test tube; the Mn pack test is based on an oxidising reaction of potassium periodate ions. It allows measuring Mn ion concentrations in various samples like industrial waste water and environmental waters. Different concentrations and two LCCs were explored to determine the appropriate concentration by which the Beer's law is not violated. The response factors that affect the passage of current through a photoresistors are explored in the preceding sections.

Over 40 different parameters have been successfully determined by colorimetric method and systematized for routine determination (Kyoritsu Chemical Check Lab., Corp, 2010) using the Digital Water Analyser (DWA) and pack test kit. These are the parameters which have been determined successfully using colorimetric techniques utilising a commercial colorimeter: aluminium, boron, calcium, chloride, residual chlorine, residual chlorine (free), total residual chlorine, chlorine dioxide, free cyanide, total cyanide, chemical oxygen demand with $KMnO_4$, colour, chromium hexavalent, total chromium, copper, anionic surfactants, dissolved oxygen, fluoride (free), iron, iron divalent, formaldehyde, hydrogen peroxide (high range), potassium, potassium permanganate consumption, manganese, ammonium, nickel, nitrite, nitrate, ozone, lead, phenol, phosphate, sulphide (hydrogen sulphide), silica, sulphate, total hardness, total nitrogen, total phosphorus, turbidity, zinc, and absorbance. Apart from these, many more parameters can be determined by colorimetric method as long as a stable product with a stable colour is generated with an appropriate reagent and its colour intensity changes linearly (at an appropriate concentration) with increase or decrease in concentration.

In this vein, a low-cost colorimeter can have limitless applications for investigating water pollution at high school level.

This study endeavoured to compare and verify the effectiveness of colorimetric methods by comparing the results of the same water samples but obtained by standard techniques of investigating heavy metal pollution in water, that is, by Atomic Absorption Spectroscopy (AAS) and Inductively Coupled Plasma (ICP). This study focused on the determination of Mn ions in an effluent water sample obtained from a copper mine in the Copperbelt Province of Zambia.

## 7.2. Low-cost colorimeters (LCCs)

### 7.2.1 Materials

The materials used for the LCCs are: voltmeter, photoresistors, resistors, tri-colour light emitting diodes (LED) (rated 150mA, 3.0-3.5V), Darlington transistor, transformers (100V ac to 12V ac & 100V ac to 4.4V dc), multimeter (or voltmeter), batteries, two-way switch, 9V battery, cuvette, and improvised colorimeter boxes.

### 7.2.2 Circuit diagrams of (LCCs)

A circuit diagram of the low-cost colorimeter1 (LCC1) incorporating a 4 volt transformer and a separate 9 volt battery is shown in Figure 38. On the other hand, the low-cost colorimeter 2 (LCC2) incorporates a Darlington transistor as shown in Figure 39.

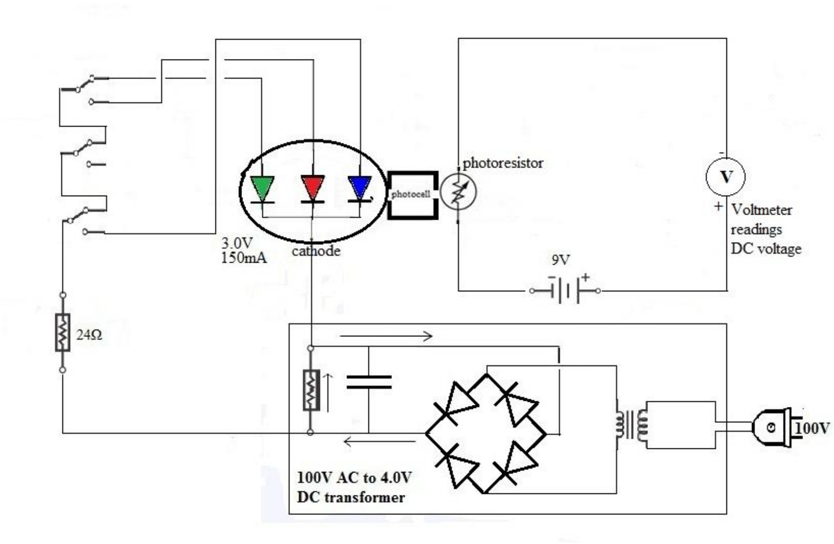

**Figure 38.** Circuit of the low-cost colorimeter 1 (LCC1) incorporating a 4 volt transformer and a separate 9 volt battery

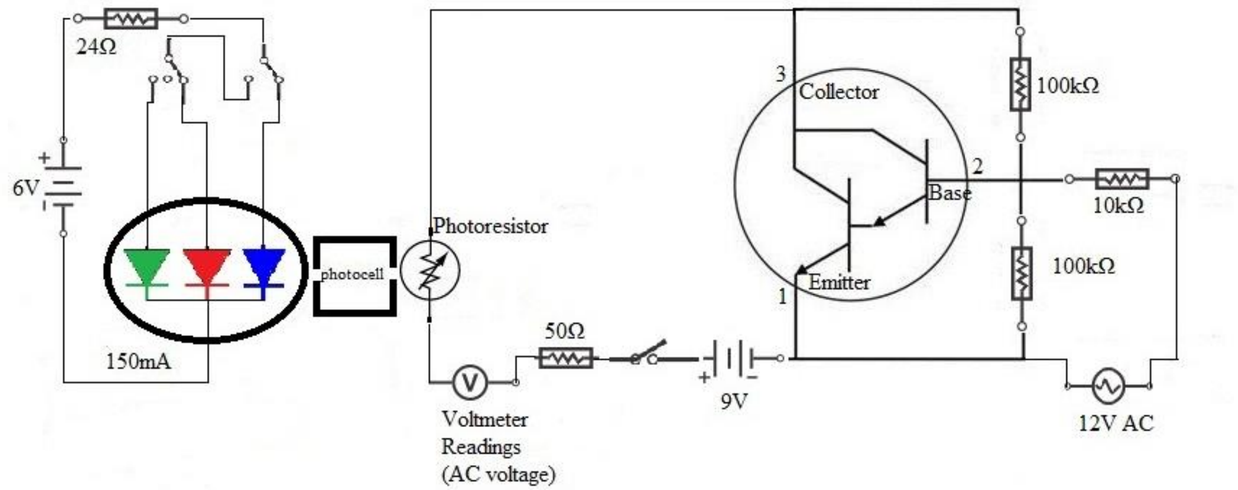

**Figure 39.** Circuit of the low-cost colorimeter 2 (LCC2) incorporating a Darlington transistor

An in-depth analysis of the performance of LCC1 and LCC2 compared to the standard analytical instruments was performed and the results are reported in the subsequent sections.

### 7.2.3 Calculating the LED resistor value

An LED must have a resistor connected in series to limit the current through and hence avoid damaging it instantly. The LED resistor was worked out using the Ohm's law formula.

The resistor value, R was given by:

$$R = \frac{V_S - V_L}{I} \tag{7.1}$$

Where: $V_S$ = supply voltage; $V_L$ = LED voltage (in this case $3.0V_{max}$); and I = LED current through resistor (in this case 150mA or 0.150A).

The supply voltage (to the LED) used in this experiment $V_S$ = 6V, that is for LCC2, and the tri colour-LED rated forward voltage, $V_L$ = 3.0V, and requiring a forward current *I* of 150mA (0.150A).

$$R = \frac{(6V - 3.0V)}{0.15A} = 20\Omega \tag{7.2}$$

Because the calculated resistor value, 20Ω, was not available, the nearest standard resistor value which is greater was used (and should always be used), so that the current was a little less than the rated current. A greater resistor value was chosen to reduce the current and also to increase the battery life (but this can consequently make the LED less bright).

A 24Ω resistor connected in series (the nearest standard value which is greater than the calculated resistance) to the anode of the tri-colour LED was chosen. Alternatively, a variable resistor or rheostat can be used instead of a fixed value resistor. A similar resistor rated 24Ω was used in LCC1 because the voltage from the transformer was only 4V.

In LCC2, the output current passing through the photoresistors was amplified using a simple circuit incorporating a Darlington transistor.

### 7.2.4 Sample preparation and cost of the instruments

The next stage involved preparing solutions of known concentrations to be used in the colorimetric determination. A 320 ppm standard solution of $Mn^{2+}$ was prepared by adding 170.60 mg of 98% pure $Mn(NO_3)_2.6H_2O$ to a 100 ml volumetric flask and adding distilled water up to the mark. From the standard solution, serial dilutions of $Mn^{2+}$were prepared (1 ppm, 2 ppm, 4 ppm, 8 ppm 16 ppm and 32 ppm). Using the potassium periodate method to generate a colour, the LCC1 and LCC2 were used to collect data which was used to prepare (linear) graphs. An effluent water sample (point source) obtained from the tailings dump of Mufulira town and known to be contaminated with Mn was determined on the same colorimeters. Furthermore, two other samples were determined for Mn contamination using the DWA; Sample 1 was an upstream river water sample collected from Lusaka's Mutendere compound. Sample 2 was a river water sample obtained from Lusaka's Chipata/Marapodi at Garden Park (stream) area.

An aliquot of the effluent water sample was determined using the DWA for the purpose of comparing its effectiveness relative to the LCC1 and LCC2. The DWA was set to measure Mn, and the following procedure was adhered to: a cell (cuvette) was filled with the sample up to the 1.5 ml line and inserted into the cell box and the instrument zeroed; the whole cell sample was drawn into the tube containing periodate ions and the instrument timer was started and the tube was shaken lightly six times and its content returned to the cell gently. The cell was inserted into the cell box and after 3 minutes passed, the measurement value was displayed automatically.

The effectiveness of the DWA (using all three samples) was in turn counter-checked by comparing the results of the three same samples but obtained by a Perkin Elmer (PE) AAnalyst 100 Flame Atomic Absorption Spectrophotometer (AAS) and Varian 720-ES Inductively Coupled Plasma (ICP) optical emission spectrometer-model 720 ICPOES.

**Table 32.** Cost needed to assemble the Low-cost Colorimeters (LCC1 & LCC2)

| No | Item | LCC1 | | LCC2 | |
|---|---|---|---|---|---|
| | | Source | Unit price (¥) | Source | Unit price (¥) |
| 1 | Power converter low voltage electronic transformer – 110V ac to 12V ac | na | na | eBay | 316 |
| 2 | Power converter low voltage electronic transformer – 110V ac to 4V dc | Junk | na | | na |
| 3 | Five mm ultra-bright common cathode tri-colour RGB LED WL × 10pieces @ 393 | eBay | 40 | eBay | 40 |
| 4 | Photo light dependent resistor photoresistors GL5549 × 5pieces @ 238 | eBay | 48 | eBay | 48 |
| 5 | TIP142 transistor NPN Darlington 100V 10A | na | na | eBay | 123 |
| 6 | Improvised colorimeter box | Daiso | 100 | Daiso | 100 |
| 7 | Two way cable connector | Nafco | 98 | Nafco | 98 |
| 8 | Four way cable connector | Nafco | 148 | Nafco | 148 |
| 9 | Two way switch @ 200/unit | na | 600 | | 400 |
| 10 | Resistors ×50 pieces @ 82 | eBay | 2 | eBay | 9 |
| 11 | Four battery holder for 6v | na | na | eBay | 250 |
| 12 | One metre cable | Nafco | 40 | Nafco | 40 |
| 13 | Soldering wire | Nafco | 100 | Nafco | 100 |
| 14 | Circuit board | | 300 | | 300 |
| 15 | Battery – 9V | eBay | 124 | eBay | 124 |
| 16 | Voltmeter | eBay | 180 | eBay | 180 |
| Total | | | 1,780 | | 2,276 |

na, not applicable

The PE AAnalyst system is used for flame operation and comes complete with air acetylene burner head, burner chamber, six lamp turret holder, background correction and safety drain bottle and sold (reconditioned instrument) at a cost of ¥915,000 (£6,995) (Speck & Burke, 2012).

A similar instrument, a used STS Inductively Coupled Plasma High Density Plasma Etch System, as the Varian 720-ES Inductively Coupled Plasma (ICP) on ebay.com was priced at ¥ 11,337,868) (STS Inductively Coupled Plasma High Density Plasma Etch System, 2013). The total cost of the DWA is ¥288,000 (As One, 2013). The LCC1 used in this experiment cost ¥1,780 and the LCC2 cost ¥2,276 to assemble (Table 32).

## 7.3. Measurement theory

### 7.3.1 Radiation absorbance

Colorimetry is a technique which applies to measurements made in the visible region of the electromagnetic spectrum that is, between 380 nm and 780 nm. The extent to which light is absorbed by a sample is dependent upon many factors. The main contributors are the wavelength of the incident light and the colour of the solution. Many compounds absorb ultraviolet or visible radiation. Figure 40 shows a beam of monochromatic radiation of radiant power $P_0$, directed at a sample solution. Absorption takes place and the beam of radiation leaving the sample has radiant power $P$.

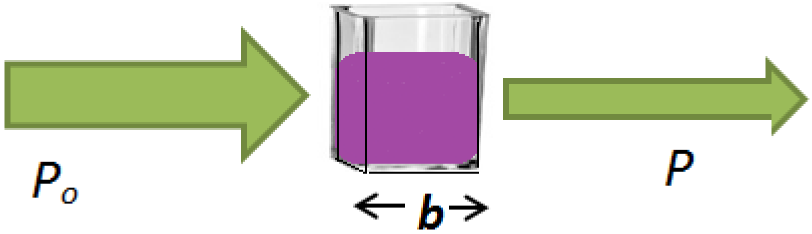

**Figure 40.** Monochromatic radiation passing through an absorbing species

The amount of radiation absorbed may be measured in a number of ways:

Transmittance (T),

$$T = P / P_0 \qquad (7.3)$$

$$\%T = 100\ T \qquad (7.4)$$

Absorbance (A),

$$A = \log_{10} P_0 / P \qquad (7.5)$$

$$A = \log_{10} 1 / T \qquad (7.6)$$

Modern absorption instruments can usually display the data as transmittance, per cent transmittance, or absorbance. An unknown concentration of an analyte can be determined by measuring the amount of light that a sample absorbs and applying Beer's law. If the absorptivity coefficient is not known, the unknown concentration can be determined using a working curve of absorbance versus concentration derived from standards (as performed in this study).

In principle, if all the light passes through a solution without any absorption, then absorbance is zero, and per cent transmittance is 100%. If all the light is absorbed, then per cent transmittance is zero, and absorption is infinite.

### 7.3.2 The Beer-Lambert Law

The law describes the quantitative relationship between the absorbance of radiant energy, the concentration of the sample solution, and the length of the path through the sample.

$$A=\varepsilon bc \qquad (7.7)$$

Where: $A$ is absorbance (no units, since $A = \log_{10} P_0 / P$); **ε** is the molar absorptivity with units of L $\text{mol}^{-1}$ $\text{cm}^{-1}$; ***b*** is the path length of the sample - that is, the path length of the cuvette in which the sample is contained, this measurement will be expressed in centimetres; ***c*** is the concentration of the compound in solution, expressed in mol $\text{L}^{-1}$.

Absorbance is directly proportional to the other parameters, as long as the law is obeyed.

From $A = \varepsilon bc$, it can be deduced that absorbance depends on the total quantity of the absorbing compound in the light path through the cuvette. If absorbance against concentration is plotted, a straight line passing through the origin (0, 0) is obtained.

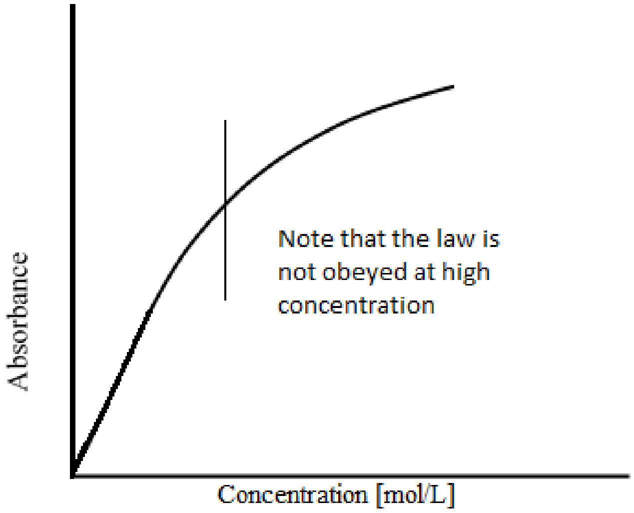

**Figure 41.** Absorbance vs. concentration

The linear relationship between concentration and absorbance is both simple and straightforward, and for this reason it will be used to investigate the aspect of chemistry teaching involving determination of pollutants in aqueous medium.

### 7.3.3 Light source and colour of analyte

Colorimetry is just one of the types of photometric analysis techniques; it is a light measuring analytical procedure. It is imperative to note the colour of the solution and correlate it with a light source of the appropriate wavelength. The LED or wavelength of the light source that will produce the maximum absorbance can be selected in two ways: taking readings throughout the spectrum on a typical standard solution of the substance under investigation and establish the peak wavelength ($\lambda_{max}$) and; method two (the method used in this study) involves choosing a light source of the complementary colour to the solution under investigation.

In colour theory, two colours are called complementary if, when mixed in the proper proportion, they produce a neutral colour (grey, white, or black). Complementary colours can also be visualized as pairs of colours that are opposite hues in a colour model (Westland et al., 2007). If one references a colour wheel, a set of complimentary colours would be the colours directly across from each other. These exact opposites help create contrast within a design and can help in choosing an appropriate monochromatic light source. In this study the reaction of Mn ions with periodate produced a purple solution and hence a green LED was used for the analysis as shown in Figure 40.

### 7.3.4 Reaction of manganese ions with periodate

This study presents a novel way of LCC design which include among other things, signal amplification based on a 1 watt amplifier. These kinds of colorimeters can be applied to analyse various parameters similar to a conventional colorimeter. For Mn ion analysis involving periodate, the measurements were conducted at 520 nm.

This study further shows a brief description of several experimental results using the LCCs in comparison to data obtained from standard equipment, and to verify its applicability to $Mn^{2+}$ determination.

Small quantities of Mn are readily determined colorimetrically by oxidation to the highly coloured permanganate ion. Potassium periodate is an effective oxidizing agent.

$$5IO_4^- + 2Mn^{2+} + 3H_2O \rightarrow 2MnO_4^- + 5IO_3^- + 6H^+ \qquad (7.8)$$

Permanganate solutions containing an excess of periodate are relatively stable.

There is little interference in this procedure. The presence of coloured ions can be compensated by employing a blank, that is, a sample that has not been oxidized by periodate. However, this method is not effective in the presence of appreciable quantities of chromium (III) ions, for it is oxidized to some extent by periodate, and their reaction products absorb in the spectral region commonly employed for permanganate (Bright & Larrabee, 1929).

### 7.3.5 Caution in using the periodate method with the Digital Water Analyser (DWA)

Only dissolved Mn ions (from divalent up to hexavalent) can be determined in this method.

For measurement of total Mn fraction including suspended particles, a pre-treatment was needed; in this study there was pre-treatment as the objective was to determine the total amount of dissolved Mn.

Another caution is in the measurement of heptavalent Mn ion; a lot of reducing agent has to be added into the sample in order to counteract red colour, and the blank measured.

The pH of the solution is known to affect the colour development especially if too acidic or alkaline. For this experiment pH was in the acceptable range of between pH 5 - 9, so there was no cause to adjust the pH with dilute sulphuric acid or sodium hydroxide solution. The temperature was kept within the acceptable range of 15 - 30°C.

Interference is expected because the built-in calibration curve is determined from standard solutions. However, coexisting ions can modify the reaction colour. This method of determining manganese is considered to be equally suitable for seawater samples. Table 33 reports ion concentrations under which interferences are insignificant:

**Table 33.** Ion concentrations under which interferences are insignificant using the DWA

| Concentration (ppm) | Species |
|---|---|
|  | Miscellaneous ions |
| ≤1000 | B(II), $Ca^{2+}$ , $Cl^-$ , $F^-$, $K^+$ , $Mg^{2+}$ , $Na^+$ , $NH_4^+$ , $NO_3^-$, $PO_4^{3-}$, $SO_4^{2-}$, Anionic Surfactant, Residual Chlorine, Formaldehyde |
| ≤50 | $NO_2^-$ |
| ≤20 | $CN^-$ |
| ≤5 | $I^-$, Phenol |
|  | Heavy metal ions |
| ≤1000 | Mo (VI) |
| ≤500 | $Ni^{2+}$ |
| ≤200 | $Al^{3+}$, $Ba^{2+}$, $Zn^{2+}$ |
| ≤100 | $Cu^{2+}$, $Fe^{2+}$ , $Fe^{3+}$ |
| ≤50 | Cr (VI) |
| ≤20 | $Co^{2+}$ |
| ≤5 | $Cr^{3+}$ |

A lot of reductive substances can make negative error. For example, sodium hydrogen sulphite coexisting at higher than 10g/l is known to cause interference (Kyoritsu Chemical-Check Lab., Corp, 2010).

### 7.4. Results and Discussion

The water samples suspected to be contaminated with Mn ions and whose results were used to test the colorimeter were obtained from Zambia. All the methods (AAS, ICP, DWA and LCCs) have been reported in the subsequent sections and the results compared to determine if they are similar despite their huge cost differences of the instruments and amount of time needed for sample preparation before the actual analysis.

### 7.4.1 Comparison of LCC1 and LCC2

The different colorimeter designs or configurations were compared to establish under which conditions the Beer-Lambert law fails to maintain a linear relationship between absorbance and concentration of analyte, these deviations are classified into three categories namely: the real deviations, these are fundamental deviations due to the limitations of the law itself; the chemical deviations, these are deviations observed due to specific chemical species of the sample which is being analysed, and in this study it was the reaction of Mn with $IO_4^-$; and the lastly the instrument deviations. The instrument deviations occur due to how the absorbance measurements are taken, in this case two colorimeter designs were compared with some slight variations in the way measurements are taken. Figure 42 shows the results when values obtained using LCC1 were used to plot a graph of absorbance versus concentration, and Figure 43 shows the result when LCC2's experimental values were used to plot a graph of absorbance versus concentration.

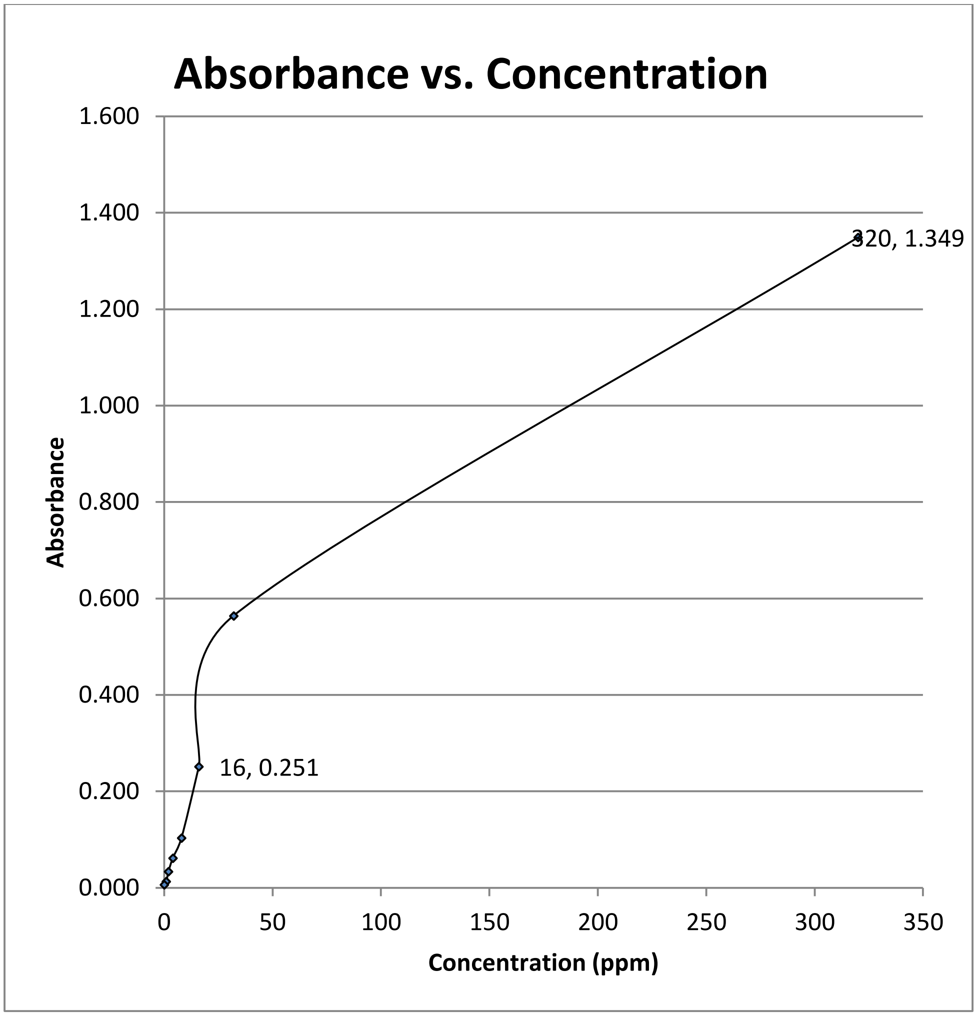

**Figure 42.** Plot of manganese concentration versus absorbance using the LCC1 (0 ppm, 1 ppm, 2 ppm, 4 ppm, 8 ppm, 16 ppm, 32 ppm, 320 ppm)

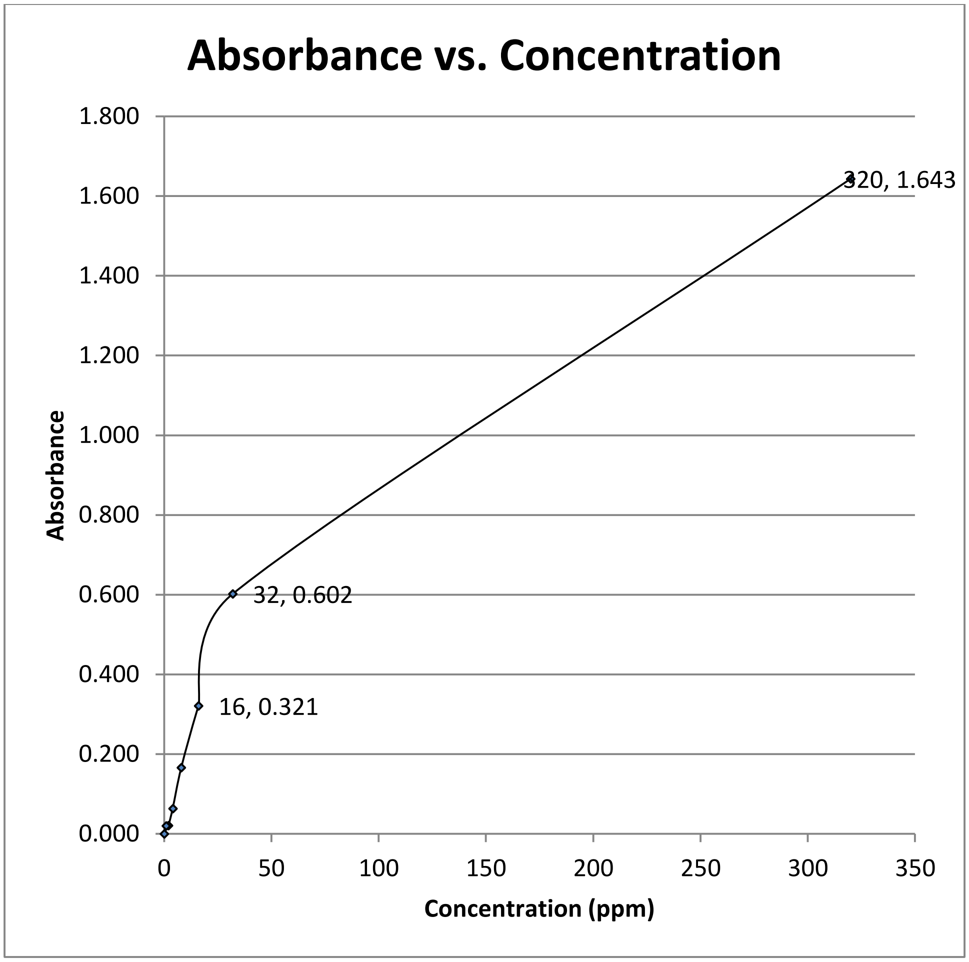

**Figure 43.** Plot of manganese ion absorbance using the LCC2 (0 ppm, 1 ppm, 2 ppm, 4 ppm, 8 ppm, 16 ppm, 32 ppm, 320 ppm)

Using both LCC1 and LCC2, it can be deduced that both instruments had the same range of linearity with reference to Mn analysis with periodate. The instruments show that for analytical purposes, it is appropriate to prepare standards not exceeding 16 ppm. And using concentration values higher that 16 ppm leads to a compromise on the obtained values as the Beer-lambert law is not obeyed as shown by both the figures representing LCC1 and LCC2. It is also important to note that these results apply only to the $Mn/IO_4^-$ reaction and that the procedure should be repeated if the LCCs are to be used to analyse a different pollutant, for example Cu, or if the Mn is to be analysed using a different reagent to generate a colour; different reagents can be used to generate a colour for subsequent analysis, some examples of the reagents that have been used before include the persulphate oxidation, formadoxime, and malachite green colorimetric methods as reported by Delfino and Lee (1969).

### 7.4.2 Comparison of values obtained by DWA, ICP and AAS

Table 34 shows the experimental values obtained when the concentration of sample 1 was determined by three methods namely, DWA, ICP, and AAS.

**Table 34.** Concentration of Sample 1 as generated by different methods

| Method/ Instrument | Measurement1 (ppm) | Measurement 2 (ppm) | *Average (ppm)* |
|---|---|---|---|
| DWA | 0.60 | 0.90 | *0.75* |
| ICP | 0.52 | 0.52 | *0.52* |
| AAS | 0.56 | - | *0.56* |

Average (ICP&AAS) = 0.54 ppm

The average of the ICP and AAS was taken as the acceptable value and the per cent deviation of DWA was found to be 39%.

**Table 35.** Concentration of Sample 2 as generated by different methods

| Method/ Instrument | Measurement1 (ppm) | Measurement 2 (ppm) | *Average (ppm)* |
|---|---|---|---|
| DWA | 0.70 | 0.80 | *0.75* |
| ICP | 0.80 | 0.81 | *0.81* |
| AAS | 1.12 | - | *1.12* |

Average (ICP&AAS) = 0.97 ppm *taken as acceptable value*

The effectiveness of the DWA compared to the results obtained by ICP and AAS on sample 2 was compared, as shown in Table 35, and the per cent deviation was found to be 23%.

**Table 36.** Concentration of Sample 3 (effluent water) as generated by different methods

| Method/ Instrument | Measurement1 (ppm) | Measurement 2 (ppm) | *Average (ppm)* |
|---|---|---|---|
| DWA | 6.40 | 6.30 | *6.35* |
| ICP | - | - | - |
| AAS | 9.50 | - | *9.50* |

The value obtained by AAS is taken as the acceptable

The analysis was repeated using sample 3 (mine effluent water) and the effectiveness of the DWA compared to the results obtained by AAS and the per cent deviation was found to be 33%. When three samples were determined by the three standard methods, it was proved that the result obtained by colorimetric method (the DWA) was in many cases lower in comparison to the results by ICP and AAS. Furthermore, the results show that determining lower concentrations of Mn (less than 1 ppm) was less accurate as can be perceived by the relative higher per cent deviation of sample 1. The deviations ranged from 39% to 33%. The DWA is taken as the standard colorimetric instrument from which the LCCs were developed and so it was imperative to ascertain its accuracy relative to the systematic instruments: ICP and AAS.

### 7.4.3 Results obtained by LCC1 and LCC2 with comparison to results by AAS, ICP and DWA

From the sample of unknown concentration (effluent water) and seven standard samples of known concentration, from a maximum of 320 ppm to 1 ppm (and a blank solution) of Mn as shown in Table 37, absorbance values were obtained using both LCC1 and LCC2. The absorbance values versus concentration were plotted on graphs for comparison of the effectiveness of the two instruments. From the graphs obtained by a combination of known concentrations (Figure 44 to Figure 47), the unknown concentration of the effluent water was determined.

**Table 37.** Absorbance values of the standard samples and the copper mine effluent sample obtained from Zambia using the low-cost colorimeters (LCC1 and LCC2)

| **LCC1** | | | Absorbance | **LCC2** | | Absorbance |
|---|---|---|---|---|---|---|
| Concentration | $P_o$(V) | P(V) | (Log $P_o$/P) | $P_o$(V) | P(V) | (Log $P_o$/P) |
| 320 ppm | 6.70 | 0.30 | 1.3490 | 4.40 | 0.10 | 1.6435 |
| 32 ppm | 6.60 | 1.80 | 0.5643 | 4.40 | 1.10 | 0.6021 |
| 16 ppm | 6.60 | 3.70 | 0.2513 | 4.40 | 2.10 | 0.3212 |
| 8 ppm | 6.60 | 5.20 | 0.1035 | 4.40 | 3.00 | 0.1663 |
| 4 ppm | 6.80 | 5.90 | 0.0617 | 4.40 | 3.80 | 0.0637 |
| 2 ppm | 6.70 | 6.20 | 0.0337 | 4.20 | 4.00 | 0.0212 |
| 1 ppm | 6.70 | 6.50 | 0.0132 | 4.40 | 4.20 | 0.0202 |
| Blank Solution | 6.70 | 6.60 | 0.0065 | 4.40 | 4.40 | 0.0000 |
| Effluent Water | 6.60 | 5.40 | 0.0872 | 4.40 | 3.40 | 0.1120 |

A graph of absorbance against concentration was plotted and the results show that the LCC1 and LCC2 produced reasonably linear graphs. The Mn concentration (9.50 ppm) obtained by AAS was taken as the accepted value for the mine effluent water from which the subsequent per cent deviations were calculated.

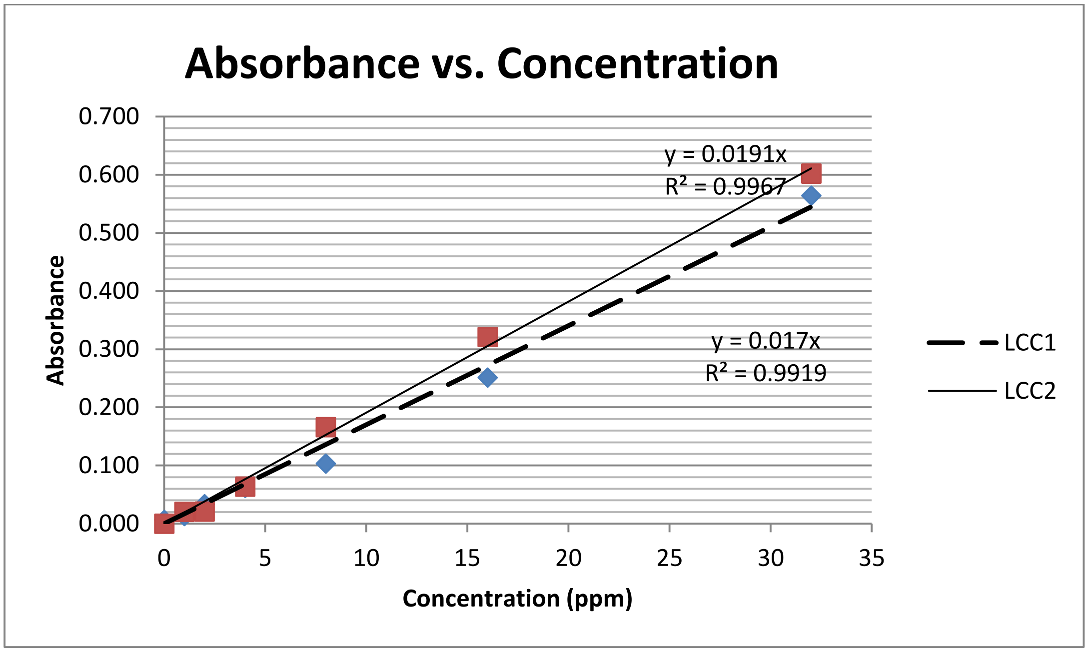

**Figure 44.** Plot of absorbance vs. concentration (0 ppm, 1 ppm, 2 ppm, 4 ppm, 8 ppm, 16 ppm, 32 ppm)

Using the linear equation $y = 0.017x$ obtained by using LCC1 and generated by plotting the standard concentration values from 0 ppm to 32 ppm (Figure 44), it was found that the effluent water had a Mn concentrations of 5.13 ppm and a per cent deviation from the systematic instrument of 46%. Using LCC2, the Mn levels in the same effluent water was determined to be 4.57 ppm (with a deviation of 52%).

A second graph (Figure 45) was plotted where the 32 ppm value was eliminated and the standard concentrations from 0 ppm to 16 ppm were plotted in order to check the effect of the higher value(s) on the unknown concentration of the sample.

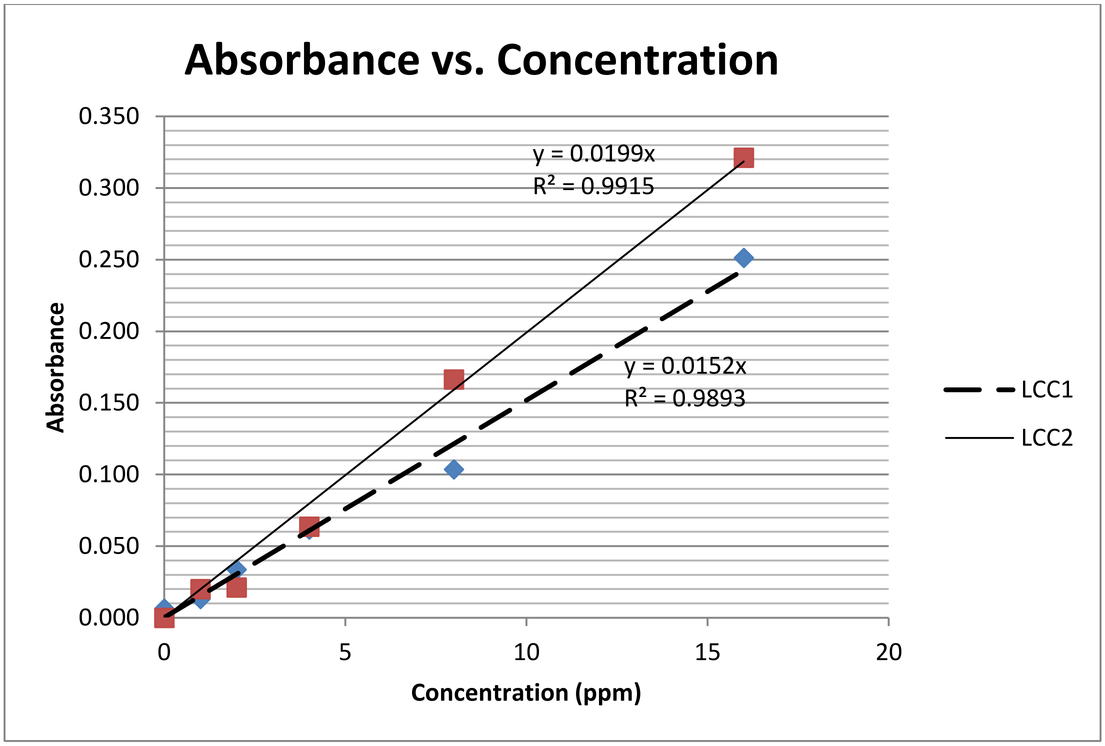

**Figure 45.** Plot of absorbance vs. concentration (0 ppm, 1 ppm, 2 ppm, 4 ppm, 8 ppm, 16 ppm)

Once more using the linear equation, $y = 0.0152x$ as generated by LCC1, it was found that the effluent water yielded concentration 5.7 ppm (with deviation of 39.6%). On the other hand, using LCC2, the effluent water's Mn levels was determined as 4.38 ppm with a deviation of 53.9%. It can be deduced from the results that when the higher value (32 ppm) is not included in plotting of the linear graph, LCC1 gave a more accurate value; however, the LCC2 value was less accurate and a further deviation from the value obtained by AAS. In this particular case, it can be deduced that not including the 32 ppm sample affected the accuracy of the determined value of the effluent water differently, more accurate for LCC1 and less accurate for LCC2.

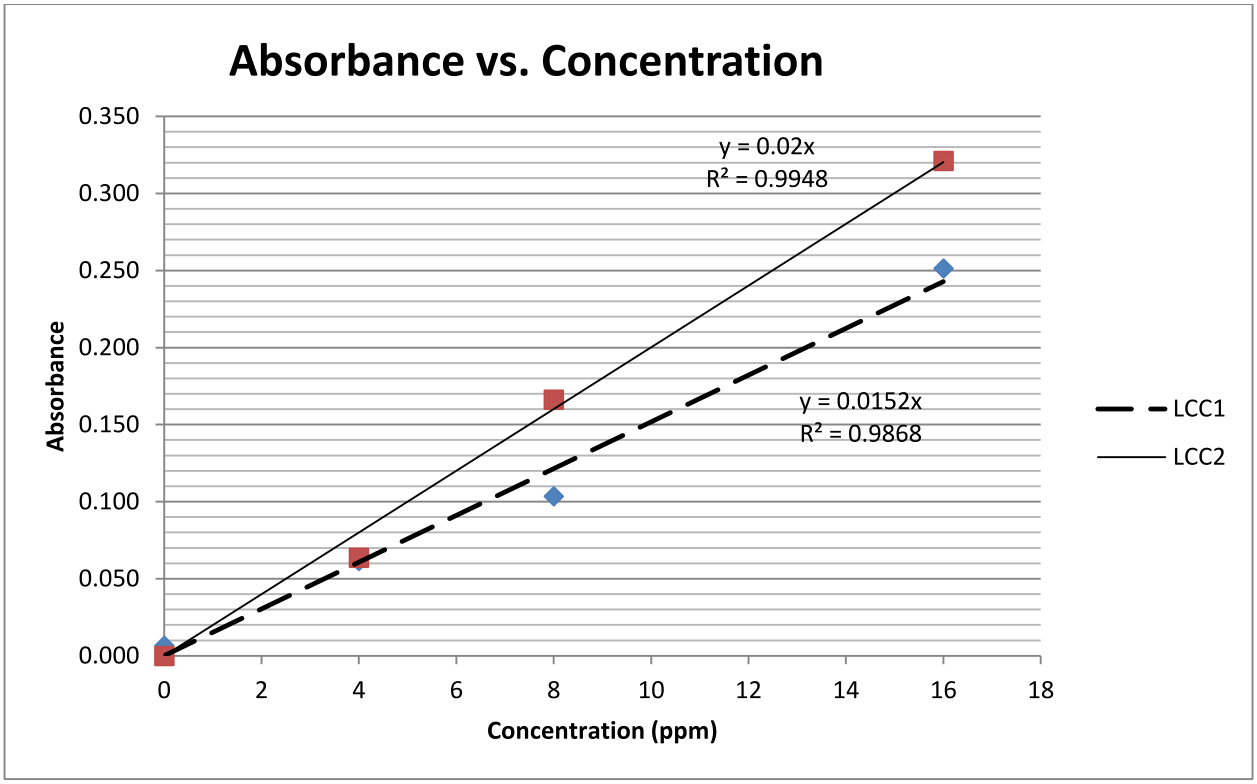

**Figure 46.** Plot of absorbance vs. concentration (0 ppm, 4 ppm, 8 ppm, 16 ppm)

The third graph (Figure 46) was plotted in which case the calibration curve was derived by considering only four standard concentration values (0 ppm, 4 ppm, 8 ppm & 16 ppm) obtained using the LCCs. The LCC1 resultant graph is shown above. Using the linear equation, $y = 0.0152x$, the effluent water's Mn levels was determined as 5.73 ppm with a deviation of 40%. The analysis was repeated by using LCC2 and the effluent water was determined to have a Mn concentration of 4.36 ppm with a deviation of 54%.

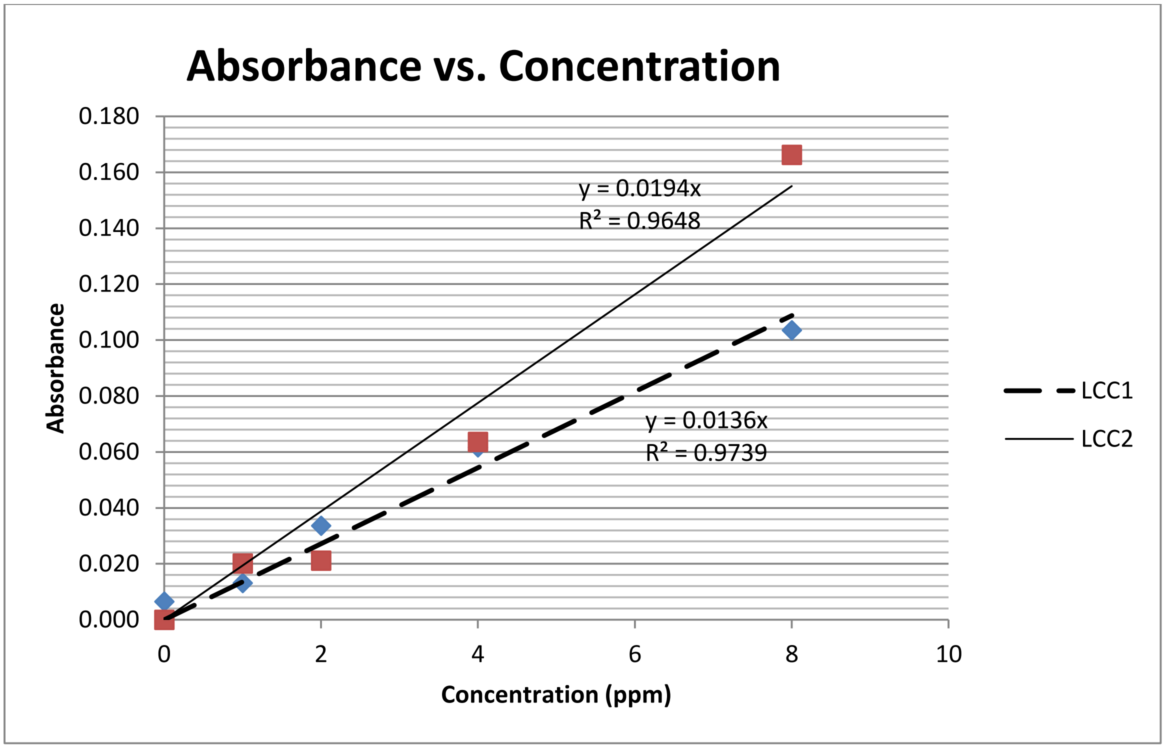

**Figure 47.** Plot of absorbance vs. concentration (0 ppm, 1 ppm, 2 ppm, 4 ppm, 8 ppm)

The fourth graph (Figure 46) was plotted in which case only the lower concentration values (0 ppm, 1 ppm, 2 ppm, 4 ppm, 8 ppm) were used to prepare a calibration graph. The same effluent water sample, using LCC1, was determined as 6.4 ppm and per cent deviations of 33%; using LCC2 the same sample was determined as 4.49 ppm and corresponding to a per cent deviation of 53%.

The fourth scenario gave the closest values and per cent deviations like those obtained by comparing DWA to ICP and AAS. The sample 3 (the effluent water) was determined using the DWA and was compared with ICP and AAS, it yielded a deviation of 33%. However, the deviations when LCC1 and LCC2 were used to analyse the same effluent water sample, were 33% and 53% respectively. The DWA's accuracy is comparable in accuracy to the LCC1. On the other, the LCC2 gave results that are less accurate than the DWA. LCC1 gave results that were very close to the results obtained by the more expensive and systematic instruments. LCC1 proved, beyond reasonable doubt that it was more reliable, accurate and hence a feasible approach for investigating the state of the environmental waters.

### 7.5. Major findings

In this study, the relationship between the concentration of a light-absorbing species and the intensity of the transmitted light was investigated, under the conditions of a constant path-length and fixed wavelength (520nm). The experiment demonstrated that the LCC is appropriate, reasonable and a feasible option for use at high school level for investigating the condition of the water in the environment. The results show that using the LCC, it was possible to generate similar results as those generated by the DWA and also similar to the high cost instruments, namely ICP and AAS. It is appropriate that this simple application is considered for adoption in Zambia and other low income countries overwhelmed by lack of resources for effective teaching of science and especially investigation of water based pollutants in the environment. This type of colorimeter can simplify measurement procedures, and is able to work in any environment. Thus, it introduces two types of benefits: a decreasing of equipment and procedures costs and, an uncovering what's hidden in the water found in the environment where the students reside. The findings suggest that using concentration from 0 ppm, 2 ppm, 4 ppm and 8 ppm for calibration of the graph was the more acceptable scenario because the values obtained produced the most favourable calibration curve which yielded concentration values close to the values obtained by more accurate/precise instruments (DWA, ICP and AAS). Despite the huge cost differences, the results obtained using the LCC1 was comparable to the ones generated by ICP, AAS and the DWA.  It was further proved that LCC1 was the favourable colorimeter configuration for producing the best fit linear graph for pollutant determination (and hence strongly recommended for high school use). LCC2 was not as favourable as LCC1 because the concentration of the effluent water obtained using the former produced huge deviation from the accepted values or values obtained by more systematic analytical instruments.  Apart from accuracy superiority, LCC1 is less costly to assemble and hence an added advantage over LCC2.

# Chapter 8

## 8. High school activities on pollution treatment

### 8.1 Introduction

Since 1500 BC, when ancient Egyptians and Hindus first filtered water and medicines with activated carbon (AC), it has been used as a filter to remove impurities from water, air, gases, processed beverages and pharmaceuticals (Trogolo, 2011). AC filtration is most effective in removing organic contaminants from water. Because organic chemicals are sometimes responsible for taste, odour, and colour problems, AC filtration can generally be used to improve aesthetically disagreeably water. AC filtration will also remove chlorine and heavy metals. AC filtration is recognized as an acceptable method to maintain certain drinking water contaminants within safe limits (Seelig, Bergsrud & Derickson, 1992).

Several factors influence the effectiveness of activated charcoal. The pore size and distribution varies depending on the source of the carbon and the manufacturing process. Large organic molecules are adsorbed better than smaller ones. The adsorption capacity of the dyes on AC increase in acidic solutions, but decrease in basic solutions (Al-Degs et al., 2008). Contaminants are also removed more effectively if they are in contact with the activated charcoal for a longer time, so flow rate through the charcoal affects filtration.

An AC filter will remove certain impurities while ignoring others. Substances, like sodium, fluoride, and nitrates, are not as attracted to the carbon and are not filtered out. Adsorption works by chemically binding the impurities to the carbon; it also means that, once all of the bonding sites are filled, an AC filter stops working. At that point, it must be replaced. Activated carbon can be used to remove and recycle hexavalent chromium from electroplating industries (Ouki & Neufeld, 1997), as adsorbents for the removal of acid dyes from aqueous solution (Malik, 2003), controlling emissions of volatile organic compounds (VOCs) (Ruhl, 1993; Juang, Wu & Tseng, 2002), removal of cadmium and zinc (Mohan & Singh, 2002). It is generally used in waste water treating processes (Grutsch & Mallatt, 1981).

In Zambia, the use of charcoal as a fuel is widespread. However, this study was designed to add to the list of the possible uses of charcoal as a water pollutant removal amongst the possible high school activities. Because the charcoal available in Zambia is manufactured using the same procedure, but from different tree species, it was imperative to design a method for testing its efficiency for pollutant treatment and to ascertain if different tree species adsorb pollutants differently. The results are discussed in the subsequent sections.

Other methods were explored such as the chemistry concept of precipitating dissolved metal ions in the form of a metal hydroxide by increasing the pH of the solution. This concept has been taught in the Zambian curriculum as one of the reaction of heavy metals, but without any apparent application to real-life situations. Thus, this study was intended to add an element of application of the concepts taught to real-life situations. Allen (2002, p. 21) argues that “keeping a careful eye on the learner’s understanding of the value of the material should be a critical part of every teacher’s agenda.” In his argument, he considers the axiom: Nothing is taught, if nothing is learned; nothing is learned, if nothing is applied. This study is intended to induce application of the knowledge that is learned in the Zambian schools by combining learning with enjoyment which, according to Allen (2002), leads to retention of what is learnt. In essence, he argues that without application, nothing else matter; if the learners cannot find a way to rapidly integrate the knowledge into something they know and are familiar with, the information may quickly fade from their memory. In the same vein, Bigge (1964) argues that it would be difficult to justify any achievement of school learning which had no bearing upon students’ future learning in life situation; a predominant purpose of formal education in schools is to facilitate learning outside them. In fact, non-formal education could provide students with the means to maintain and reinforce the knowledge and skills that they have learnt during their school years (Scoullos & Malotidi, 2004).

Furthermore, using a reaction which results into precipitation, the hydrotalcite-like compound ($Mg^{2+}$—$Al^{3+}$—$SO_4^{2-}$) was prepared by mixing continuously an aqueous solution of sodium hydroxide and a mixed aqueous solution of magnesium chloride and aluminium sulphate as explained under the methodology section. The white precipitates formed were tested for their efficiency in heavy metal treatment. Hydrotalcite-like compounds are some of the few inorganic anion exchangers that have relatively high capacities of about 3 meq/g according to Miyata (1983). Anion-exchanger resins induce an ion-exchange reaction with a hydrated anion, whereas, hydrotalcite-compounds induce ion-exchange reactions with bare, non-hydrated anions. By utilising their characteristic ion selectivity, hydrotalcites are expected to find application in the removal of acid dyes, $HPO_4^{2-}$, $CN^-$, $CrO_4^{2-}$, $AsO_4^{3-}$, $(Fe(CN)_6)^{4-}$, etc. from waste waters, as well as in the neutralisation and thermal stabilisation of halogen-containing polymers (Miyata, 1983). The detailed results of water treatment involving the hydrotalcite-like compound are discussed in the subsequent sections.

## 8.2 Iodine number

Fats and oils are a mixture of triglycerids. Triglycerides are made up of three fatty acids linked to glycerol by fatty acyl esters. Fatty acids are long chain hydrocarbons with carboxyl groups (COOH groups). These fatty acids can be classified into saturated or unsaturated based on the number of double bonds present in the fatty acid. Saturated fatty acids contain only single bond between the carbon atoms and tend to be solids at room temperature. Unsaturated fatty acids contain double bonds between the carbon atoms in addition to the single bonds present in the fatty acid chain. They are likely to exist as liquids at room temperature (McMurry, 2000).

Unsaturated hydrocarbons such as fatty acids and alkenes can be saturated by the process of hydrogenation. Depending upon the degree of unsaturation, the fatty acids can combine with oxygen or halogens to form saturated fatty acids (Jones, 2000). So it is important to know the extent to which a fatty acid is unsaturated. There are different methods for checking the unsaturation level in fatty acids (Netting, 1986; Thomas, Mitchell & Blanksby, 2009), one among them is by determining the iodine value (Grunbaum & Kirk, 1952). Iodine value or number is the number of grams of iodine consumed by unsaturated bonds in 100 g of fat (Tucker & Robinson, 1990). A higher iodine value indicates a higher degree of unsaturation.

The concept of iodine number has found applications beyond fats and is one of the physical properties frequently used in determining the efficiency of the carbon-activation process. Iodine number of carbon is dependent on particle size. When the particle size increases, the iodine numbers increase. Smaller particles burn out early due to faster reaction rates, resulting in pore coalescence and reducing iodine numbers. Thus higher particle sizes are required to give a matrix to the product with developed pore structure (Satyasai, Ahmed & Krishnaiah, 1997). In the subsequent section (section 8.3), iodine number of charcoal obtained from various tree species will be determined. The iodine number is an indicator of the efficiency by which the ACs can treat pollutants, especially, organic pollutants in aqueous medium.

## 8.3 Results and data analysis

In the Zambian curriculum, the concept of titrations is utilised in classroom activities where pupils are asked to determine the concentration of an unknown solution in which case the solution is prepared in the lab. The other utilisation of the same concept is in the preparation of salts. In both cases, the teaching does not give any meaning application of the same concept in the daily activities of the pupils. However, this study used the same titration technique as an EE activity by reorienting the said method in the determination of the efficiency of various forms of AC in order to determine the most effective form(s) of carbon for water treatment.

The method was designed to solve real-life problems confronting the pupils in their everyday life using titration which hitherto has not been applied to solve real problems. The method was applied on several forms of AC obtained from Zambia. The detailed activities are further explained in the proceeding sections. The treatment methods suggested in the chapter utilises well known high-school level chemistry concepts so that the activities are as realistic as possible. Moreover, the Association for Supervision and Curriculum (1954) contends that pupils reject tasks that are beyond their level of achievement and activities meaningless to students may result in apathy and inertia. Sometimes, the rules which humans learn are a complex combination of simpler rules or concepts. It is often the case that these more complex, or high order rules are invented for the purpose of solving practical problems or a category of problems. It can be argued that when students work out the solution to a problem, which represents real events, they are engaging in the behaviour of thinking (Gagné & Briggs, 1979).

### 8.3.1 Standardisation of $Na_2S_2O_3$ with $KIO_3$

Potassium iodate was reacted with iodide in slightly acid solution to form iodine.

$$IO_3^- + 5I^- + 6H^+ \longleftrightarrow 3H_2O + 3I_2 \quad (8.1)$$

Iodate reacts with iodide in slightly acid solution to form iodine that can be titrated with thiosulphate as shown in the equation. One mole of iodine reacts with two moles of thiosulphate according to equation 8.2.

$$2Na_2S_2O_3 + I_2 \longleftrightarrow Na_2S_4O_6 + 2NaI \quad (8.2)$$

The mixture (8.1) was titrated with thiosulphate to a pale yellow colour and 1ml of starch solution was added and titration continued to a sharp colour change from blue to colourless. The process was repeated twice.

Standardisation of sodium thiosulphate was carried out using a 0.0167M, 12.0 ml primary standard of $IO_3^-$ in which an average volume of 12.20 ml sodium thiosulphate was consumed. Equation 8.3 represents the overall reaction.

**Reaction**

$$6Na_2S_2O_3 + 3I_2 + IO_3^- + 5I^- + 6H^+ \longrightarrow 3H_2O + 3Na_2S_4O_6 + 6NaI \quad (8.3)$$

Moles of $IO_3^-$ = Molarity × Volume

Moles = 12.00 ml x 0.0167 = 0.2004 mmol

Moles of $Na_2S_2O_3$ consumed is given by:

$$\frac{\mathrm{IO_3^-}}{0.2004\ \mathrm{mMoles\ of\ IO_3^-}} = \frac{\mathrm{6Na_2S_2O_3}}{\mathrm{x\ Moles\ of\ Na_2S_2O_3}}$$

Moles of $Na_2S_2O_3$ = mmols $Na_2S_2O_3$ = 1.2024 mmol

Therefore the molarity of $Na_2S_2O_3$ = Moles/Volume = 1.2024 mmols/12.20 ml = 0.0986 Molar

**Blank reagent versus sodium thiosulphate**

Next was the determination of the amount of initial iodine present in the Hanus reagent. This was achieved by considering the reaction of the standardised $Na_2S_2O_3$ with Hanus reagent before any charcoal treatment is performed. The blank titration gave a $Na_2S_2O_3$ volume of 43.80 ml.

**Initial Iodine present**

$$2Na_2S_2O_3 + I_2 \longrightarrow S_4O_6^{2-} + 2I^-$$

n = MV

= 43.80 ml x 0.0986 mols/l

= 4.31868 mmol

$$\frac{2S_2O_3^{2-}}{4.31868\ \mathrm{mMole\ of}\ 2S_2O_3^{2-}} = \frac{I_2}{\mathrm{x\ moles\ of}\ I_2}$$

$I_2$ mmols = 2.15934 mmol

Initial mass of Iodine = moles x Mr

= 2.15934 mmol x 253.8g/mol $I_2$

= 0.548 g

### 8.3.2 Determining the iodine number of activated carbon from Mubanga Tree

Equation for the reaction of thiosulphate with iodine is:

$$2S_2O_3^{2-} + I_2 \longrightarrow S_4O_6^{2-} + 2I^-$$

Blank reading of $S_2O_3^{2-}$ represents total iodine present in solution

Experimental reading of $S_2O_3^{2-}$ = total $I_2$ - that adsorbed by carbon

Blank - Experimental reading of $S_2O_3^{2-}$ equates to $I_2$ adsorbed by AC = *X* ml (experimental values) for various brands of AC

From the equation:

2 molecules of $S_2O_3^{2-}$ react with 1 molecule of $I_2$

2 moles of $S_2O_3^{2-}$ react with 1 mole of $I_2$

1 mole of $I_2$ has a mass of 253.8 g

*X* ml $S_2O_3^{2-}$ × its molarity contains *Y* mole of $S_2O_3^{2-}$

The Hanus reagent (20.00 ml) was treated with AC obtained from Mubanga tree (Pericopsis Angolensis) and the resultant solution after 30 minutes was titrated with $Na_2S_2O_3$ (as titrant) requiring an average volume of 25.50 ml.

mmols $Na_2S_2O_3$= Molarity × Volume (ml)

= 25.50 ml x 0.0986 mols/l

= 2.5143 mmols of $Na_2S_2O_3$

$$\frac{2S_2O_3^{2-}}{2.5143 \text{ mMole of } 2S_2O_3^{2-}} = \frac{I_2}{\text{x mols of } I_2}$$

x = 1.25715 mmols of $I_2$

Mass of $I_2$ = mols x Mr ($I_2$)

= 1.25715 x $10^{-3}$ ×253.8 g/mol

=0.3191 grams

Mass of $I_2$ used = $I_i$ - $I_f$

= 0.548 g – 0.3191 g

= 0.2289 g

0.2289 g adsorbed by 1 gram of carbon

Therefore, Hanus Iodine number = 22.89

The same procedure was followed to calculate the iodine numbers of the other tree species considered in this study. The results are shown in Table 38.

**Table 38.** Iodine numbers of Activated carbon derived from various tree species

| No | Tree species | Hanus reagent volume (ml) | $Na_2S_2O_3$ (ml) | Mass of $I_2$ adsorbed/g of AC | Hanus Iodine number |
|---|---|---|---|---|---|
| 1 | Pericopsis angolensis | 20.00 | 25.50 | 0.2289 | 22.89 |
| 2 | Parinari Curatellifolia | 20.00 | 32.95 | 0.1357 | 13.57 |
| 3 | Julbernardia Paniculata | 20.00 | 24.20 | 0.2452 | 24.52 |
| 4 | Brachystegia Boehmii | 20.00 | 31.55 | 0.1532 | 14.32 |
| 5 | Uapaca Kirkiania | 20.00 | 28.95 | 0.1858 | 18.58 |
| 6 | Albizia Adianthifolia | 20.00 | 17.90 | 0.3240 | 32.40 |
| 7 | Commercial Activated Carbon | 20.00 | 2.93 | 0.5113 | 51.13 |

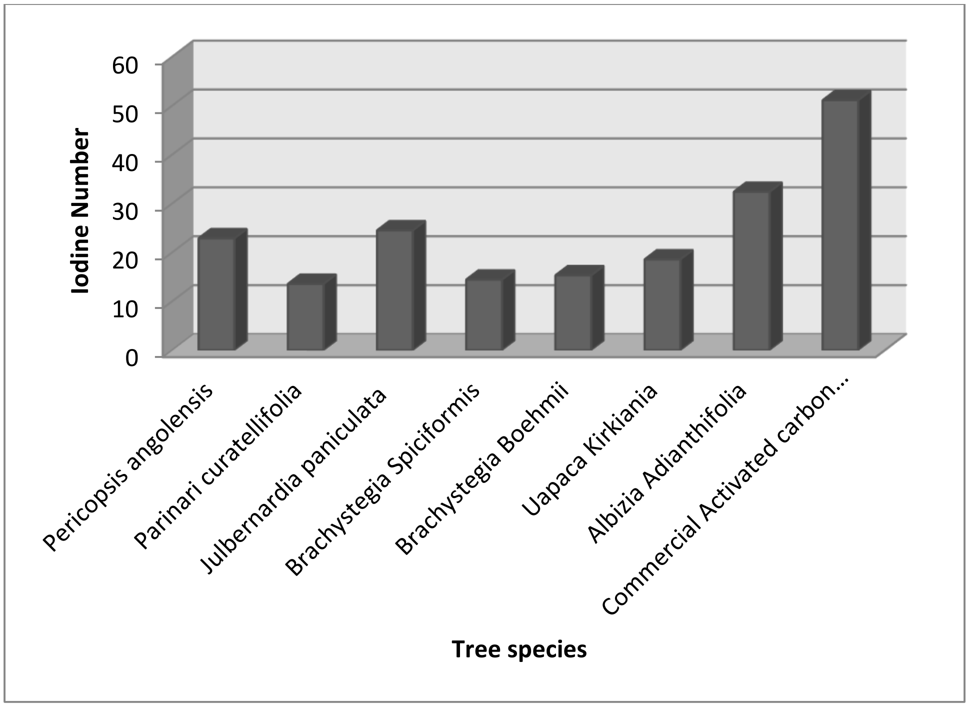

**Figure 48.** Iodine number of the activated carbon obtained from different tree species

Figure 48 shows the results of the iodine number determination activities using titration. It is apparent that commercial AC proved to be the most efficient as judged by the higher iodine number. It was followed by Albizia Adianthifolia. The experiment further demonstrated that despite using the same activation method, the charcoal obtained from different tree species remove pollutants by different amounts. This activity is important to assisting pupils in choosing the appropriate charcoal when treating organic and other pollutants treatable with AC.

### 8.4 Removal/Reduction of copper contamination from water

There is nothing like hands-on activities to make a lesson stick with students. When studying science, specifically environmental science of lab instruction, a great beginning lesson is to build a simple water filter. The materials and methods are simple and straightforward and the learners can do most of the work themselves. This is demonstrated in the subsequent section for treatment of water contaminated with heavy metals.

### 8.4.1 Effect of mass of activated carbon on the ability to adsorb $Cu^{2+}$

Two grams of charcoal was accurately weighed and put into a 250 ml separatory funnel. To this portion, 20 ml of 400 ppm was added and the reaction monitored for one hour. The separatory funnel was shaken every 6 minutes and vented to avoid any possible build-up of pressure inside the flask (venting is particularly useful when dealing with organic solvents). The experiment was repeated two more times, each time varying the mass of the AC used, reducing it by half. The results are shown in Table 39 and Figure 49.

**Table 39.** Effect of mass of activated carbon on the adsorption power of $Cu^{2+}$

| No | Vol. of $Cu^{2+}$ (ml) | Initial Conc. of $Cu^{2+}$ (ppm) | Mass of Carbon (g) | Duration of the Expt. (hours) | Determined Conc. of $Cu^{2+}$ | % removal of Conc. of $Cu^{2+}$ |
|---|---|---|---|---|---|---|
| 1 | 20 | 400 | 2 | 1 | 3.75 | 99.1 |
| 2 | 20 | 400 | 1 | 1 | 5.05 | 98.7 |
| 3 | 20 | 400 | 0.5 | 1 | 250 | 37.5 |

The results show that the gradual increase in the mass of carbon by 0.5 g produced a drastic increase in the ability of carbon to treat a solution contaminated with 400 ppm of $Cu^{2+}$. A 0.5 g sample of AC treeted 37.5% of the $Cu^{2+}$, an increase by a further 0.5 g of AC treated almost all the $Cu^{2+}$ at 98.7%. A further increase in the mass of AC by 0.5 g did not produce any significant change in the amount of $Cu^{2+}$ treated. For a 400 ppm contaminated solution, it was found that a ratio of 20:1 (vol.[ml]/mass [g]) was most ideal for Cu pollution contamination.

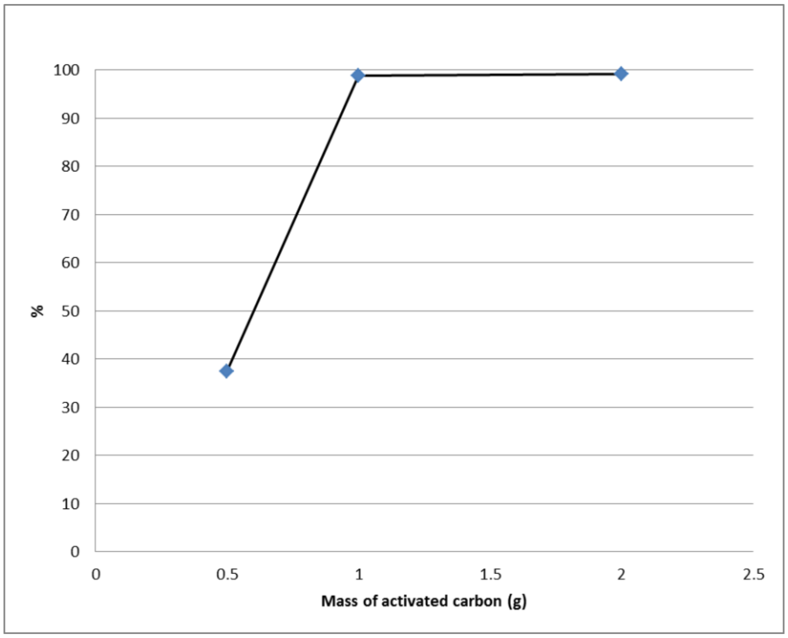

**Figure 49.** Increasing mass of activated carbon and treatment effectiveness

### 8.4.2 Effect of initial concentration on the ability to adsorb $Cu^{2+}$ by AC

In the second experiment to investigate the adsorption power of AC on solutions with different levels of $Cu^{2+}$, a 20 ml solution of 400 ppm concentration was mixed with 1 gram of AC and the mixture thoroughly mixed in a separatory funnel. The mixture was shaken intermittently every 10 minutes for 1 hour. The experiment was repeated, but only changing the initial concentration of the $Cu^{2+}$. The original 400 ppm was diluted further to 100 ppm by adding a 12.5 ml aliquot to a 50 ml volumetric flask and adding distilled water up to the mark. The preparation of the 20 ppm solution was done by pipetting a 12.5 ml solution of the original 400 ppm and adding it to a 100 ml volumetric flask and adding distilled water up to the mark. The results are shown in Table 40 and Figure 50.

**Table 40.** Investigation of the effect of initial concentration on the ability to adsorb $Cu^{2+}$ by AC

| No | Vol. of $Cu^{2+}$ (ml) | Initial Conc. of $Cu^{2+}$ (ppm) | Mass of Carbon (g) | Duration of the Expt. (hours) | Determined Conc. of $Cu^{2+}$ | % removal of Conc. of $Cu^{2+}$ |
|---|---|---|---|---|---|---|
| 1 | 20 | 400 | 1 | 1 | 189 | 52.6 |
| 2 | 20 | 100 | 1 | 1 | 4.14 | 99.0 |
| 3 | 20 | 20 | 1 | 1 | 0.92 | 99.6 |

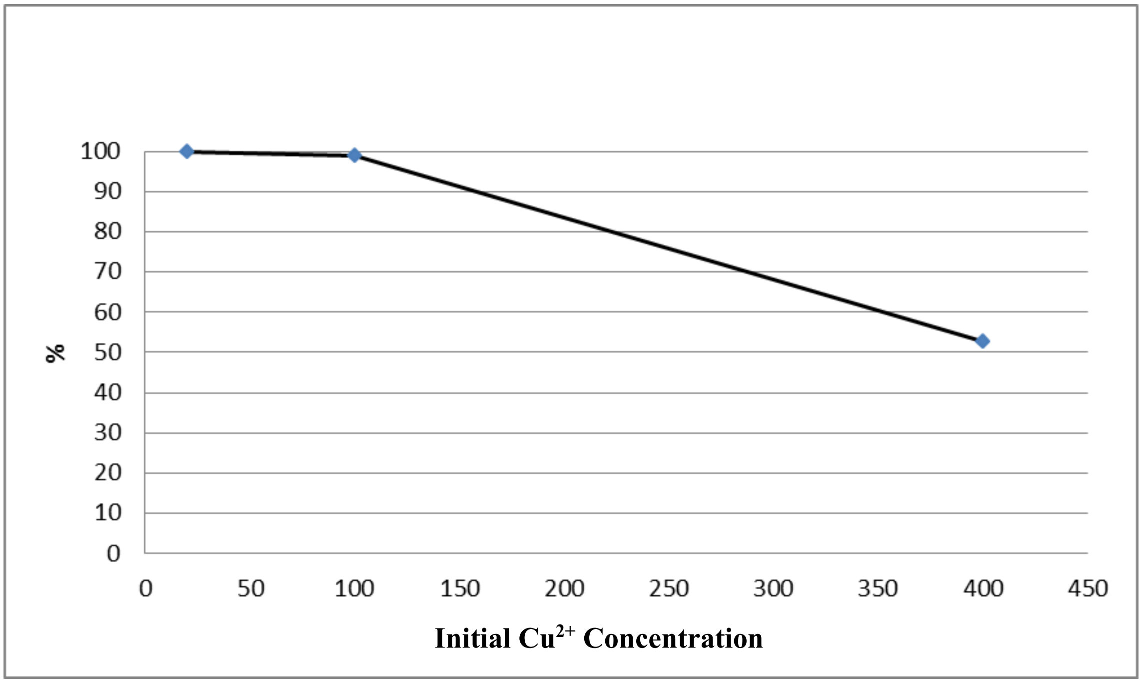

**Figure 50.** Treatment ability of 1 gram activated carbon on different levels of $Cu^{2+}$ contamination

Furthermore, starting with a 100 ppm $Cu^{2+}$ contaminated solution, it was further found that a ratio of 20:1 (vol. [ml]/mass[g]) was appropriate for maximum treatment benefit of the contaminated solution. This ratio proved to be effective for the treatment of different concentrations of the $Cu^{2+}$ contaminated water samples.

### 8.4.3 Time of exposure on the adsorption power of carbon on $Cu^{2+}$

Experiment 3 was designed to investigate the effect of duration or time of exposure on the adsorption ability of AC. One gram of AC was accurately weighed and transferred to a 250 ml separatory flask. To the flask, 20 ml of a 400 ppm solution was added and the reaction monitored for one hour for the first trial. The separatory funnel was shaken every 10 minutes and vented to avoid any possible build-up of pressure inside.

**Table 41.** Investigating time of exposure on the adsorption power of carbon on $Cu^{2+}$

| No | Vol. of $Cu^{2+}$ (ml) | Initial Conc. of $Cu^{2+}$ (ppm) | Mass of Carbon (g) | Time of the Expt. (hours) | Determined Conc. of $Cu^{2+}$ | % removal of Conc. of Cu2+ |
|---|---|---|---|---|---|---|
| 1 | 20 | 400 | 1 | 1 | 193 | 51.6 |
| 2 | 20 | 400 | 1 | 3 | 186.5 | 53.4 |
| 3 | 20 | 400 | 1 | 6 | 174 | 56.5 |

The experiment was repeated two more times, each time varying the duration of the experiment, increasing by three hours. In all the three trials, the volume, initial concentration, and mass of carbon was held constant and the concentration of the $Cu^{2+}$ was determined after 1 hour, 3 hours and finally 6 hours as shown in Table 41. The separatory funnel in subsequent activities was shaken vigorously after every 20 minutes.

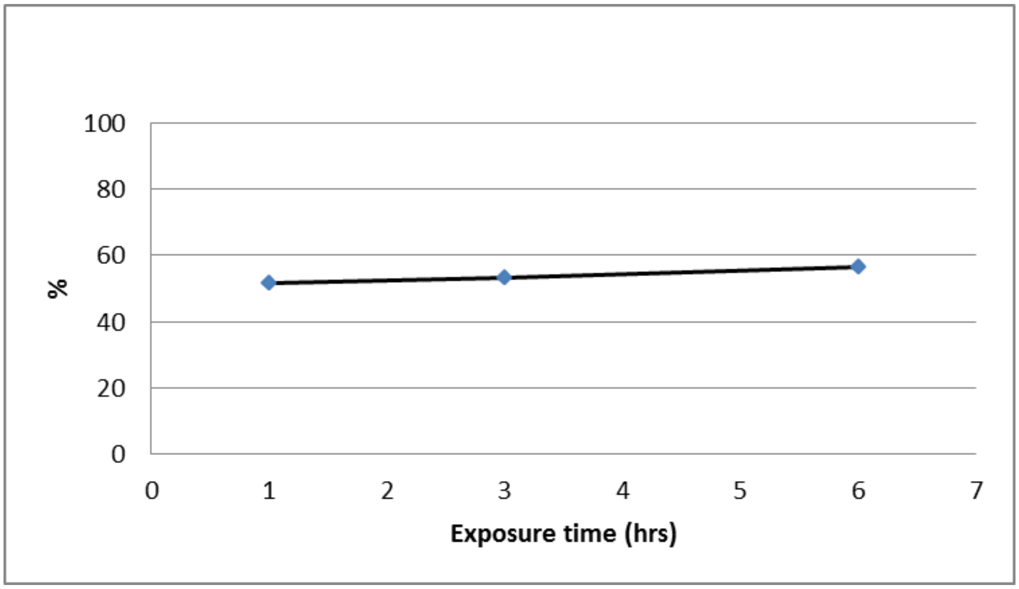

**Figure 51.** Comparison of time (hrs.) against determined concentration of $Cu^{2+}$ (mg/l) using a fixed initial concentration of 400 ppm

The preliminary findings suggest that there is a rapid increase in the absorption power of charcoal with reference to $Cu^{2+}$ when the mass was increased from 0.5 g to 1 g; almost an exponential increase. Nonetheless, time of exposure was not a big factor in this experiment because after six hours, the adsorption potential of the AC was not significantly different from the results obtained after one hour and three hours of exposure to the AC.

### 8.4.4 $Mn^{2+}$ absorption ability of 1 gram of various activated carbons per minute

Experiment 4 was designed to study the effect(s) of competing ions on the efficiency of the AC in pollution mitigation. A solution containing 10 ppm of the following ions, $Cu^{2+}$, $Ni^{2+}$, $Fe^{3+}$ and $Mn^{2+}$, was prepared. The ability of eight brands of the ACs was tested for their efficiency in treating the $Mn^{2+}$ and $Cu^{2+}$ in a mixture with two other ions $Ni^{2+}$ and $Fe^{3+}$. Furthermore, the ability of Albizia Adianthifolia and commercial AC was tested against a solution containing only 10 ppm of $Mn^{2+}$. For all the experiments, the time of exposure of the charcoal was maintained at 1 minute. The results are reported below.

Figure 52 shows the $Mn^{2+}$ absorption ability of 1 gram of AC per minute on a solution containing 10 ppm of each of the heavy metal ions $Cu^{2+}$, $Ni^{2+}$, $Fe^{3+}$ and $Mn^{2+}$

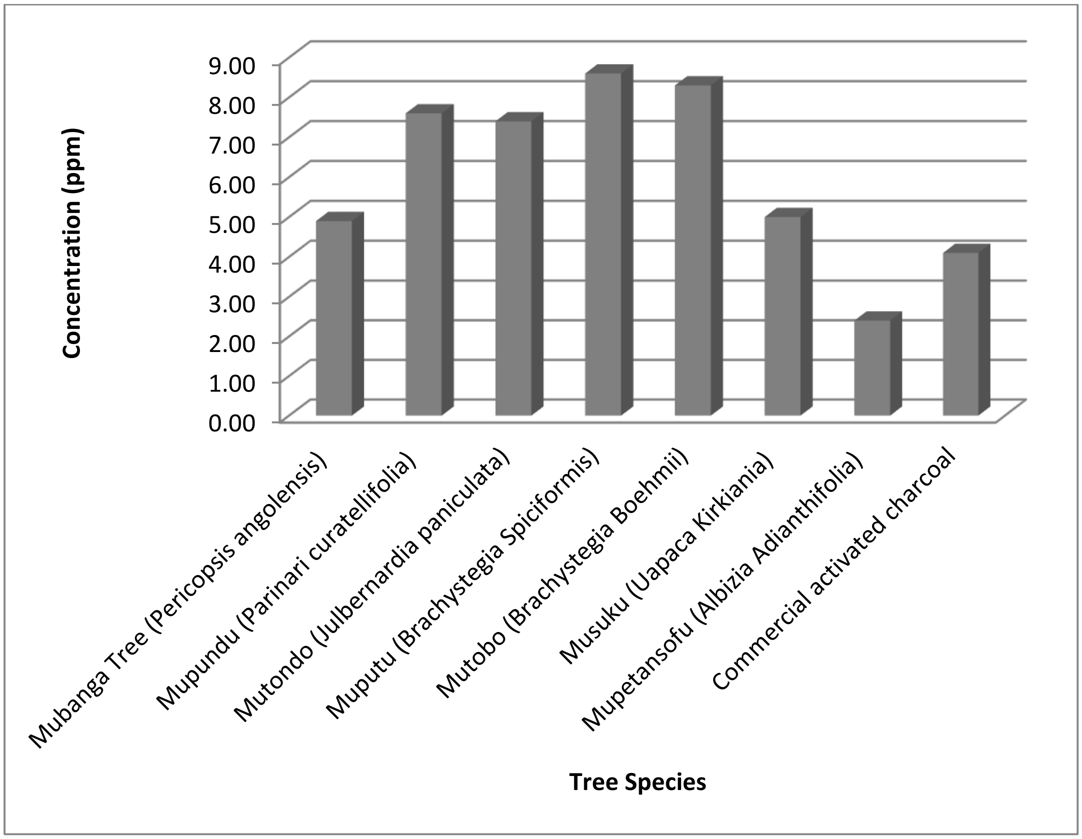

**Figure 52.** Heavy metal adsorption capability of various activated carbons

Figure 52 shows that Mupetansofu, despite having the highest iodine number, was the least effective in the ability to adsorb heavy metals. In one minute, Muputu was able to adsorb 8.60 ppm of $Mn^{2+}$ (out of the 10 ppm initially present in the solution) despite the presence of other competing ions. Its heavy metal adsorbing properties was higher than that of even commercially available AC (supplied by cica-reagent).

Figure 53 shows the $Mn^{2+}$ absorption ability per minute of 1 g commercial AC (1g) and 1g Albizia Adianthifolia on a solution containing 10 ppm of each of the following ions, $Cu^{2+}$, $Ni^{2+}$, $Fe^{3+}$ and $Mn^{2+}$, and another solution containing 10 ppm $Mn^{2+}$ as the only ion.

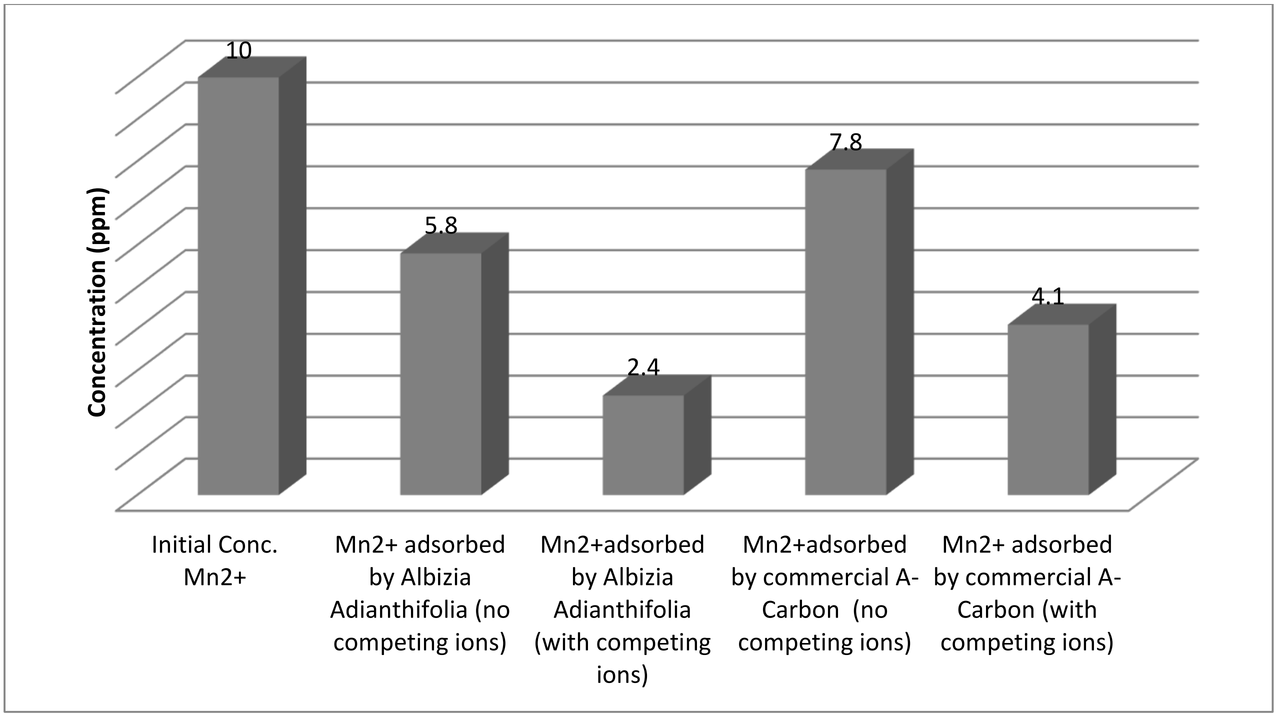

**Figure 53.** $Mn^{2+}$ adsorption ability per minute of activated carbons with and without competing ions

The effect of competing ions was investigated and it was found that the efficiency of the AC in reducing pollutants is drastically affected if there are other competing ions. The adsorption of Mn was hindered by the presence of the other metals. The metals apparently compete for adsorption sites. This also confirms results obtained by Netzer and Hughes (1984). The Mupetansofu AC was 58% efficient in removing Mn from contaminated water but this ability reduced drastically in the presence of competing ions to 24%. Commercial AC was 78% efficient in removing heavy metals, but in the presence of competing heavy metal ions, the efficiency reduced to 41%. The reduction in efficiency was more severe in the case of Mupetansofu AC compared to commercial AC. In all the experiments, despite having an initial concentration of 10 ppm of $Cu^{2+}$ before treatment, no $Cu^{2+}$ was detectable as revealed by the Digital Water Analyser (using pack test) whose detection limit was 0.1 ppm. The findings suggest that 10 ppm of $Cu^{2+}$ can be removed from contaminated water in one minute by just 1 gram of AC to below 0.1 ppm. However, $Mn^{2+}$ poses a big challenge as the amount of AC that was required to achieve the same results is higher. In another experiment to determine if AC can remove nitrates, it was found that if was, in fact, instead of removing nitrates (contamination of nitrates depends on how the AC was manufactured), it added to the contamination, and hence not a viable option for dealing with nitrate pollution.

### 8.4.5 $Mn^{2+}$ adsorbed by AC from a solution with competing ions

Experiment 5 was designed to check the adsorption power of commercial activated charcoal if the same solution is repeatedly filtered up to three times. Figure 54 shows that filtration thrice produced the best scenario with 7.4 ppm of the Mn adsorbed from the initial 10 ppm. This scenario can be explained from the relatively high time exposure needed for the solution to be exposed three times. However, this hypothesis is not explained by the second case where filtration twice produced a somewhat lower adsorption ability compared to the first case where 6.9 ppm of $Mn^{2+}$ was adsorbed.

Figure 54 shows the amount $Mn^{2+}$ adsorbed by AC from a solution containing $Mn^{2+}$, $Fe^{2+}$, $Cu^{2+}$, $Ni^{2+}$ (same solution was repeatedly filtered).

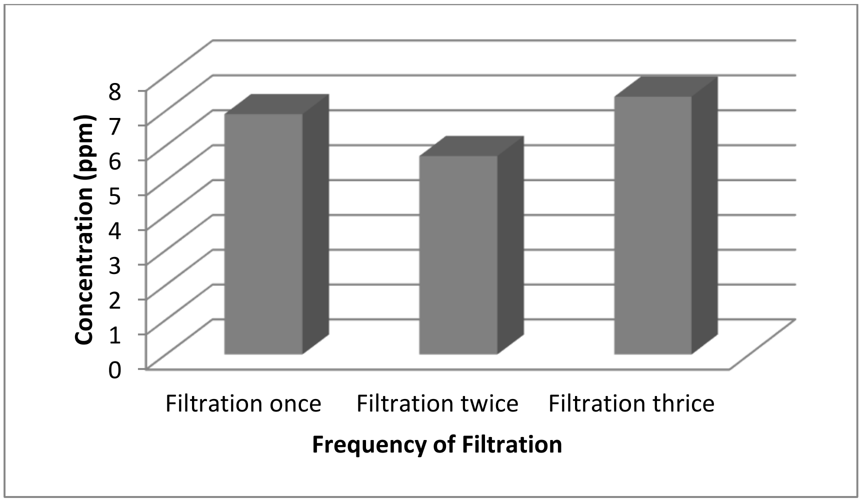

**Figure 54.** $Mn^{2+}$ adsorbed by activated charcoal from a solution containing $Mn^{2+}$, $Fe^{2+}$, $Cu^{2+}$, $Ni^{2+}$ following repeated filtration

The last part of the experiment involved determination of adsorption power of AC if the same carbon is repeatedly used to remove pollutants from successive water samples. The second part of the experiment, as shown in Figure 55, indicates that the AC is most effective when it is used for the first time. The subsequent use of the AC is less effective. As is the case with the first part of the experiment, the results were somewhat unpredictable as the filtration with two portions of the 20 ml contaminated solution produced a lower value as compared to three portions of the 20 ml portions. A linear relation was not supported in this experiment because there was no progressively reduction in adsorption ability with subsequent use of the charcoal.

Figure 55 shows the $Mn^{2+}$ Adsorbed by activated charcoal from a solution containing 10 ppm of $Mn^{2+}$, $Fe^{2+}$, $Cu^{2+}$, $Ni^{2+}$ (same Charcoal repeatedly used with different 20 ml aliquots of the solution).

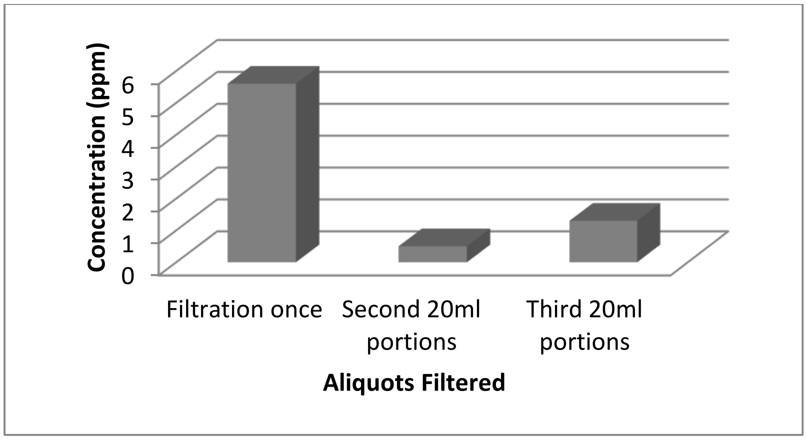

**Figure 55.** $Mn^{2+}$ adsorbed by activated carbon from a solution containing 10 ppm of various heavy metals (reusing of same activated carbon with new solutions)

### 8.5 Preparation and activation of carbon prepared from biomass waste and sucrose

In the Zambian approved grade 12 textbook (by Mukuma, Swazi & Chirwa, 1997, p. 98), concentrated $H_2SO_4$ is explained as having a high affinity for water. It is further revealed that:

> It will remove water from organic materials just as well as from chemical reactions. It is therefore a very dangerous substance because the burns which it causes are deep and slow to heal.
>
> The reaction between sulphuric acid and water is highly exothermic. The sulphuric acid molecules break up and the hydrogen ions that are formed bond with water molecules. Bond formation gives out energy. We can represent the reaction in the equation:
>
> $$H_2SO_4(l) + 2H_2O(l) \longrightarrow 2H_3O^+ + SO_4^{2-} \qquad (8.4)$$

The textbook does not give the useful applications of the reaction apart from alarming the pupils about its dangers. However, the dehydrating effect of $H_2SO_4$ as dangerous as it might be, can be safely utilised in EE lesson. The subsequent section discusses how the reaction can be put in the perspective of EE through a series of hands-on activities. The use of acid as a dehydrating agent has hitherto, not been demonstrated in EE lesson and how this property of acids can be utilised in the day to day activities of the pupils. The application is hereby explained in the proceeding section.

Ordinary household sugar (270g) was put in a glass beaker and 60 ml concentrated sulphuric acid (the sugar can be dampened with a small volume of water before adding the sulphuric acid but was not done in this activity). The sulphuric acid removes water from the sugar in a highly exothermic reaction, releasing heat, steam, and sulphur oxide fumes. The white sugar turned into a black carbonised tube that pushes itself out of the beaker. Sugar is a carbohydrate, so when the water is removed from the molecule, basically elemental carbon is left. The dehydration reaction is a type of elimination reaction.

$C_{12}H_{22}O_{11}$ (sugar) + $H_2SO_4$ (sulphuric acid) → 12C (carbon) + 11 $H_2O$ (water) + mixture water and acid (8.5)

Although the sugar is dehydrated, the water is not 'lost' in the reaction. Some of it remains as a liquid in the acid. Since the reaction is exothermic, much of the water is boiled off as steam.

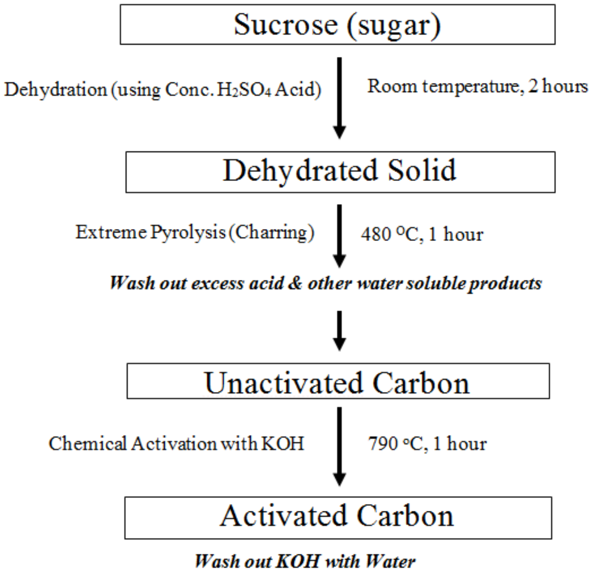

**Figure 56.** Preparation of activated carbon using $H_3PO_4$ and KOH

After soaking in $H_2SO_4$ acid, the resulting dehydrated carbon was pyrolysed at 480°C. Pyrolysing the hydrolytic solid left, primarily, only carbon. This product was washed to eliminate all the unreacted sucrose and excess acid. The resulting carbon after pyrolysing was heated with KOH at higher temperature (790$^{o}$C). In the high temperature activation process, KOH is believed to penetrate the carbon and exfoliate the carbon matrix into groupings of graphene layers.

**Table 42.** Common raw materials used for preparing activated carbon

| Precursor | Initial mass of waste biomass (g) | After oven drying (g) | Vol. of acid (ml) | Dehydration/Hydrolytic product (g) | Resulting mass (g) after treatment at 480$^{o}$C | Resulting mass (g) after KOH treatment at 790$^{o}$C |
|---|---|---|---|---|---|---|
| Corncob | 334.34 | 78.60 | 100.00 | 78.31 | 44.38 | 4.34 |
| Banana peels | 325.33 | 56.25 | 100.00 | 85.00 | 45.74 | 11.89 |
| Sugar | 270.00 | nd | 50.00 | 25.58* | 11.40 | 4.82 |

*only 25.58g was used out of the 294.71g lump of the dehydrated sugar

For the mass balance in this study, an activation temperature of 790°C and a KOH:C ratio of 3:1 was used, since carbons activated at these conditions have shown the most favourable characteristics for adsorption (Leimkuehler, 2010).

In general, the chemical reaction between KOH and carbon material can be written as follows:

$$4KOH + C \longrightarrow K_2CO_3 + K_2O + 2H_2 \quad (8.6)$$

Considering the decomposition of KOH into $K_2O$, as well as the reducing ability of carbon, Viswanathan, Indra Neel and Varadarajan (2009) suggest that additional reactions do take place during the process of activation as shown:

$$2KOH \longrightarrow K_2O + H_2O \quad (8.7)$$

$$C + H_2O\text{ (steam)} \longrightarrow H_2 + CO \quad (8.8)$$

$$CO + H_2O \longrightarrow H_2 + CO_2 \quad (8.9)$$

$$K_2O + CO_2 \longrightarrow K_2CO_3 \quad (8.10)$$

$$K_2O + H_2 \longrightarrow 2K + H_2O \quad (8.11)$$

$$K_2O + C \longrightarrow 2K + CO \quad (8.12)$$

$$K_2CO_3 + 2C \longrightarrow 2K + 3CO \quad (8.13)$$

After the activation process, the KOH was washed from the crevices creating spaces suitable for pollutant adsorption.

The study further found that biomass garbage can effectively be carbonised by a number of steps starting with $H_3PO_4$ acid, then followed by oven treatment at high temperature in order to activate the material. This was found to have a high potential of reducing surface and ground water pollution if the organic matter treated in this manner is utilised. In particular, heavy metals were treated as shown in Table 44. The principle of 3Rs was demonstrated in which case there was an added advantage that pollutants were treated from the resulting activated carbon prepared from biomass destined for the landfills. The effectiveness of KOH activation relative to either physical activation methods or activation by other chemical agents can be attributed to the ability of potassium to form intercalation compounds with carbon easily (ibid).

### 8.6 Pollutant reduction by precipitation of the metal hydroxide

The most common used method to remove soluble metal ions from solution is to precipitate the ion as a metal hydroxide. By raising the pH value of a solution with a common alkaline material such as lime, or sodium hydroxide, the corresponding metallic hydroxide compounds become insoluble and precipitate from solution. In the approved grade 12 chemistry textbook, it is explained that the hydroxides are soluble in water giving alkaline solutions. It is further explained that sodium and potassium hydroxides are very soluble; sodium hydroxide is used as a convenient source of hydroxide ions in solution. It is used to precipitate the hydroxides of other metals for the cations:

The idea is correct, but the equation presented is erroneous.

$$\underset{\text{Blue colour}}{Cu^{2+} + 2OH^{-}(aq)} \longrightarrow \underset{\text{blue-green colour}}{Cu(OH)_2(s)} \qquad (8.14)$$

The correct equation, according to Tanaka and Koga (1990), representing the precipitation product of $Cu^{2+}$ and a metal hydroxide is known to be:

$$4CuSO_4 + 6OH^{-}(aq) \longrightarrow Cu_4(OH)_6SO_4\,(s) + 3SO_4^{2-}(aq) \qquad (8.15)$$

The textbook can be revised by showing the importance of such reactions in EE lessons and particularly in heavy metal treatment. Apart from inclusion of the application part, the textbook can be corrected for equation misnomer.

In this study, manganese pollution was treated from contaminated water by utilising the precipitation reaction of hydroxide and a heavy metal. The concept used in this treatment method is well known in high school chemistry. Furthermore, using the concept of pH taught in chemistry, it was demonstrated that the increase in pH led to more precipitation of the Mn ions from a contaminated water sample (Table 43). The concept of pH is taught mainly by exposing the pupils to the phenomenon of changing colours of a universal indicator against changing acidity and alkalinity. Hardly is the pH concept connected to other useful applications, as in the case of the Zambian curriculum. This study demonstrated that with changing pH, it was possible to remove manganese from a water sample to undetectable levels.

**Table 43.** Removal of manganese from contaminated water

| | initial pH | final pH | initial conc. (ppm) | mMoles of $OH^-$ usedx10 | Mn removed (ppm) | final conc. (ppm) |
|---|---|---|---|---|---|---|
| Expt. 4 | 4.16 | 7.85 | 32.00 | 0.20 | 12.70 | 19.30 |
| Expt. 3 | 4.16 | 8.74 | 32.00 | 0.50 | 21.90 | 10.10 |
| Expt. 2 | 4.16 | 11.71 | 32.00 | 2.50 | 31.00 | 1.00 |
| Expt. 1 | 4.16 | 11.91 | 32.00 | 5.05 | 32.00 | nd |

nd, not detectable

Manganese contamination in the form of Hexaaquamanganese(II) ion - $[Mn(H_2O)_6]^{2+}$ was reacted with $OH^-$ to form the neutral precipitate $[Mn(H_2O)_4(OH)_2]$. The precipitate was further filtered out from the solution to obtain a water sample with negligible heavy metal pollution.

### 8.7 Preparation and activation of carbon prepared from biomass waste

The banana peels and corncobs were cut into small pieces. The samples were then dried in an oven at 100°C for 24 hours. The resulting products were milled into powder, weighed and put into beakers. To the milled substrates was added concentrated $H_3PO_4$ and the reaction left at room temperature for 24 hours. The hydrolytic products were weighed and put into high temperature crucibles and heated at 480°C for 1 hour to form the pyrolysed product. These products were washed in distilled water to eliminate excess acid still lurking in the pyrolysed products and other water soluble products in the carbon. The washed product was dried, weighed and mixed with KOH in the ratio of 3:1 (OH: C). Both samples were activated by the same method as shown in Figure 57 and Table 42. The resulting carbon after pyrolysing was heated with KOH at 790°C. In the high temperature activation process, KOH is believed to penetrate the carbon and exfoliate the carbon matrix into groupings of graphene layers. Graphene is the two-dimensional building block for carbon allotropes of every other dimensionality (Ferrari et al., 2006). The activated carbon prepared in this manner proved to be effective in water treatment of manganese and copper contamination as shown in Table 44. This activity has an added advantage in that the concept of allotropes is also demonstrated.

The science curriculum requires the pupils to understand that carbon has several allotropes such as graphite, diamond and amorphous carbon among others. The curriculum does not, however, require the pupils to prepare carbon and subsequently use it for water treatment. It was desired in this study to use this concept to demonstrate the interconnectedness of science and how useful allotropes of carbon can be wisely used in EE lessons. In the uses of carbon, as explained in the approved grade 12 chemistry textbook (Mukuma, Swazi & Chirwa, 1997), no application of carbon in water pollution treatment is alluded to. The following account is given (p.103):

> Carbon is the form of charcoal (charred wood or bone) has been known since the earliest times. Crystalline carbon (diamond) has been highly prized as a gemstone for thousands of year. A pair of diamond earrings was sold in 1980 for more than US$6 million! Graphite the most stable allotrope of carbon crystallizes in grey shiny plates. Small amounts are found naturally but most is made by heating coke and sand at about 2000°C in an electric furnace for 24 hours.

Further, the textbook lists fuel, as lubricant (graphite) cutting wheels (diamond), gemstones (diamond) as some of the uses of the allotropes of carbon. This study, however, successfully managed to go beyond just listing the uses and explaining the history of carbon, but highlighted the various methods and precursors that can be used to prepare it and many of the applications in EE lessons.

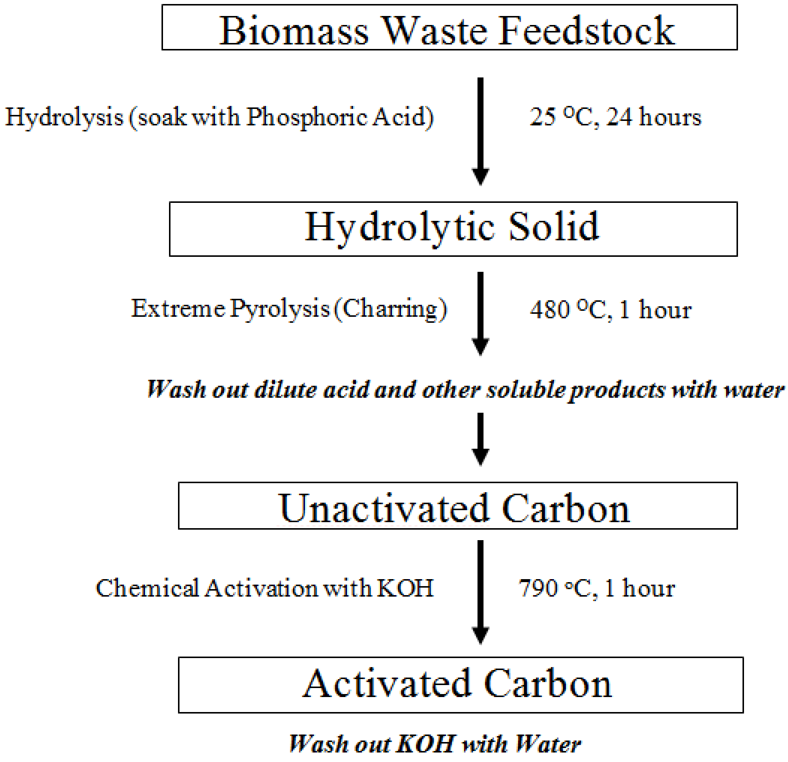

**Figure 57.** Activation of the waste biomass material
Source: Modified from Leimkuehler (2010)

**Table 44.** Adsorption efficiency of Mn and Cu metals by various activated carbons and hydrotalcite

| No. | Treatment Method | Heavy Metal | Initial Conc. (ppm) | Final Conc. (ppm) | Absorption Efficiency (%) |
|---|---|---|---|---|---|
| 1 | Banana | Mn | 10.40 | < 0.60 | 100 |
| | | Cu | 10.00 | 0.51 | 94 |
| 2 | Corncob | Mn | 10.00 | 1.10 | 89 |
| | | Cu | 10.00 | nd | |
| 3 | Hydrotalcite | Mn | 10.40 | 1.70 | 84 |
| | | Cu | 10.00 | 0.30 | 97 |
| 4 | Sugar | Mn | 10.40 | < 0.60 | 100 |
| | | Cu | 10.00 | 0.48 | 95 |

Apart from the use of carbon as a pollutant treatment method, Table 44 clearly shows that the hydrotalcite is comparable to the treatment efficiency obtained by other ACs hence an addition option when it comes to pollution treatment in water. The concept of ion exchange is reemphasised here in this section and also helps in reducing the layered-cake type of science curriculum obtaining in Zambia. Analysis of the authorised Zambian textbook suggested that knowledge is compartmentalised. The process by which heavy metals are removed in this procedure is similar to the ion exchange processes that are taught in high school biology. Hence this is a demonstration that science can be considered as one whole rather than separate forms of discipline. The concepts taught in chemistry should be applicable in biology, mathematics or physics and vice versa.

When learners act with the benefits of an ever-evolving elastic sense of purpose as to why they are doing a class investigation, they begin to discern the whole of the water problem than simply the garbage or sanitation issues. Figure 58 gives summary of the advantages of recycling of the waste biomass (lignocellulose biomass material). The water problem starts with dumping of garbage into the landfills, open dumps and waterways, consequently the quality of the environment is heavily compromised and the heaviest impact takes place in the water. Water is usually the conveyer of most pollutants, soluble and insoluble. However, at high school, it is possible to determine both qualitatively and quantitatively, fairly accurate as shown in chapter 7, the amount of pollutions in the water. Armed with this information, pupils can then decide what action to take in order to treat the water pollutants. Some of the options at their disposal include preparing AC from the same waste, preparing AC from charcoal and utilising precipitation reaction of metals using $OH^-$ and better still, lifestyle change to completely eliminate the sources of pollution. It is also correct to argue, as shown by DeVito (1976, p.165), that “examining what we throw out as we clear the household of daily trash can furnish a steady supply of science equipment – all free and expendable.” Figure 58 also demonstrates how learning (science activities) about pollution and pollution treatment is a product or consequence of many interrelationships.

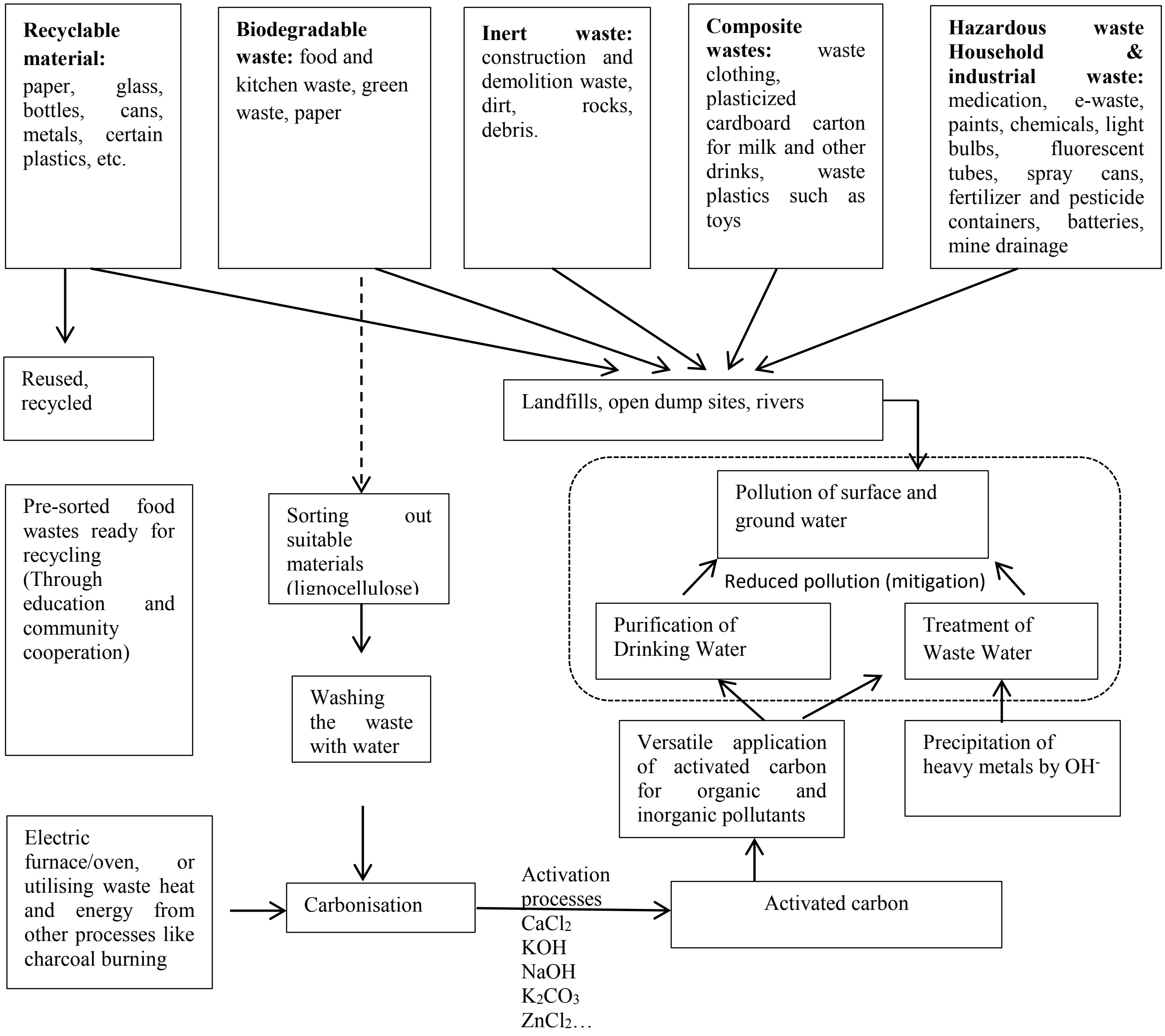

**Figure 58.** Relationship between waste, contamination of water and treatment route

### 8.8 Major findings

In natural water samples, it is not possible to determine how much of the pollutants will be removed by a given brand of AC and so a challenge is in designing a one-size-fit-all filter. But if the extent of pollution is known, it is possible to estimate the amount and type of carbon to use. The ability of various AC, is different, in dealing with different types of pollutants as revealed by the inconsistencies in the iodine numbers and the ability to handle heavy metal pollution. Not only is the ability to deal with inorganic and organic compounds different, but even the ability to deal with the same pollutant is different under different conditions. The ability to deal with the same heavy metal parameter by the same brand of AC under different conditions was found to be significantly different. The study found that $Cu^{2+}$ is readily removed by all the brands of the AC considered in this study and that Mn is more challenging to treat and best dealt with by Muputu AC. Because of lack of prior knowledge of contaminants present in a natural water sample, it is difficult to calculate the amount of AC needed to deal with the contamination and almost impossible to predict when saturation is reached hence rendering the AC ineffective. However, as a general guide, it was found that for a 20 ml solution contaminated with 20 ppm of $Cu^{2+}$, the best ratio of mass (in grams) to volume (in ml) needed for effective separation was found to be 1:20. The mass of 1g was capable of reducing contamination of 20 ppm of $Cu^{2+}$ to below 1 ppm which is considered the maximum contamination level in drinking water. A 1 ppm $Cu^{2+}$ contamination in drinking water is considered as the maximum contamination level by Zambia Bureau of standards and Japan water standards. The method by which the charcoal was prepared and nature of the charcoal has an effect as revealed by the differences in the iodine numbers AC.

The study further demonstrated that it is better to prevent waste than to treat or clean up waste after it is formed. One method of reducing disposable waste was demonstrated whereby waste biomass materials where converted to AC. But if the waste was disposed of in a landfill, it would contaminate ground water sources with both inorganic and organic waste (as shown in chapter 4) and increase cost of water treatment. It is better to prevent waste than to treat or clean up waste after it has formed and accumulated.

The synthetic methodologies were designed to use and generate substances that possess little or no toxicity to human health and the environment. Other carbon activation methods chosen in this study such as the $CaCl_2$ method of activation was intended to be as environmentally friendly as possible since the processing method was conducted at ambient temperature and pressure.

For most of the treatment methods suggested in this study, the raw material or feedstock were renewable resources such as corn cob, banana peels, a polysaccharide (sugar) and various other lignocellulose waste biomass materials and from wood. Furthermore, the chemical products at the end of their function do not persist in the environment and can be reused after treatment and do not in any way break down into innocuous degradation products. All the products (Banana, Corncob, Hydrotalcite, and Sugar) tried in this study proved to be effective in pollutant treatment, because more than 80% of the pollutants where removed from contaminated water. The synthesis processes use widely known chemistry and hence easy to apply in high schools without the need for addition concepts or major revising of the curriculum; it builds on what the students already know.

# Chapter 9

## 9. Environmental educational modules

### 9.1 Interconnectedness and interdependence of science Concepts, Guided and open-ended Inquiry

The module is intended to show the interconnectedness and interdependence of science concepts. The activities introduced herein include, electrical resistance in relation to photoresistors, light emitting diodes (which in most cases have not been applied for useful activities in science lessons but familiar to students as illuminations for Christmas and events of a like nature), principle of radiation absorbance in relation to coloured solutions, further understanding of the nature of light (as taught in ninth grade environmental science) (Horscroft, 2003), ion selectivity of certain reactions, and how all these concepts can be assembled to come up with activities for detection and investigation of pollutants in EE lessons. The module activities reveals that items found in the environment can be explored culminating into insight to guide students to answer questions about water quality parameters of interest to them or their school and community.

The practical exercises integrate many concepts, into the module, to the success of student learning. These exercises promote learning by incorporating kinaesthetic and visual learning activities, as well as sense-making activities, into the learning environment. The module activities are designed to promote critical thinking skills. Students use prior knowledge as they plan and later predict possible outcomes of an experiment. They increase their observation skills and they are asked to record their observations. Students are encouraged to incorporate the new information so that they can use it in a variety of real-life situations. The exercises can be separated into two main categories, guided or structured inquiry exercises, sometimes called "guided discovery labs", and open-ended inquiry exercises. For the open ended, they are to decide on what materials to use for fabrication of the colorimeter depending on what material is at their disposal. In addition, they can decide on which chemical combination to use for the colorimetric experiment depending on cost, and other factors such as toxicity.

#### 9.1.1 Guided Inquiry

Guided Inquiry is a means by which student enquiry can be facilitated in schools, while simultaneously being the vehicle for evidence based practice (FitzGerald, 2011). In guided inquiry, students begin by observing something interesting or generating some data. Power (2012, p. 1) notes that:

> Allowing students greater input into the selection of topic or focus of the activity may encourage students to engage more deeply with the learning task. Students are likely to

> experience greater learning benefit from access to developmentally appropriate resources, increased time to explore topics and multiple opportunities to undertake information searches throughout the learning activity. Finally, increasing the cognitive challenge can enhance both the depth of students' learning and their information literacy skills.

With some help from guiding questions, they must then 'discover' the relation between light intensity and resistance of a photoresistor and the physical principles behind their observations. In these guided inquiries, the instructor often has a very specific outcome in mind. The outcome expected is that, the higher the light intensity reaching the photoresistor, the lower the resistance.

#### 9.1.2 Open-ended Inquiries

The open-ended inquiry is another powerful way to assess student's scientific understanding of the natural world. Open-ended questions provide a means for students to inquire, to apply scientific ideas to solve a problem, and to communicate effectively (Hassard, 2000). When a teaching method is described as inquiry-based learning, it typically involves active learning in the setting of an open-ended investigation inspired by a specific question, problem, or project (Schmidt-Jones, 2013). In open-ended inquiries, the process of doing inquiry into the state of the water is emphasised. Students may begin by proposing a question they would like to investigate, designing experiments, collecting data, analysing the data, and defending their results. In these open-ended inquiries, the instructor does not necessarily have a specific outcome in mind (for example the types and levels of pollution in a given water sample, but rather sets up a situation where students can be creative while learning science, and develop their skills at experimental design and data analysis.

### 9.2 Activity 1: Turning household trash into an educational resource: preparation of activated carbon for pollutant treatment and testing its efficiency on effluent water

#### 9.2.1 Background

Water is essential to all living organisms. However, water resources are becoming increasingly polluted around Zambia due to increased mining and the rapidly booming population which has not matched with the social infrastructure like garbage collection and piped sewer systems and effluents from agricultural areas such as the Nakambala Sugar Estate (Chabwela, 1998).

The water pollution problem gets complicated as water is no longer contaminated only by soil, dirt and floating debris, but also heavy metal ions, pesticides, fertilizers, industrial wastes, domestic sewage, microorganisms, and other organic and inorganic compounds. This situation greatly threatens water quality around the country; it also threatens our well-being.

### 9.2.2 Transforming Waste into a Water Purification Agent

Production of activated carbon (AC) from waste materials commonly found in Zambia like corncob, banana peel and other biomass materials have not yet been explored. The inedible hard shells, stems or other parts which probably have high carbon content make some biomass material suitable candidates for being the raw materials for producing AC.

Food wastes such as fruit residues and nut shells can be cleaned, carbonised and transformed into activated carbon. This can reduce the amount of food wastes ending up in landfills, thus reducing the wastage of land and contamination of ground and surface water resources. As useful AC is produced from waste, economic benefits are brought about by transforming valueless waste into a beneficial commodity.

More importantly, the AC produced from food wastes can be used in water purification (as explored in chapter 8). This can reduce water pollution around the country. Since the AC is produced from food wastes, it is not necessary to obtain raw materials such as wood. Using wood encourages deforestation and using coal to manufacture activated carbon is equally not sustainable because it is a non-renewable energy source. Thus, by utilizing food wastes and minimizing the need for using up valuable natural resources such as wood, the AC is more environmentally friendly, and its ecological footprint emanating from the manufacturing process is reduced.

If food waste could be transformed into useful substances, for example, AC, it would reduce the need for schools to buy educational materials from established manufacturers and suppliers. The carbon prepared by the pupils can be used in measuring water treatment efficiency.

The activities in the subsequent sections will focus on manganese decontamination in water; and the oxidative reaction of potassium periodate on manganese to produce a purple colour. Through a visual observation of the colour change of some standard solutions and the effluent water, before and after treatment using the prepared AC, the pupils will make informed conclusion about the best activation method, the nature of the carbon, and generally its usefulness in heavy metal treatment.

### 9.2.3 Theory

Activated carbon is a crude form of graphite with an amorphous structure which is highly porous over a broad range of pore sizes. Activated carbon is made from substances with high carbon content like coal, wood and nutshells through the processes of carbonization and activation.

Carbonization is a process in which the carbonaceous materials are decomposed by heat so as to turn the organic substances into carbon and remove any non-carbonaceous materials. The residue will then have higher carbon content. Activation occurs immediately after carbonization; it is a process to remove those hydrocarbons which may block the pores of charcoal (see Chapter 8 for more details).

### 9.2.4 Prerequisites

Students should have basic knowledge of science covered from grades 9 – 11 and part of grade 12. The pupils should have learned the topic on carbon and carbonates. Students must also have basic measuring, pouring, reading volumetric apparatuses (pipettes, measuring cylinders etc.) and stirring skills. They should know how to work with beakers, graduated cylinders, and filters. The skill on preparation of solutions and conducting accurate dilutions is essential. The topic on volumetric analysis is essential to successfully carry out all the instructions.

### 9.2.5 Lesson objectives

Through this investigation, the pupils will transform corncob, banana peels, coconut shells waste or any lignocellulose material which is common in their location or school in which the lesson is to be conducted and to ascertain which AC is capable of reducing pollutants to safe levels:

1. Students will recognize that waste or trash as a raw material for other processes, examples would include, compositing, reusing some of it and burning the biomass for energy purpose and converting to AC.
2. Students will categorise trash into waste biomass (convertible into carbon) and non-biomass waste.
3. Students will conclude that biomass material, by hydrolysis and pyrolysis, can be converted to carbon.
4. Students will relate that the prepared charcoal is one of the allotropes of carbon which include diamond, graphite, graphene and amorphous carbon.
5. Students will relate that as sulphuric acid has a high affinity for water and so is phosphoric acid used for this lesson to hydrolyse the carbohydrate components in the biomass into water soluble components and isolating the water insoluble carbon containing components.

6. Students will justify the concept that acids hydrolyses lignocellulosic biomass material as they will observe the hydrolysis effects of phosphoric acid on the corncob or any lignocellulose waste product to be used in their experiments.
7. Students will test the effectiveness of the prepared AC.
8. Students will prescribe the use of the AC for water treatment (from household taps, river, ground and effluent water in their school and residential areas or any location of interest.
9. Students will calculate the needed volumes for preparation of the serial dilutions.
10. Students will determine the most appropriate activation method of carbon for water treatment.
11. Students will determine, using a colour chart, the concentration of the pollutants before and after treatment.
12. Students will learn to apply the reduce-reuse-recycle approach to real-life situations in their environment and determine how their lives are part of the pollution problem.

**Table 45.** Taxonomy table on preparation of activated carbon for pollutant treatment

| **The knowledge dimension** | **The cognitive process dimension** | | | | | |
|---|---|---|---|---|---|---|
| | **1.Remember** | **2. Understand** | **2. Apply** | **4. Analyse** | **5. Evaluate** | **6. Create** |
| A. Factual Knowledge | Objective 1 | | | | | Objective 2 |
| B. Conceptual Knowledge | | | | Objective 4<br>Objective 5 | Objective 6 | Objective 8 |
| C. Procedural Knowledge | | | | Objective 9 | Objective 3<br>Objective 7<br>Objective 10<br>Objective 11 | |
| D. Meta-cognitive knowledge | | | Objective 12 | | | |

The taxonomy table is based on the work done by Anderson et al. (2001)

### 9.2.6 Materials

Chemicals and apparatus and requisites for this activity include: food waste; spatulas; potassium hydroxide; phosphoric acid; electronic balance or a sensitive beam balance; crucibles; deionised water; electric oven or traditional brick ovens; electric kiln.

### 9.2.7 Procedure A: preparation of activated carbon from trash

1. Cut the banana peels and corncobs into small pieces obtained from a pile of garbage or biomass materials sorted out before they are discarded on a dumpsite.

**Figure 59.** Garbage situation in Lusaka
Source: "Photo of the day" (2013)

2. Weigh each sample and put into different crucibles.
3. Dry the samples in an oven at 80°C to a constant weight (air drying without an oven is possible but it will take longer).
4. Mill the resulting products into powder, weigh and put into beakers.

**Table 46.** Data recording format

| Precursor | Initial mass of waste biomass (g) | Mass after oven drying (g) | Vol. of acid (ml) | Dehydration/Hydrolytic product (g) | Resulting mass (g) after treatment at 480°C | Resulting mass (g) after KOH treatment at 790°C |
|---|---|---|---|---|---|---|
| Corncob | | | | | | |
| Banana peels | | | | | | |
| Coconut shell | | | | | | |

5. To the milled substrates, add concentrated $H_3PO_4$ and leave the reaction at room temperature for 24 hours.
6. After 24 hours, weigh the hydrolytic products and put them in high temperature crucibles and heat at 480°C for 1 hour to generate the pyrolysed product.
7. Wash the products with distilled water to eliminate excess acid still lurking in the pyrolysed products and other water soluble products in the carbon. Weigh the product once again.
8. Dry the washed product in an oven to a constant weight (sun drying is possible but takes longer), weigh the dried product and mix with KOH in the ratio of 3:1 (OH: C).

9. Heat the resulting pyrolysed carbon with KOH at 790ºC. In the high temperature activation process, KOH is believed to penetrate the carbon and exfoliate the carbon matrix into groupings of graphene layers.
10. Wash the resulting product with excess distilled water to remove KOH and any other soluble product still embedded in the AC.
11. Dry the product, crush and filter it to a consistent size using a mesh with the smallest hole diameter possible. Store it in a zip lock bag until you are ready to use it for water treatment.

### 9.2.8 Preparation of activated carbon from charcoal

Chemicals, apparatus and other requisites for this activity include: charcoal; spatulas; electronic balance or beam balance; 25% calcium chloride; crucibles; deionised water/distilled water; oven; electric kiln and; beakers.

### 9.2.9 Procedure B

1. Find any locally available charcoal prepared from any tree species.
2. Pulverise it in a ceramic mortar and pestle or using the traditional wooden mortar and pestle.


(a) (b)

**Figure 60.** Mortar and pestle that may be used to grind the charcoal (a) and (b)

3. Use a home kitchen wire mesh sieve to filter the charcoal to a consistent size, use a sieve with smallest hole diameter as possible; mesh diameter of 0.5 mm or smaller would be ideal.

**Figure 61.** Kitchen sieve for filtering the activated carbon to a consistent size

4. Add 25% calcium chloride solution to the filtered charcoal and let the material soak overnight.
5. Dry the resultant AC and wash with deionized water or distilled water and oven dry at 110$^{o}$C.
6. Pound the charcoal to loosen it and filter once more. Store the AC in a zip lock bag for the next experiment.

### 9.2.10 Assessment

Student will be assessed for the ability to relate the pulverising of charcoal to the topic on rates of reactions which includes ideas such as “the smaller the particles the greater the surface area for the reaction to take place”. Therefore, the smaller the particle sizes the higher is the ability of carbon to remove impurities.

The assessment of the lesson is judged by the pupils’ ability to point out the extent to which the 3Rs (reduce, recycle and reuse) have been demonstrated. The pupils should recognise the merits and demerits of using the waste products for AC preparation. They should discuss the merits and demerits of using wood charcoal for preparation of AC.

**Reduce:** Reduce can mean using fewer resources in the first place. This is the most effective of the three R's and the place to begin. This activity uses biomass as the starting material. Biomass material is usually destined for the landfills increasing the volume of the trash. If the garbage is utilised for the conversion to a useful product, AC, pupils will pinpoint that a small amount of AC has resulted from a relatively large volume of biomass trash. The student should be able to recognise that effective recycling of trash means that little of the waste will be taken to the landfill. The pupils will calculate the exact yield based on the data collected in Table 46. Furthermore, the pupils will be able to relate that reducing consumption of certain goods will reduce the amount of garbage generated. Pupils should be able to connect that when they shop, they should shop differently; look for things that will last, things that are not just durable and well-made, but useful and desirable enough to please them for a long time. The extra money they spend on buying durable items will be offset by the money they do not spend replacing them (Eisenberg, 2008). The pupils will further compare the starting mass of the biomass and the resulting mass of carbon. Thereafter, they will observe and take note of the big reduction both in mass and volume, of the amount of initial biomass used in this activity.

**Reuse:** Pupils will discuss other options related to use of biomass garbage. Before they dispose of anything, they should consider whether it has life left in it. A jam jar can store screws or pins for charts, food scraps can become compost. Used envelope(s) can become a shopping list. A magazine can be shared (ibid). However, for this lesson, pupils should discuss how waste biomass was used for the purpose of treating contaminated water and how the same AC can be reused several times by removing pollutants. Boiling of the used AC can remove the pollutants, hence can be reused over and over again.

Reusing keeps new resources from being used for a longer period, and old resources from entering the waste stream.

**Recycle**: Recycling is the "R" that is frequently mentioned. Currently in Zambia, there are few recycling programs or well developed programs (recycling of base metals is common). Recycle - discards can be separated into materials that may be incorporated into new products, that is, into high-value products or into low-value raw materials. This is different from Reuse in that energy is used to change the physical properties of the material. Pupils should criticise this lesson in this regard because large amounts energy is used in the process of carbonising the biomass materials. Pupils can suggest compositing as a better way of recycling biomass material. But if the objective is to decontaminate water, then there is little option but to recycle the biomass to AC.

Pupils will discuss what the Zambian household waste is usually made up of. Most pupils will agree that apart from biomass related waste, there is a lot of plastic packaging made from an assortment of organic monomers. There are no restrictive measures on how to discard these products.

**Table 47.** Plastic materials commonly discarded with household waste in Zambia

| **PETE** | **HDPE** | **V** | **LDPE** | **PP** | **PS** | **OTHER** |
|---|---|---|---|---|---|---|
| **Polyethylene Terephthalate** | **High Density Polyethylene** | **Vinyl** | **Low Density Polyethylene** | **Polypropylene** | **Polystyrene** | **Other** |
| soda bottles | milk, water and juice jugs | clear food packaging | bread bags | ketchup bottles | meat trays | ketchup |
| water bottles | detergent bottles | Shampoo bottles | frozen food bags | yogurt and margarine tubs | egg cartoons | 10 and 20 litre containers |
| shampoo, mouthwash bottles | yogurt and margarine tubs |  | squeezable bottles (mustard, honey) |  | cups and plastics | Some juice bottles |
| peanut butter jars | grocery bags |  |  |  |  |  |

The pupils will discuss the impact on ground water resources in their locality if garbage is left unchecked, that is, not prevented, not reused, not recycled and not reduced in volume.

Decomposition or putrefaction of solid waste can pollute groundwater through percolation of the landfill leachate primarily as a result of rain. Leachate, the liquid formed by the percolation of rainwater through the refuse can be a source of pollution even for surface water.

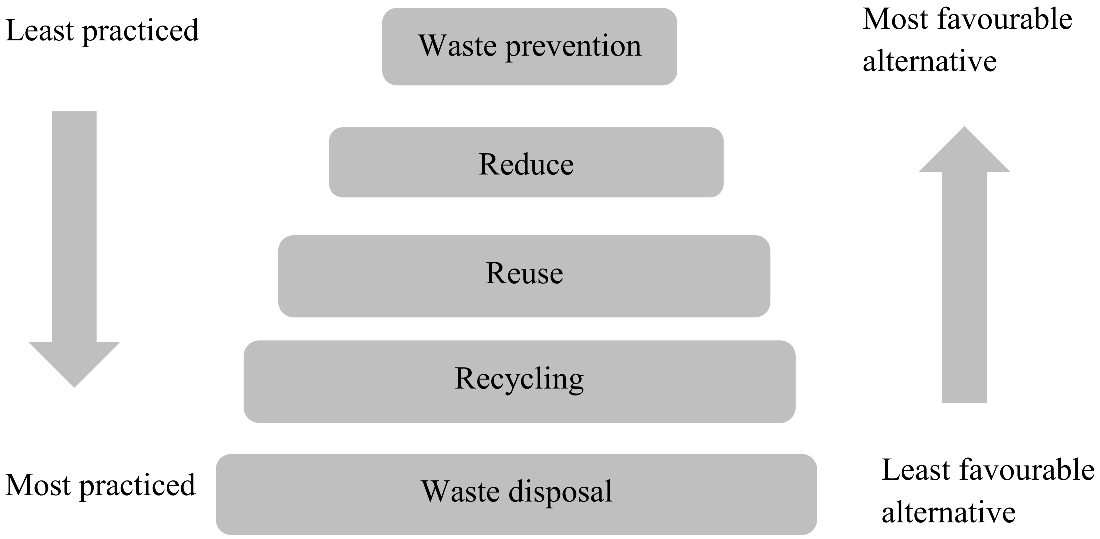

**Figure 62.** Waste hierarchy

Pupils will recall that most landfilling operations in their residential area and municipal/city council typically do not include facilities designed to collect and contain leachate on-site. Migration of leachate has the potential to degrade groundwater and surface water quality far away from the source of the contamination.

Pupils will list and classify the sources of the water they drink and pollution hazards likely to affect it.

The groundwater and surface water monitoring programs in EE should address these areas to ensure that water quality is not adversely affected by landfilling operations.

After discussing the reduce-reuse-recycle concept, pupils will classify the waste hierarchy in terms of most favourable alternative and least favourable alternative; most practiced and least practiced (Figure 62).

Pupils will discuss the best and most feasible alternative for their school and community for the various waste products. The categories include recyclable and non-recyclable; Biomass and non-biomass materials.

One of the disadvantages of carbonising is that it requires a lot of energy for the conversion process from lignocellulose biomass to carbon, pupils can discuss if the demerits overrides the merits of activating carbon. Some of the points of discussion that the pupils can focus on are the vast uses of AC shown in Table 48. The discussion is meant to induce critical thinking about the relevance of performing this taxing and time consuming experiment.

Table 48. Some of the practical uses of activated carbon

| **States** | **Purpose** | **Applications** | **Examples** |
|---|---|---|---|
| **Gas Phase** | **Recovery** | **Gasoline Vapour Recovery** | **Gasoline Fuel recovery** |
| | | Solvent Recovery | Methyl Ethyl Ketone, Cyclohexanone, $CS_2$, Furan, Trichloroethane |
| | Odour Removal | Room Order Removal | Tobacco, CO, Room filters, Toilet Odour, Pet Odour |
| | | Refrigerator | Deodorizer |
| | | Automobile | Cabin Air Filters |
| | | Tobacco | Cigarette Filter |
| | | Hospital | Aesthetic Gas Removal |
| | | Ozone Removal | Copiers, Laser Printers |
| | Harmful Gas | Closed Environment | Dioxin removal, Space Ships, Underground $CO_2$ |
| | Gas Separation | Nitrogen, Pressure Swing Adsorption (PSA) | Nitrogen Gas Separation |
| | | Other PSA | Radio Active Gas |
| **Liquid Phase** | Water Treatment | Factory Waste Water | Cleaning Waste Water |
| | | Drinking Water Treatment | Trihalomethane, Chlorine, VOCs, Heavy Metals, Arsenate Removal |
| | Decolourization of Industrial Chemicals | Industrial Use | Sugar refinement, Pharmaceutical use, Whisky Distilment |
| | Medical Applications | Medical and Nursing | Kidney Machine, Nursing supplies, Respirators |
| | Mineral Recovery | Gold Recovery | Gold Recovery |
| | | | |

Source: modified from Kuraray Chemical Co., LTD. (2004)

### 9.2.11 Evaluation of quality of the activated carbon produced by the analysis of its manganese adsorption capability

The materials needed in order to choose the most efficacious AC include: beakers; conical flask; rubber stopper; pipette; measuring cylinder; universal indicator (pH meter if available); electronic balance or beam balance; stirring rods; distilled water; filter paper; funnel; reagent bottles; volumetric flasks × 6 and; potassium periodate (or any compound which selectively reacts with $Mn^{2+}$).

### 9.2.12 Procedure C: Determining concentration of $Mn^{2+}$ in a contaminated solution using a colour chart

1. Prepare solutions of known concentrations to be used to create a standard colour chart for subsequent comparison. As a starting point, you can prepare 100 ml of a 500 ppm standard solution of $Mn^{2+}$.
2. From the standard solution, prepare serial dilutions (0.5 ppm, 1 ppm, 2 ppm, 4 ppm, 8 ppm and 16 ppm). From the diluted solutions, take 10 ml aliquots and transfer them into test tubes labelled with the concentrations of the diluted solutions and to each solution add about 0.05 g of potassium periodate and about 0.05 g of citrate phosphate buffer. The developed colour should appear as in Figure 63.
3. Transfer 10 ml of the contaminated solution (effluent water) into a test tube and add a pinch (about 0.05g) of potassium periodate (the contaminated solution is shown in Figure 63.
4. Estimate the concentration of the effluent water by colour comparison against the standard chart.
5. To separate conical flasks, add 1 g of each of the following: AC prepared from charcoal and sieved using a kitchen mesh (AC 1); un-activated carbon prepared from charcoal and sieved using a kitchen mesh (AC 2); activated carbon prepared from charcoal and sieved using a 20µm filter (AC 3) and the activated carbon (AC 4) prepared using biomass KOH.
    (a) A 50 ml sample of effluent water treated with 1 g of carbon (AC 4) prepared from banana peels (KOH activation).
    (b) A 50 ml sample of effluent water treated with 1 g of Albizia Adianthifolia ($CaCl_2$ activation) sieved with a household kitchen mesh (AC 1).
    (c) A 50 ml sample of effluent water treated with 1 g of Albizia Adianthifolia (un-activated carbon) sieved with a household kitchen mesh (AC 2).
    (d) A 50 ml sample of effluent water treated with 1 g of Albizia Adianthifolia ($CaCl_2$ activation) sieved using 2.0µm mesh (AC 3).
    (e) Effluent water, colour developed by using potassium periodate without trisodium citrate dihydrate buffer (pH 7.8 – 9.0). The content of test tube (e) shows that colour development is

negatively affected if the buffer is not added prior to the addition of potassium periodate; it is always important to add the buffer reagent.

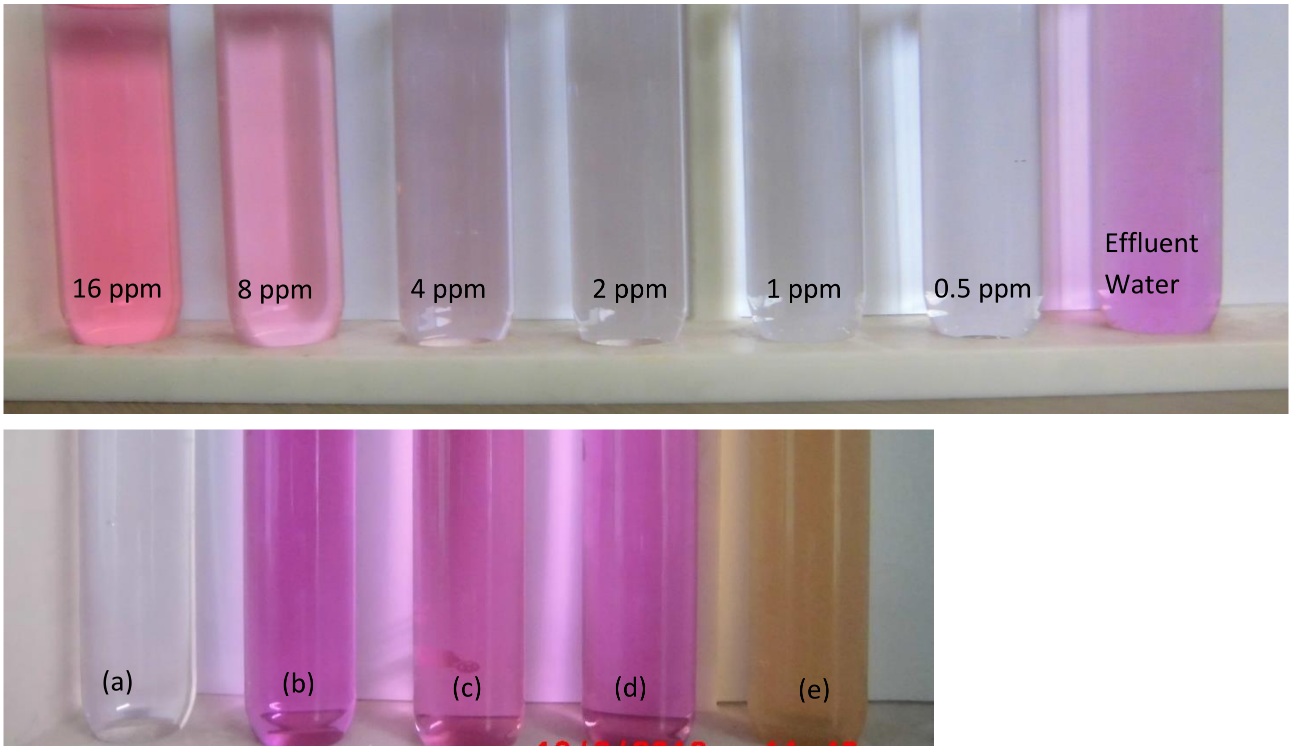

**Figure 63.** Colours of the standard solutions and analyte water samples

6. To the four conical flasks containing AC 1, AC 2, AC 3 and AC 4 add 50 ml of the contaminated water to each flask and swirl the flask for one minute and filter the solution to remove the carbon.
7. Get 10 ml of the filtrates from each conical flask and transfer the solution to a test tube and add about 0.05 g of potassium periodate and about 0.05 g of citrate phosphate buffer. Using the colours of the standard solution, approximate the concentration of the effluent water before and after the carbon treatment.
8. Determine which AC is more efficient.
9. Which one would you recommend for treatment of the contaminated water in your community?
10. Using the colour chart you have developed, determine the levels of manganese from portable and river/stream water in your community (as many samples as time can allow).
11. What are the limitations of this method of detecting levels of pollution by using a colour chart and/or visual comparison of the colours?
12. How can we improve the procedure?

### 9.2.13 Method of assessment

The student will be judged according to the ability to make rational conclusion about the efficiencies of the AC which they prepared. They should make a conclusion about the ability of AC to treat manganese and other metal contaminants. The pupils should be able to criticize the methods of treating water by chlorination, boiling, ozone and filter paper filtration because these methods do not remove heavy metal pollution and other dissolved pollutants.

### 9.2.14 Remarks

Determining the levels of pollutants by a colour chart is inaccurate hence the need to improve the technique by use of a colorimeter.

Colorimetric analysis is a method of determining the concentration of a chemical element or chemical compound in a solution with the aid of a colour reagent. It is applicable to both organic compounds and inorganic compounds and may be used with or without an enzymatic stage. It has wide application and can move this lesson from approximating the concentration of the ions in a solution to determining, fairly accurate, the actual concentration.

The idea of colorimetric works as follows: suppose you look at two solutions of the same substance, one a deeper colour than the other. Your common sense tells you that the darker coloured one is the more concentrated. In other words, as the colour of the solution deepens, you infer that its concentration also increases. This is an underlying principle of colorimetric technique: the intensity of colour is a measure of the amount of a given material in a solution. A second principle of Colorimetry is that every substance absorbs or transmits certain wavelengths of radiant energy but not other wavelengths. For example, chlorophyll always absorbs red and violet light, while it transmits yellow, green, and blue wavelengths. Colorimetry is applicable to many industrial and clinical problems involving the quantitative determination of compounds that are coloured or that react to form a coloured product (Chemistry 111 Lab: Intro to Spectrophotometry, 2005).

When light falls on a substance, three things can happen: the light can be reflected by the substance, it can be absorbed by the substance, certain wavelengths can be absorbed and the remainder transmitted or reflected. For colorimetric technique, the main interest is the absorbance and transmittance of light (ibid). The colour we see in a sample of solution is due to the selective absorption. This technique will be used to determine the levels of ions of interest in an aqueous medium or contaminated solution using a low cost colorimeter (refer to Chapter 7 for Colorimetry details).

## 9.3 Activity 2: Familiarising with light emitting diodes

### 9.3.1 Lesson objective

Students will demonstrate that an LED can produce light of a particular colour (or wavelength when connected to a DC supply and protected by a 1KΩ resistor. This objective represents application of factual knowledge.

### 9.3.2 Light sources in electronics

Light can be produced and/or controlled electronically in a number of ways. Under specific conditions, solid state light sources can produce coherent light, as in laser diodes.

Some LED types last 100,000 hours, compared to about 1000 hours for an incandescent bulb (Curran & Keeny, 2008; Wright, 2012). In 1993, Shuji Nakamura of Nichia Chemical Industries came up with a blue LED using Gallium Nitride (GaN). Now that blue LEDs have become a reality, white light LEDs can be produced by combining the red, green and blue chips in a single device (Soni & Devendra, 2008).

Furthermore, a light-emitting diode does not have any moving parts, which makes the device extremely resistant to damage due to vibration and shocks. These characteristics make it ideal for purposes that demand reliability and strength. LED lighting scheme provides additional advantages such as cool light, decreased maintenance cost, longer life, more flexibility and easier handling (ibid).

Light Emitting Diode (LEDs)

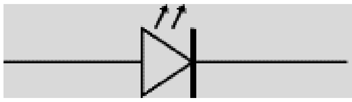

**Figure 64.** Circuit symbol

### 9.3.3 Connecting and soldering

LEDs must be connected the correct way round; the diagram may be labelled as ***a*** (+) for anode and ***k*** (-) for cathode.

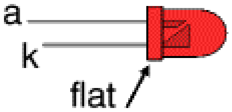

**Figure 65.** Anode and cathode of an LED

The cathode is the short lead and there may be a slight flat on the body of round LEDs. If you can see inside of the LED, the cathode is the larger electrode (but this is not an official identification method).

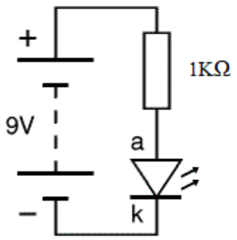

**Figure 66.** How to connect an LED

Never connect an LED directly to a battery or power supply. It will be destroyed almost instantly because too much current will pass through and burn it out.

LEDs must have a resistor in series to limit the current to a safe value. For quick testing purposes, a 1kΩ resistor is suitable for most LEDs if the supply voltage is 12V or less. Remember to connect the LED the correct way round.

*Discussion*: After you have connected the components as shown in Figure 66 observe what happens and record your observation………………………………

*Expected answer: The LED emit light when an electric current passes through it*

In light emitting diodes (LEDs), light is produced by a solid state process called electroluminescence (Paschotta, 2013).

### 9.3.4 Colours of LEDs

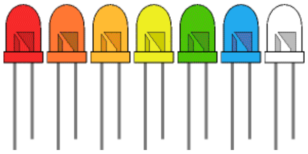

**Figure 67.** Variety of LEDs

LEDs are available in red, orange, amber, yellow, green, blue and white.

The colour of an LED is determined by the semiconductor material, not by the colouring of the 'package' (the plastic body). LEDs of all colours are available in uncoloured packages which may be diffused (milky) or clear (often described as 'water clear'). The coloured packages are also available as diffused (the standard type) or transparent (Yadav, 2008).

### 9.3.5 Tri-colour LEDs

The most popular type of tri-colour LED has a red and a green LED combined in one package with three leads. They are called tri-colour because mixed red and green light appears to be yellow and this is produced when both the red and green LEDs are on (Jaffery, 2013).

### 9.3.6 Bi-colour LEDs

A bi-colour LED has two LEDs wired in 'inverse parallel' (one forwards, one backwards) combined in one package with two leads. Only one of the LEDs can be lit at one time and they are less useful than the tri-colour LEDs described above (Held, 2008).

### 9.3.7 Sizes, shapes and viewing angles of LEDs

LEDs are available in a wide variety of sizes and shapes. The ‘standard’ LED has a round cross-section of 5 mm diameter and this is probably the best type for general use, but 3 mm round LEDs are also popular. Round cross-section LEDs are frequently used and they are very easy to install on boxes by drilling a hole of the LED diameter, adding a spot of glue will help to hold the LED if necessary. LED clips are also available to secure LEDs in holes. Other cross-section shapes include square, rectangular and triangular.

As well as a variety of colours, sizes and shapes, LEDs also vary in their viewing angle. This tells you how much the beam of light spreads out. Standard LEDs have a viewing angle of 60° but others have a narrow beam of 30° or less (Khope, 2012).

## 9.4 Activity 3: Connecting light emitting diodes

### 9.4.1 Lesson objectives

1. Students will calculate the suitable resistor value for a given LED. This objective belongs to application of procedural knowledge.
2. Students will point out the necessary precaution when connecting an LED. This objective belongs to factual knowledge.
3. Students will recognise the most important technical data about LEDs. This objective belongs to remembering factual information.

### 9.4.2 Calculating an LED resistor value

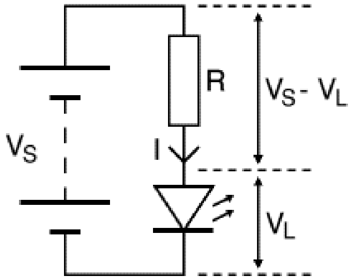

**Figure 68.** Determining resistance of resistor R

An LED must have a resistor connected in series to limit the flow of current, otherwise it will burn out. The resistor value, R is given by:

$$R = \frac{(V_S - V_L)}{I}$$

$V_S$ = supply voltage

$V_L$ = LED voltage (voltage value is given on the label depending on manufacture)

Working out the LED resistance using Ohm's law

Ohm's law states that the resistance of the resistor is given by $R = \frac{V}{I}$, where:

V = voltage across the resistor (= $V_S$ - $V_L$ in this case)

I = the current through the resistor

So $R = \frac{(V_S - V_L)}{I}$

I = LED current (e.g. 10mA = 0.01A, or 20mA = 0.02A)

Make sure the LED current you choose is less than the maximum permitted and convert the current to amps (A) so the calculation will give the resistor value in ohms (Ω).

To convert mA to A, divide the current in mA by 1000 because 1mA = 0.001A.

If the calculated value is not available choose the nearest standard resistor value which is greater, so that the current will be a little less than you chose. In fact you may wish to choose a greater resistor value to reduce the current (to increase battery life for example) but this will make the LED less bright.

For example, if the supply voltage $V_S$ = 9V, and you have a red LED ($V_L$ = 2V), requiring a current I = 20mA = 0.020A,

$$R = \frac{9V-2V}{0.02A} = 350\Omega$$

So choose 390 (the nearest standard value which is greater).

### 9.4.2 Precaution

Avoid connecting LEDs in parallel!

Connecting several LEDs in parallel as shown in Figure 69, with just one resistor shared between them is generally not a good practice.

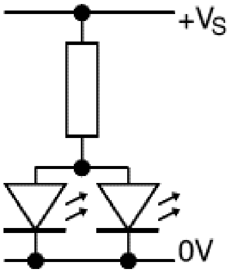

**Figure 69.** Wrong way to connect an LED

If the LEDs require slightly different voltages only the lowest voltage LED will light and it may be destroyed by the larger current flowing through it. Although identical LEDs can be successfully connected in parallel with one resistor, this rarely offers any useful benefit because resistors are very cheap and the current used is the same as connecting the LEDs individually. If LEDs are in parallel each one should have its own resistor (Taruntishitu, 2011).

### 9.4.3 Reading a table of technical data for LEDs

Suppliers' catalogues usually include tables of technical data for components such as LEDs. These tables contain a good deal of useful information in a compact form but they can be difficult to understand if you are not familiar with the abbreviations used.

Table 49 shows typical technical data for some 5 mm diameter round LEDs with diffused packages. Only three columns are important and these are shown in italics.

**Table 49.** Technical data for LEDs

| **Type** | **Colour** | ***$I_F$ max.*** | ***$V_F$ typ.*** | ***$V_F$ max.*** | **$V_R$ max.** | **Luminous intensity** | **Viewing angle** | **Wavelength** |
|---|---|---|---|---|---|---|---|---|
| Standard | *Red* | *30mA* | *1.7V* | 2.1V | 5V | 5mcd @ 10mA | 60° | 660nm |
| Standard | *Bright red* | *30mA* | *2.0V* | 2.5V | 5V | 80mcd @ 10mA | 60° | 625nm |
| Standard | *Yellow* | *30mA* | *2.1V* | 2.5V | 5V | 32mcd @ 10mA | 60° | 590nm |
| Standard | *Green* | *25mA* | *2.2V* | 2.5V | 5V | 32mcd @ 10mA | 60° | 565nm |
| High intensity | *Blue* | *30mA* | *4.5V* | 5.5V | 5V | 60mcd @ 20mA | 50° | 430nm |
| Super bright | *Red* | *30mA* | *1.85V* | 2.5V | 5V | 500mcd @ 20mA | 60° | 660nm |
| Low current | *Red* | *30mA* | *1.7V* | 2.0V | 5V | 5mcd @ 2mA | 60° | 625nm |

Source: Hewes (2013)

| | |
|---|---|
| $I_F$ max. | Maximum forward current, forward just means with the LED connected correctly. |
| $V_F$ typ. | Typical forward voltage, $V_L$ in the LED resistor calculation. This is about 2V, except for blue and white LEDs for which it is about 4V. |
| $V_F$ max. | Maximum forward voltage. |
| $V_R$ max. | Maximum reverse voltage |

| | |
|---|---|
| | You can ignore this for LEDs connected the correct way round. |
| Luminous intensity | Brightness of the LED at the given current, mcd = millicandela. |
| Viewing angle | Standard LEDs have a viewing angle of 60°, others emit a narrower beam of about 30°. |
| Wavelength | The peak wavelength of the light emitted, this determines the colour of the LED. nm = nanometre. |

## 9.5 Activity 4: unifying science concepts to make a useful instrument

### 9.5.1 Lesson objectives

1. Students will analyse the relationship of light intensity and resistance of a photoresistor.
2. Students will prescribe, using the colour wheel, the correct LED wavelength to use depending on the colour of the analyte they generated.
3. Students will determine under which conditions is the Beer-lambert law not obeyed.
4. Students will determine qualitatively the presence of contaminants in the water obtained from their communities.
5. Students will determine quantitatively, using colorimetric technique, the heavy metal concentration of the water samples obtained from their community.

**Table 50.** Taxonomy table for unifying science concepts to make a useful instrument

| **The knowledge dimension** | **The cognitive process dimension** | | | | | |
|---|---|---|---|---|---|---|
| | **1.Remember** | **2. Understand** | **2. Apply** | **4. Analyse** | **5. Evaluate** | **6. Create** |
| A. Factual Knowledge | | | | | | |
| B. Conceptual Knowledge | | | | Objective 1 | Objective 2 | |
| C. Procedural Knowledge | | | | | Objective 3<br>Objective 4 | |
| D. Meta-cognitive knowledge | | | | | | |

The subsequent activities explain how the assembled concepts can be used meaningfully in a classroom situation.

Precaution for Cell Handling

1. Use the same cell from zero adjustment through measurement completion.
2. Do not hold the light path. The light goes through the shorter side of the cell.

**Figure 70.** Correct way to handle a cuvette

3. If the sample temperature is very low compared with the ambient temperature, the cell could be misted and could induce a measurement error.
4. Clean up the cell surface to wipe off water drops or fingerprints before inserting it into the cell box.
5. After use, rinse the cell several times with tap water and then thoroughly with distilled water.
6. If distilled water is not available, rinse a cell with the sample water before using it.
7. A crack or dirt on the cell surface may result in error. Replace with new one if necessary.
8. Cells or cuvettes are usually made from materials such as optical glass, quartz, pyrex, and polystyrene.

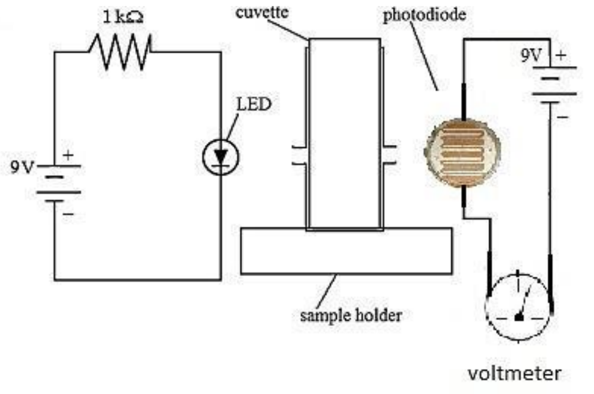

**Figure 71.** Light effect on a photoresistor

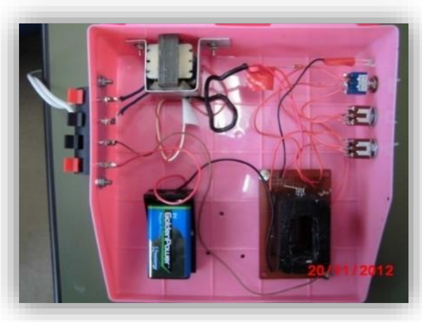

**Figure 72.** Example of an actual low-cost colorimeter

The activity will demonstrate what happens when light is shone on a photoresistor. Connect the components as shown in Figure 71. The cuvette should be filled with a coloured solution. Or if you have $CuSO_4$ solution, you can prepare the solution as shown in Table 51. Since the copper (II) sulphate is blue in colour, an LED of appropriate wavelength should be chosen.

**Table 51.** Concentration needed for the colorimetric determination

| Test Tube | 0.4 M $CuSO_4$ (ml) | Distilled $H_2O$ (ml) | Concentration (M) |
|---|---|---|---|
| 1 | 2 | 8 | 0.08 |
| 2 | 4 | 6 | 0.16 |
| 3 | 6 | 4 | 0.24 |
| 4 | 8 | 2 | 0.32 |
| 5 | 10 | 0 | 0.40 |

If you choose any other coloured solution for your activity, you should match it with an appropriate LED of the correct wavelength, refer to activity 5 under section 9.5.2. The subsequent solutions to be used in the experiment should be diluted by half of the initial solution, $\left(\frac{N}{1}, \frac{N}{2}, \frac{N}{4}, \frac{N}{8} \ldots\right)$. Where N/1 represents the highly concentrated solution. If no significant light pass through the solution after dilution, further dilutions can be done and the experiment repeated.

This will enable light of different intensities to reach the photoresistor and take note of the changes in the voltage readings. Plot a graph of concentration against voltage.

1. If you had used a blue solution of copper (II) sulphate, what LED colour should be used for the activity?
2. What happens when the intensity of light reaching the photoresistor is increased?
3. What conclusion can you make about a photoresistor?

Expected answers:

1. Red LED
2. The voltage reading increase
3. The photoresistor's resistance is dependent on the intensity of light. More light reduces its resistance and less light increase its resistances

### 9.5.2 Relationship of light-wavelength and absorbing species

#### *9.5.2.1 Choosing an appropriate LED for a given solution*

Understanding the relationship between the light source (wavelength) and colour of analyte is important for colorimetric analysis.

Colorimetry is just one of the many types of photometric analysis techniques; it is a light measuring analytical procedure. It is important to note the colour of the solution and correlate it with a correct light of an appropriate wavelength. The LED or wavelength of the light source that will produce the maximum absorbance can be selected in two ways:

1. Taking readings throughout the spectrum on a typical standard solution of the substance under investigation and establish the peak wavelength. Figure 73 shows an example of how this can be achieved in order to determine the correct LED wavelength for the analysis. The complex, in figure 73, is reported to have a peak around 546 nm. So the best LED to analyse this complex (haemoglobin–cyanide complex) would be a 510 nm LED in the green part of the spectrum because that is where there is maximum absorbance ($\lambda_{max}$).

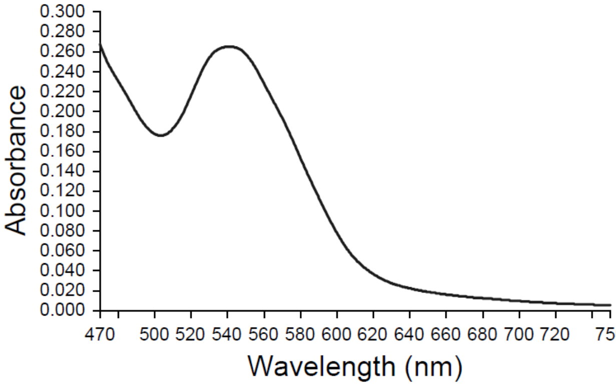

**Figure 73.** Absorption spectrum of haemoglobin–cyanide complex
Source: Upstone (2000)

2. Method two involves choosing a light source of the complementary colour to the solution under investigation. Figure 74 shows the basic relationship between colours. In colour theory, two colours are called complementary if, when mixed in the proper proportion, they produce a neutral colour (grey, white, or black). Complementary colours can also be visualized as pairs of colours that are opposite hues in a colour model (Westland et al., 2007). If one references a colour wheel, a set of complimentary colours would be the colours directly across from each other. These exact

opposites help create contrast within a design and can help in choosing an appropriate monochromatic light source.

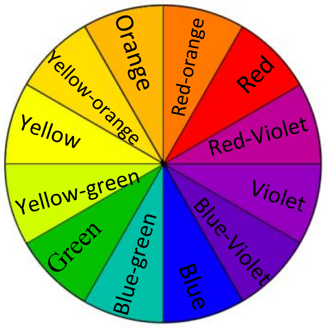

**Figure 74.** Colour wheel showing a set of complementary colours
Source: modified from Chapman (2010)

### 9.5.3 Application of Colorimetry

#### *9.5.3.1 Preparation of standard solutions*

Small quantities of Mn are readily determined colorimetrically by oxidation to the highly coloured permanganate ion. Potassium periodate is an effective oxidizing agent:

$5IO_4^- + 2Mn^{2+} + 3H_2O \rightarrow 2MnO_4^- + 5IO_3^- + 6H^+$

Permanganate solutions containing an excess of potassium periodate are relatively stable.

Prepare solutions of known concentrations to be used in the colorimetric determination. As a starting point, you can prepare 100 ml of 100 ppm standard solution of $Mn^{2+}$.

1. From the standard solution, prepare serial dilutions (0.5 ppm, 1 ppm, 2 ppm, 4 ppm, 8 ppm 16 ppm and 32 ppm) of $Mn^{2+}$.
2. To 10 ml of each of the standard diluted solutions (0.5 ppm to 100 ppm) placed in separate test tubes, add 0.05 g and 0.1 g of trisodium citrate dehydrate.
3. The actual procedure for preparing the diluted solutions depends on the sizes of the volumetric flask at your disposal. The equation below can be used for working out the appropriate volumes needed for the dilutions:

   $$M_1V_1 = M_2V_2$$

   Where: $M_1$, initial concentration; $V_1$, initial volume; $M_2$, final concentration; $V_2$, final volume
4. Shake each of the test tubes 6 times as shown (Figure 75) and wait for about 3 minutes for the colour to fully develop.

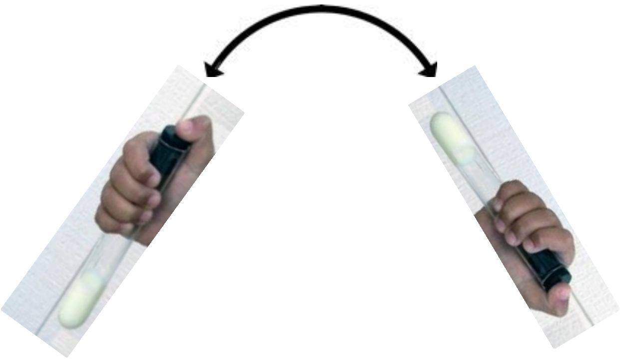

**Figure 75.** Correct way to shake the test tube

5. To 10 ml of the sample(s) placed in the test tube and believed to be contaminated, add an excess of potassium periodate, about 0.05 g and 0.1g of trisodium citrate dehydrate.
6. Using the potassium periodate method to generate a colour, use the colorimeter you have assembled (an example is shown in Figure 72) to collect data which will be used to prepare (linear) graphs.
7. Take note of the voltage reading with distilled only and then distilled with potassium periodate and buffer added, this represent the blank. Fill the cell (cuvette) with the standard samples without buffer and potassium periodate added (one at a time) up to the 1.5 ml line and switch on the colorimeter; take note of the voltage reading and record. Repeat the procedure by recording the voltmeter reading of the colorimeter on the standard samples with the colour fully developed after adding buffer and potassium periodate.
8. Do the same for the unknown solution (before potassium periodate is added and after); take note of the voltage reading for the unreacted solution and the voltage after the reaction. If the colour of the sample of unknown concentration is too deep and no light pass through it as indicated by the voltmeter reading, dilute the sample and proceed with the measurement once again.
9. Record your results as shown in Table 52.
10. Determine the colorimeter reading for the blank and each of the standard solutions. Refer to the measurement procedure for the proper operation of the colorimeter. Do likewise for the unknown solution. Using the collected data, calculate the absorbance (log *Po/P*), where *Po* represents voltage before the reaction with potassium periodate and *P* represents voltage after reaction with potassium periodate.

**Table 52.** Concentration vs. Absorbance

| Concentration (ppm) | Voltmeter readings | | Absorbance |
|---|---|---|---|
| | $P_o$(V) | P(V) | $(\boldsymbol{log}\frac{\boldsymbol{P_o}}{\boldsymbol{P}})$ |
| 100 | | | |
| 32 | | | |
| 16 | | | |
| 8 | | | |
| 4 | | | |
| 2 | | | |
| 1 | | | |
| 0 | | | |
| Contaminated Water | | | |

### 9.5.4 Determining the region of linearity

The Beer-Lambert Law describes the quantitative relationship between the absorbance of radiant energy, the concentration of the sample solution, and the length of the path through the sample.

***A=εbc***

Where: $A$ is absorbance (no units, since $A = \log_{10} P_0 / P$); **ε** is the molar absorptivity with units of L $\text{mol}^{-1}$ $\text{cm}^{-1}$; ***b*** is the path length of the sample - that is, the path length of the cuvette in which the sample is contained, this measurement will be expressed in centimetres; ***c*** is the concentration of the compound in solution, expressed in mol/L.

Absorbance is directly proportional to the other parameters, as long as the law is obeyed.

From ***A = εbc***, it can be deduced that absorbance depends on the total quantity of the absorbing compound in the light path through the cuvette. If absorbance against concentration is plotted, a straight line passing through the origin (0, 0) is obtained.

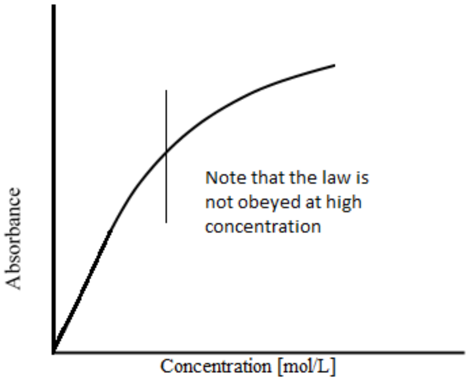

**Figure 76.** Absorbance vs. Concentration

The linear relationship between concentration and absorbance is both simple and straightforward, and for this reason it can be used to investigate the aspect of chemistry teaching involving determination of pollutants in aqueous medium. To determine the best fit linear graph, the following can be considered:

1. Using the various combinations of the concentrations (for example, 1 ppm, 2 ppm, 4 ppm; 8 ppm 16 ppm, 32 ppm & 100 ppm; 2 ppm, 4 ppm & 8 ppm) to plot calibration graphs.
2. Determine which graph gives the best fit line (highest correlation, R) and equation of the straight line to determine the concentration of the unknown sample.
3. Determine at which concentration is there a deviation from linearity (This is the point where beer lambert-Lambert law is not obeyed).
4. From the best fit linear graph, determine the concentration of the solution believed to be contaminated

### 9.5.5 Ion identification

This is a general guide as many other reagents can be used to do a colorimetric analysis. The teacher in conjunction with the pupils can determine what appropriate reagents to use depending on what is locally available and affordable to the school. Appendix 5 shows the well-known chemistry reactions that can be used for analysis of water, the range of accurate analysis and the reaction time needed for the reaction to go to completion are also indicated. The same reactions can be used for identification of ions in water samples. Using a colour chart, it is possible to estimate the concentration of a given pollutant of interest, for example copper ions. Coupled with a low-cost colorimeter, it is possible to determine, fairly accurate, the actual concentration of the ions in water.

## 9.6 Activity 5: Lesson on pollutant removal and treatment

Using the Colorimetry method just explained in the previous lesson, it is possible to know how polluted a given river, borehole or water sample from a domestic tap is. But more importantly is what to do with that information. Finding treatment methods and avoiding future pollution is cardinal. As important as it is, water treatment of chemical pollutants is easy to overlook. For one thing, the benefits are hidden from sight, as are the potential harms. The goal of this activity is to produce water fit for a specific purpose, for example drinking. Generally, the water treatment methods used include: physical processes such as filtration, sedimentation, and distillation; biological processes such as slow sand filters or biologically active carbon; chemical processes such as flocculation and chlorination and; the use of electromagnetic radiation such as ultraviolet light (Alleman & Leeson, 1997; WHO, 2007). The standards for surface water and ground water quality (see appendix 2) are typically set by ECZ and/or Zambia Bureau of standards and in some cases WHO standards and other international standards are also utilised. It is not possible to tell whether water is of an appropriate quality by visual examination, taste and smell alone.

If you are like one of most people out there, you may say ‘I have been drinking untreated water for years, I have never been sick’. Some diseases or harmful effects of chemical contamination take time to present visible signs, but it does not mean they are inactive in your organs.

Living organisms require varying amounts of ‘heavy metals’. Iron, cobalt, copper, manganese, molybdenum, and zinc are required by humans. Excessive levels can be damaging to the organism (Singh et al., 2011). Certain elements that are normally toxic are, for certain organisms or under certain conditions, beneficial. One of the largest problems associated with the persistence of heavy metals is the potential for bioaccumulation and biomagnification causing intensified exposure for some organisms than is present in the environment alone (Beetseh & Abrahams, 2013) and hence the need to carry out regular monitoring not only at school level, but national level as well.

### 9.6.1 Content

The primary purpose of the lesson is to educate pupils regarding the importance of proper water and wastewater treatment. Students will learn about their ecosystem and how it relates to their surroundings. They will learn about pollution and wastewater treatment plants, as well as ways these plants deal with such pollutants and factors that interfere with treatment. These concepts will be taught through class activities and with images (pollution hazard maps) to further engage students. Students will be given a worksheet to complete during the lab activity to instil the concepts covered in the lesson. The detrimental effects of improperly treated water will be expanded upon in an introductory hands-on lab. Students will use the scientific method to make a hypothesis, make observations, and analyse the results of the lab. Students will have a discussion about the various ways to maintain the cleanliness of water bodies in their surroundings.

### 9.6.2 Prerequisites

Students should have basic knowledge of science covered from grades 9 – 11 and part of grade 12. Students must also have basic measuring, pouring, reading volumetric apparatuses (pipettes, measuring cylinders etc.) and stirring skills. They should know how to work with beakers, graduated cylinders, and filters (if they don't know, then they will learn in this activity how to work with basic scientific apparatus). Students should know the scientific processes and be enabled to apply that knowledge to analyse data and make conclusions. The Zambian high school science syllabus (CDC, 2012) stipulates that: As pupils study science they should be able to: Follow a sequence of instructions; Use techniques, apparatus and materials; Make and record observations, measurements and estimates; Interpret and evaluate observations and experimental results; Plan an investigations, select techniques, apparatus and materials and; Evaluate methods and suggest possible improvements. These skills will be used. And it is hoped that those student without these skills (or weakly developed), they will acquire them in the process of this lesson.

### 9.6.3 Background

Water is one of the most essential elements of human life. Humans use water for everything, from drinking to cleaning to cultivating crops. Water serves as a lubricant in digestion, it maintains our body temperatures, and it removes harmful toxins from our bodies. Without a steady supply of clean water, we would not be able to survive. Although water is formed from the tiniest of molecules, it can shape and control biomolecules; liquid water is a highly versatile material (Chaplin, 2006). As a result, water and wastewater treatment is essential to the maintenance of clean water sources.

Wastewater treatment plants remove contaminants from domestic, commercial, and industrial wastewater. Treatment plants produce a safe fluid waste stream (treated effluent), which can be discharged into the river safely. Minimally, wastewater should receive primary (physical removal/settling) and secondary (biological) treatment, which can be followed by disinfection before discharge. More advanced processes (advanced or tertiary treatment) may be required for special wastes. When the effluent from secondary treatment is unacceptable, a third level of treatment, tertiary treatment, can be employed. There are many basic types of sewage treatment plants employing both primary and secondary treatment stages that are in use today for treating large quantities of sewage (Caribbean Environment Programme, 1998; Water and Environmental Health at London and Loughborough, 1999).

Unlike other pollutants such as petroleum hydrocarbons and domestic and municipal litter which may visibly build up in the environment, trace metals in the environment may accumulate unnoticed to toxic levels. Generally, human health problems associated with trace metal contamination have been well highlighted in literature (refer to Chapter 5). In spite of the relatively low level of industrial activity in Zambia, there is, however, a high potential of toxic heavy metal pollution; hence the need for high school pupils to be involved in this endeavour. It should not be left to water treatment plants. In Zambia such plants are far too inadequate and most residential areas do not have piped network to convey the water to a central treatment plant but discharged in the water ways at many points.

### 9.6.4 Objectives/Goals

1. Student will apply colorimetric methods for quantitative analysis of ions.
2. Students will demonstrate the importance of wastewater treatment plants and their role in maintaining clean and reusable water sources.
3. By colorimetric technique, students will detect heavy metals, and explain their effects on the environment.
4. Students will demonstrate the relationship of pH and precipitation and how it can be used in water treatment.
5. Students will explain recycling principle in the context of heavy metal pollution.
6. Students will justify using hands-on lab activities the necessity of proper wastewater treatment and how they can treat the waste water they generate.
7. Students will assess various ways of cleaning up local bodies of water and limitation of those methods.

### 9.6.5 Materials

The materials needed include: colorimeter; pH meter (optional or if available); beakers; pipette; measuring cylinder; universal indicator; sensitive balance (if no sensitive balance is available, the volume and mass of reactants to be prepared should be increased to match the sensitiveness of the balance); stirring rods; distilled water; filter paper; funnel; potassium periodate (or any compound which selectively reacts with $Mn^{2+}$).

**Table 53.** The taxonomy table on pollutant removal and treatment

| **The knowledge dimension** | **The cognitive process dimension** | | | | | |
|---|---|---|---|---|---|---|
| | **1.Remember** | **2. Understand** | **2. Apply** | **4. Analyse** | **5. Evaluate** | **6. Create** |
| A. Factual Knowledge | | | | | | |
| B. Conceptual Knowledge | | Objective 5 | Objective 4<br>Objective 2 | Objective 3 | Objective 7 | |
| C. Procedural Knowledge | | | Objective 1 | | Objective 6 | |
| D. Meta-cognitive knowledge | | | | | | |

### 9.6.6. Procedure D: Determining Concentration of $Mn^{2+}$ by colorimeter

1. From the prepared 100 ml standard solution containing 100 ppm of $Mn^{2+}$, prepare serial dilutions (1 ppm, 2 ppm, 4 ppm, 8 ppm) of $Mn^{2+}$.
2. From the diluted solutions get 10 ml of each and add 0.05 g of potassium periodate and 0.01 g of trisodium citrate dihydrate buffer.
3. Use the colorimeter you have assembled (an example is shown in Figure 77) to collect data which will be used to prepare the calibration graph.

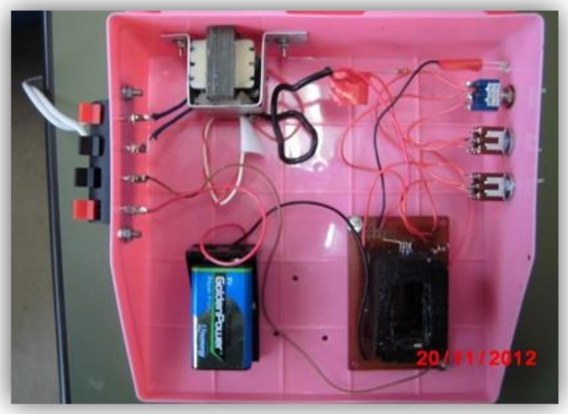

**Figure 77.** Simple Colorimeter

4. Take note of the voltage reading with the manganese contaminated solution before the potassium periodate reagent is added.
5. Fill the cell (cuvette), one at a time, with the standard samples up to the 1.5 ml line and switch on the colorimeter. Take note of the voltage and record the reading.
6. Do the same to the unknown solution; determine the voltage of the solution before potassium periodate is added and the voltage after potassium periodate/buffer is added.
7. Record your results as shown in Table 54.
8. Determine the colorimeter reading for the blank and each of the standard solutions. Refer to the measurement procedure for the proper operation of the colorimeter. Do likewise for the unknown solution.

**Table 54.** Concentration vs. Absorbance

| **Concentration (ppm)** | **Voltmeter Readings** | | **Absorbance** |
|---|---|---|---|
| | **$P_o$(V)** | **$P$(V)** | $(Log \frac{P_o}{P})$ |
| 16.0 | | | |
| 8.0 | | | |
| 4.0 | | | |
| 2.0 | | | |
| 1.0 | | | |
| 0.5 | | | |
| Blank | | | |
| Contaminated Water | | | |

$P_o$ represents voltage of analyte without potassium periodate and $P$ represents voltage reading of analyte with potassium periodate and the buffer added.

9. Using the collected data, calculate the absorbance (Log $P_o/P$), where $P_o$ represents voltage before the reaction with potassium periodate and $P$ represents voltage after reaction with potassium periodate.
10. Plot the data of absorbance against concentration and determine the equation of the straight line ($y = mx + c$).
11. Use the equation in (10) to calculate the concentration of the test solution(s).

### 9.6.7 Procedure E: water treatment by precipitation with base

1. Prepare 500 ml of about 50 ppm solution of $Mn^{2+}$.
2. Divide the stock solution into 100 ml aliquots labelled B1, B2, B3, B4.
3. Prepare 100 ml of a 1 molar solution of NaOH or a limewater (saturated solution of $Ca(OH)_2$).
4. To the first beaker (B1), add 8 drops of NaOH drop-wise and to B2 increase the drops to 16 and 24 drops in B3. To the last beaker labelled B4 add the solution (3) drop-wise until precipitation no longer results and take note of the number of drops added.
5. Filter the resultant solution and collect the filtrate in a small beaker.
6. Determine the pH using any available material or equipment (pH meter, universal indicator paper or liquid.
7. Add 0.05 g of potassium periodate and 0.1 g of buffer to 10 ml of filtrate B1, and to 10 ml of the stating solution before addition of (3). Qualitatively compare the concentrations of $Mn^{2+}$ before and after the filtration. Do the same for B2, B3 and B5.
8. Transfer 1.5 ml of the filtrate and starting material both with potassium periodate added and using the colorimeter, quantitatively compare the concentrations of $Mn^{3+}$ before and after filtration in each of the beakers (B1 to B4).

### 9.6.8 Discussion

#### *9.6.8.1 $Mn^{2+}$ reactions and opportunity for recycling*

Most high school level chemistry textbooks explain that metal ions can be precipitated from a solution using a metal hydroxide. For example, the Zambian approved 11th grade chemistry textbook (Mukuma, Swazi & Chirwa, 1997) explains that "…sodium hydroxide is used as a convenient source of ions in solution. It is used to precipitate the hydroxides of other metals in test for other cations" (p. 154). The textbook does not cite other useful applications apart from the test for some cations. This lesson is intended to tap on this concept and show useful applications in EE lessons as demonstrated in this lesson.

In secondary schools and tertiary level of education, $KMnO_4$ is often used as an oxidizing agent. One typical reaction as shown in the grade 12 approved textbook is:

$16HCl(aq) + 2KMnO_4 \rightarrow \quad 5Cl_2(g) + 2KCl(aq) + 2MnCl_2(aq) + 8H_2O(l)$

However, the disposal of the resulting $Mn^{2+}$, in this reaction and similar reaction utilising $KMnO_4$, is not mentioned, hence the purpose of this lesson to introduce chemistry practices which do not harm the environment.

The solution containing $Mn^{2+}$ resulting from the above reaction can be disposed of by reacting the resulting solution with bases such as NaOH or $Na_2CO_3$ solutions to form precipitates of $Mn(OH)_2$ or $MnCO_3$, respectively. The recovered solids can be converted to manganese (IV) oxide ($MnO_2$) by heating the solids at 400 ~ 450 ℃ in air (Tanaka, 2006).

$2Mn(OH)_2 \quad + O_2 \rightarrow \; 2MnO_2 + 2H_2O$

$2MnCO_3 \quad + O_2 \rightarrow \quad 2MnO_2 + 2CO_2$

The oxide, in particular that result from $MnCO_3$, is a good catalyst for the decomposition of hydrogen peroxide in aqueous solutions. The decomposition is a suitable reaction for making students understand an exothermic reaction, as the enthalpy of the decomposition is known to be about -100 kJ/mol (Marzzacco, 1999). The catalytic activities of the oxide can be compared by measuring rates of the decomposition of $H_2O_2$ in aqueous solutions.

In the approved 12th grade chemistry textbook (by Mukuma, Swazi & Chirwa, 1997, p. 25), it is stated that "hydrogen peroxide decomposes smoothly when dropped onto a catalyst such as powdered manganese dioxide, giving oxygen gas and water."

$2H_2O_2 \;\; (aq) \rightarrow \;\; 2H_2O\,(l) \;\; + \;\; O_2(g)$

Through this activity of recycling water polluted by manganese and producing $MnO_2$, rates at which, the recycled and the purchased $MnO_2$ decompose $H_2O_2$ can be compared. The activity has advantages of teaching student the preparation of oxygen and at the same time use the recycled $MnO_2$. The activity further shows the value of recycling and how to practically use the recycled product and avoid problems related to disposal of such pollutants.

It is also interesting to establish a reaction cycle of Mn for recycling of Mn salts in school chemistry laboratories. It is reported that the decomposition reaction catalysed by the recovered oxide is suitable as a secondary school experiment on heat of reactions as well as rate of reactions (Tanaka & Koga, 2006).

A surplus $KMnO_4$ solution can be reduced to a solution of $Mn^{2+}$ by adding a dilute solution of $H_2O_2$ to the solution of $KMnO_4$ acidified with $H_2SO_4$ (H. Tanaka, personal communication, June 5, 2013).

$2KMnO_4 + 3H_2SO_4 + 5H_2O_2 \rightarrow K_2SO_4 + 2MnSO_4 + 5O_2 + 8H_2O$

If necessary, the solid $MnO_2$ obtained above can be reduced by reacting with a warm mixed dilute solution of $H_2O_2$ and $HNO_3$ to give a solution of $Mn^{2+}$ (ibid).

$MnO_2 + 2HNO_3 + H_2O_2 \rightarrow Mn(NO_3)_2 + O_2 + 2H_2O$

**Evaluation:** The amount of information students learned can be measured by:

1) Having students turn in their notes worksheets and then grading them for accuracy.
2) Periodically asking the students questions during the lab activity to reinforce main concepts.
3) Giving the students lab analysis questions to help them connect their lab findings to real world pollution problems.

### 9.6.9 Follow-up Activities:

1. At the end of the lesson, we will ask an open ended concluding questions that will encourage students to brainstorm ideas regarding ways to reduce to below 0.1 mg/l, being the maximum allowable contaminant level or limit for drinking water (see appendix 2). The map showing Mn contamination (Figure 78) can be the focus of discussion if the lesson, for example, is to be conducted in Lusaka. This will allow students to use the information they have learned in a creative way to help solve a real problem. Pupils can also be asked to identify areas with acute levels of pollutants in relation their school. Both Mn pollution and school location are shown in Figure 78 and Figure 79 respectively.

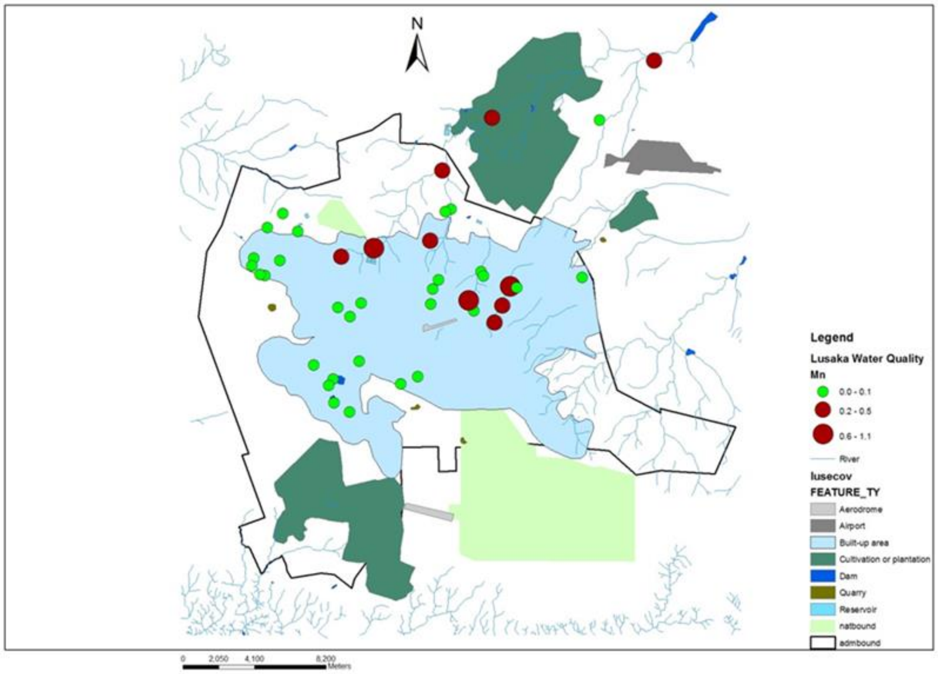

**Figure 78.** Manganese levels in Lusaka

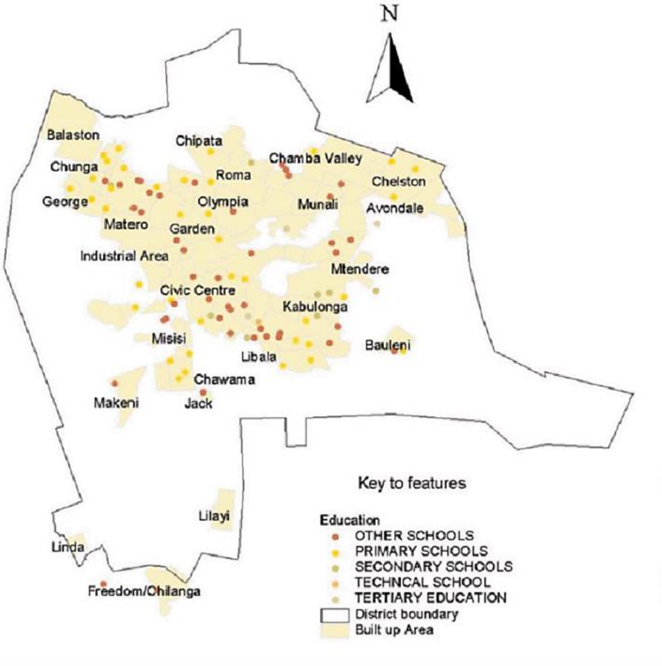

**Figure 79.** Educational institutions in Lusaka
Source: ECZ and LCC (2008)

2. After the students have completed the lesson, they can analyse the map and locate their school and residential area on the map and comment on what could have caused the higher pollution levels of

Mn in specific areas than in others. They should also comment on why surface water is more polluted with manganese than ground water.

3. The pupils can embark on further detection and removal of pollutants based on today's lessons.
4. The students can be asked to further research about Mn and its effects on the environment through any resources that are readily available to them, government reports, library resources, textbooks, newspaper, journals, magazines, and internet.

### 9.6.10 Self-Assessment

The classroom activities focus on the importance of water/wastewater treatment. In addition, the activities focus on the necessity of reducing pollutants such as manganese to safe levels. The lesson also presents a map showing distribution of pollutants in a given location, in this particular case Lusaka region.

These activities correlates in many aspects with the Zambian Ministry of Education standards because all the concepts used in the detection and treatment are derived from the approved textbooks. The lesson is, furthermore, intended to add the dimension of:

Creating – the learner generates new ideas, products, or ways of viewing things; designing, constructing, planning, producing, inventing, devising and making;

Evaluating – the learner makes decisions based on in-depth reflection, criticism and assessment; checking, hypothesising, critiquing, experimenting, judging, testing, detecting, and monitoring;

Analysing – with the help of the teacher, the pupils break down learned information into its parts to explore and understand its relationship. This category includes comparing, organising, deconstructing, outlining, finding, structuring and integrating.

Applying – Apply what has been learned to new situations to the teaching leaning process. Applying is using information in another familiar way; this encompasses implementing, and carrying out.

The lesson demonstrated the role of pupils in wastewater treatment plants in maintaining the cleanliness, this concept is important because Lusaka and Zambia in general lacks adequate wastewater treatment plants. The lesson expands upon their laboratory skills, which include measuring, pouring, and stirring, and can improve their abilities to analyse and make connections.

The pupils should also be periodically quizzed about the lab activity and their motivation for doing it. Is it because they were told to do it or they see value in the lab activity? Motivation may spring from a variety of needs, ranging from those which are largely physiological in origin to those which are primarily psychological (Bigge, 1964). It is important for the activities to be appealing to both modes of motivation.

The pupils can be assessed by the question they ask. Do they really seem engaged during and after the lab activity, and even voluntarily ask questions about water and pollution.

The notes worksheets and lab worksheets can help check student understanding, and if the activities were effective. This can be judged by how pupils answer the factual questions accurately and how they answer the open ended questions creatively. Questions like “What are some ways to reduce heavy metal pollution?” can be analysed to check how deep the pupils answers the question.

The weak part of the suggested activities is the time needed to prepare the materials and carry out the lesson to a logical conclusion. Hence, it requires frequent teacher involvement which might reduce the pupil initiative to think about the subsequent steps. However, frequent intervention and guidance from the teacher is equally beneficial. In the same vein, Kirschner, Sweller and Clark (2006) argue that approaches which uses minimal guidance ignore both the structures that constitute human cognitive architecture and the evidence from empirical studies over the past half-century which indicate consistently that minimally guided instruction is less effective and less efficient than instructional approaches that place a strong emphasis on guidance of the student learning process. ‘The advantage of guidance begins to recede only when learners have sufficiently high prior knowledge to provide “internal” guidance’ (p. 75).

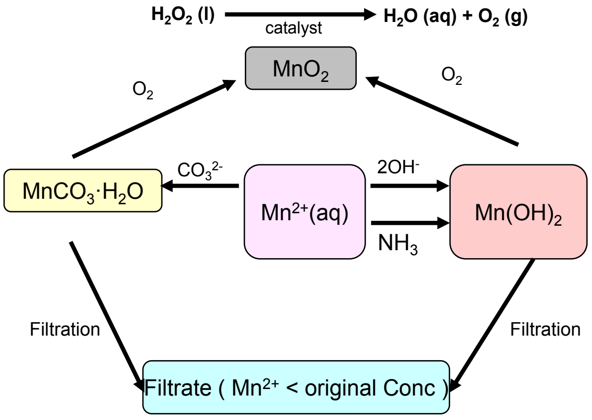

**Figure 80.** Recovering of manganese as $MnO_2$ from wastewater containing $Mn^{2+}$
Source: Modified from H. Tanaka (Personal communication, June 5, 2013)

Overall, these are compelling classroom activities which can make an impact on the students. The lesson is intended to show the interconnectedness and interdependence of science concepts. For example, the pollutant $Mn^{2+}$ can be retrieved from a contaminated solution by adding a base, either a carbonate or a hydroxide (Figure 80). The precipitate can be converted to other useful products like $MnO_2$ which is needed in another lab activity on preparation of oxygen by decomposing $H_2O_2$.

## 9.7 Activity 6: Classroom activities for the treatment of water contaminated with Iron and other heavy metals

### 9.7.1 Title: Disposal of wastewater containing some metal ions in chemistry laboratories

**Rationale:** Chemistry plays an important role in coping with water pollution. Students could discuss the method of treatment of wastewater in chemistry classes based on the knowledge they have learned and do some experiments on the disposal of wastewater in laboratories.

**Objective:** To help students reach a logical conclusion, through the discussion and experiments, that some pollutants like heavy metal ions can be removed from wastewater by using appropriate chemical and physical methods such as precipitation followed by filtration, and filtration using AC filters (adsorption).

### 9.7.2 Materials

The materials/requisites for this activity include: Polyethylene terephthalate (PET) bottles, or any other locally available bottle; colorimeter; pH meter (optional or if available); beakers; pipette; universal; indicator; sensitive balance (if no sensitive balance is available, the volume and mass of reactants to be prepared should be increased to match the sensitiveness of the balance); stirring rods; distilled water; filter paper; funnel; AC.

### 9.7.3 Supplement

1. Detection of $Fe^{3+}$ is possible by use of a very diluted solution of $K_4[Fe(CN)_6]$ or KSCN.
2. Detection of $Cu^{2+}$ can be done by bathocuproine.
3. Procedure F can be applied to possible removals, at least reduction in the concentration, of copper, arsenic and any other harmful ions in drinking water.

### 9.7.4 Procedure F

This activity demonstrates the removal of $Fe^{3+}$ from a solution of $Fe_2(SO_4)_3$ through precipitation followed by filtration:

1. Put a small amount of CaO or $Ca(OH)_2$ in 100 ml of water in a beaker and stir well to dissolve the solute.
2. Decant or filter the resultant solution to remove the solid remaining in the beaker and obtain limewater.
3. Add the limewater to 20 ml of about 50 ppm solution of $Fe_2(SO_4)_3$ until the solid of iron(III) hydroxide, $Fe(OH)_3$, no longer precipitates (or the resultant solution becomes basic).
4. Filter the resultant solution and collect the filtrate.
5. Prepare a standard solution of $Fe^{3+}$ (500 ppm).
6. From the standard solution, perform serial dilutions (1 ppm, 2 ppm, 4 ppm, 8 ppm). Get 5 ml of each of the standard diluted solutions and add a few drops of 1% $SCN^-$ solution.
7. Use the Low-cost colorimeter you have assembled (an example is shown in Figure 81) collect data which will be used to prepare the calibration graph. Match the colour of the solution (after adding $SCN^-$) with a correct LED of appropriate wavelength (see activity 9.5.2.1).

**Figure 81.** Simple Colorimeter

**Table 55.** Concentration versus Absorbance

| **Concentration (ppm)** | **Voltmeter Readings** | | **Absorbance** |
|---|---|---|---|
| | **$P_o$(V)** | **$P$(V)** | $(Log\frac{P_o}{P})$ |
| 8 | | | |
| 4 | | | |
| 2 | | | |
| 1 | | | |
| 0 | | | |
| Contaminated Water | | | |

$P_o$ represents voltage of analyte before $SCN^-$ is added reaction and $P$ represents voltage reading after the reaction with $SCN^-$

8. From the filtrate obtain a 5ml aliquot and add a few drops of $SCN^-$ and record the voltage readings before ($P_o$) and after 1% $SCN^-$ is added ($P$). Calculate the absorbance.
9. Determine the concentration of the solution after treatment with CaO or Ca(OH).
10. How does it compare with the initial concentration?

### 9.7.5 Results and Discussion

A saturated solution of calcium hydroxide (limewater) was prepared by adding an excess of CaO into 100 ml of water and stirring the mixture followed by filtration. In the preparation, waste CaO which had been used as a desiccant for dried food in a sealed container, was reused. The limewater was added to 20 ml of a 50 ppm $Fe_2(SO_4)_3$ solution until the resultant solution became alkaline. The precipitate formed was filtered and the filtrate collected. It was found that no colour phenomenon was observed when a few drops of the KSCN solution were added to the filtrate. This proves that most of $Fe^{3+}$ was removed through the present treatment.

By and large, such a precipitation method is effective particularly for the disposal of rather concentrated solutions. If $CaO/Ca(OH)_2$ is used, some excess of the solid solute should be added to prepare the limewater, because the solubility of $Ca(OH)_2$ is quite low. It is about 1.85 g/l of water at 0°C to 1.28 g/l at 50°C and 0.71 g/l at 100°C (Boynton, 1980). Thereafter, the precipitation reaction can be performed with the mixture of the solid solute with the resultant limewater without the filtration. That is, in the presence of more $Fe^{3+}$, the hydroxide ion may be provided to form the precipitate of $Fe(OH)_3$, not only from the dissolved but also solid state hydroxide ion. The heterogeneous (solid-liquid phase) precipitation reaction is described as follows:

$$Fe_2(SO_4)_3\,(aq) + 3Ca(OH)_2\,(s) \rightarrow 2Fe(OH)_3(s) + 3CaSO_4\,(aq)$$

(H. Tanaka, personal communication, June 5, 2013)

### 9.7.6 Procedure G. Removal of pollutants by Activated Carbon

1. Cut the base of several PET bottles and drill the lid with several small holes and secure it onto the bottle.
2. Insert filter paper inside and near the mouth of the bottle and put clean 230 grams of stones into the bottle.
3. Charge the PET bottle with 40 grams of AC which you prepared or purchased from a supplier. The completed filtration assemblies should look like Figure 81 (a), (b) and (c).

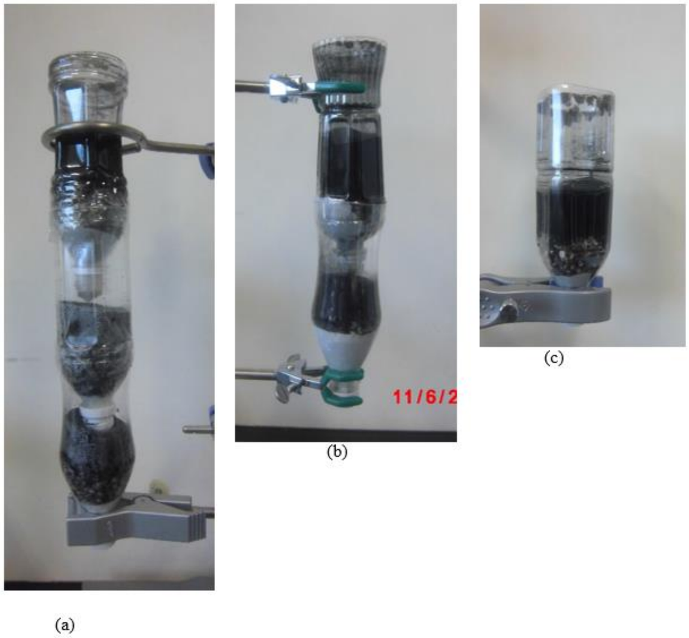

**Figure 82.** Filtration by activated carbon charged in PET bottles

4. Using the colorimeter method, determine the initial concentration of the pollutant(s) before filtering the solution suspected to be contaminated.
5. Filter 1000 ml portions or more of the contaminated solution or effluent water into each of the filtration assemblies namely (a) single filter, (b) tandem filter and the (c) triplet filter.
6. Determine the concentration of the pollutant(s) of interest in each of the filtered solutions from the different filtration assemblies (a), (b) and (c). Depending on the pollutant of interest, determination by colorimetric technique will be slightly different.

### 9.7.7 Discussion on the treatment of waste water using activated carbon

The effluent water obtained from Saijo water treatment plant was treated using three different AC filters (Figure 82). The original effluent water sample did not test for heavy metals and in order to simulate a worst case scenario, heavy metals ($Fe^{2+}$, $Mn^{2+}$, $Ni^{2+}$ and $Zn^{2+}$) were added to the solution. The results are shown in Table 56. In each of the filters, 1000 ml of effluent water was filtered.

The results show that increasing residence time for the water by using a double or triple filter can led to an increase in the efficient of pollutant removal. All the pollutants were treated to drinkable levels except for Ni. However there was an increase in the amount of nitrite with increasing number of filters. This implies that the AC had some impurities such as nitrites and other ionic substances that tended to increase the water hardness.

**Table 56.** Determination of pollutants in the Saijo waste water before and after treatment

| Parameter | Formula | Initial Conc. (ppm) | After treatment (ppm) | | |
|---|---|---|---|---|---|
| | | | Single filter | Double filter | Triple filter |
| Nitrite | $NO_2^-$ | 0.295 | 0.248 | 0.275 | 0.492 |
| Nitrate | $NO_3^-$ | 99 | 39 | 28 | 21 |
| pH | | 6.49 | 7.75 | 8.05 | 797 |
| Ammonia | $NH_4$ | 23.2 | 9.8 | 0.87 | 0.5 |
| Hypochlorite | ClO | 0.61 | <0.10 | <0.10 | <0.10 |
| Hydrogen Peroxide | $H_2O_2$ | 0.6 | <0.10 | <0.10 | <0.10 |
| Zinc | Zn | 0.26 | 0.26 | <0.10 | <0.10 |
| Total Hardness | TH | <20 | 71 | 350 | 380 |
| Copper* | Cu | 12.4 | <0.10 | <0.10 | <0.10 |
| Iron* | Fe | 0.19 | <0.05 | <0.05 | <0.05 |
| Calcium | Ca | <0.5 | <0.5 | <0.5 | <0.5 |
| Manganese* | Mn | 14.5 | 6.3 | <0.60 | <0.60 |
| Nickel* | Ni | 4.23 | 4.94 | 2.06 | 1.83 |
| Cyanide | CN | <0.020 | 0.024 | <0.020 | <0.020 |

* The heavy metals were artificially added to the water samples

### 9.7.8 Learning Outcomes

This experiment familiarizes students with several basic laboratory techniques and facilitates development of scientific thought processes. The following scientific processes are incorporated into the experiment: the student demonstrates safe laboratory practices; the student collects data and makes measurements with precision; the student expresses and manipulates chemical quantities using mathematical procedures; the student organises, analyses, and evaluates data; the student communicates a valid conclusion; and the student makes responsible choices in selecting everyday products using scientific information.

The following scientific concepts are taught in this activity: the student investigates and identifies properties of AC; investigates and compares the effect of residence time of the water inside the AC; the student investigates solubility of heavy metals in aqueous solutions by altering the pH of the solution; the student evaluates the significance of using single, double and triple filtration in the water treatment.

# Chapter 10

## 10. Conclusion and recommendations

In making the curriculum flexible and receptive to learners and collective needs, this study bridged the gap of localising some aspects of the Environmental Education (EE) curriculum. The localisation of the school curriculum, as advocated by Ministry of Education (MOESVTEE, 2012) will allow schools to adapt some aspects of the curriculum to match local needs and circumstances and especially water pollutants and how they can be detected and treated. In this way, the curriculum will provide some compensation for the indigenous knowledge, values and practical skills that learners would have acquired in their home/local environment if they had not been attending school. Traditional knowledge or society had its own water treatment method before the onset of modern education but this knowledge is rarely acquired in schools. Many indigenous populations had their systems of soundly managing the biophysical environment which constituted an integral part of the cultural identity and social integrity (McGregor, 2012). At the same time, their knowledge embodies a wealth of wisdom and experience of nature gained over millennia from direct observations, and transmitted mostly by the oral process over many generations (Mazzocchi, 2006). Therefore is important to reinforce learning which connects the student to the local environment. The indigenous knowledge is in decline and if the school system neglects the local environment, there will be no compensation of the indigenous knowledge. The responsibility of compensating for the indigenous knowledge is, without a doubt, bestowed on the school system and hence the need to promote the localisation of the curriculum as encouraged by MOESVTEE (2012). This study attempted to have an input to this endeavour.

The study demonstrated how different concepts of chemistry can be bridged to come up with an assortment of EE activity based lessons. This achievement is perfectly aligned with UNESCO-UNEP's (1978) statement that EE is the result of the reorientation and dovetailing of different disciplines and education experiences which facilitate an integrated perception of the problems of the environment, enabling more rational actions capable of meeting social needs to be taken.

Curriculum Development Centre (CDC) aims at working with stakeholders in developing guidelines on the localisation of the curriculum (MOESVTEE, 2012) and this study provided some input to this endeavour. To have a strong basis for adding appropriate content for localising the curriculum, detailed water analysis was conducted and Manganese (Mn) was the major heavy-metal pollution problem.

Mn and copper (Cu) were successfully treated from contaminated water using activated carbon and precipitation reaction utilising high-school level chemistry concepts.

Nitrate was another prevalent problem in areas with in-situ sanitation and backyard dumpsites. Pollutant detection methods were suggested (Chapter 7, 9 & appendix 5) using a colorimetric technique, but because of the complexity associated with $NO_3^-$ pollution treatment, this study recommends that pupils are made aware of the sources and extent of nitrates (as demonstrated using colorimetric techniques in chapter 7) and embark on lifestyle change and proper land use management; this implies not dumping garbage indiscriminately, recycling some of it as demonstrated in this study and avoiding the use of unprotected pit latrines (as discussed in chapter 4), and careful assessment of the possible sources of contamination relative to the wells and boreholes to be constructed. Furthermore, using the Low-cost colorimeters (LCCs), pupils can determine contaminated water sources and proscribe, where possible, such wells from service. Since this study found surface water to be relatively free of $NO_3^-$ contamination, it is further recommended, where probable, to blend high-nitrate groundwater with surface water that has lower nitrate concentrations.

Analysis of the water from the Lake Kariba, Zambezi River and its tributaries revealed that water was most polluted during the late rain season (January to March) and nature of the pollutants was different by season and so it would be appropriate to design the curriculum to take into consideration the changing nature of pollutants by season. The Zambian curriculum and the teaching process covers a global view of the world trends, strategies and practices such as lead poisoning in the global context, greenhouse effect, ozone layer depletion, acid rains and its effects, and climate change. However, this study is recommending to embrace activities which affect the pupils daily, and thoughts which could fit in the local and national situations. Furthermore, environmental issues which are less verifiable, at local level, by way of classroom activities (e.g. ozone layer depletion, global warming) can be relegated to a lower status. There should be a hierarchy of needs according to the impact it creates on the people and so this study is strongly recommending starting with water. Hence, the study of the dynamics involving deciphering sources of pollution, water pollution detection and treatment would be appropriate. In addition, this study is recommending contextualising the chemistry learnt in schools. The Zambian curriculum demands that pupils are taught, for example, about detection of ions (namely testing for $CO_3^{2-}$, $Cl^-$, $NO_3^-$, and $SO_4^{2-}$), but does not explain why they should detect these ions and how to quantitatively analyse them. In addition, the textbooks do not explain how to use this information in day to day activities or later in life after graduating from high school . This study explained how it is possible to both detect and quantify the ions, and how they cause pollution, and the impact on human beings and the ecosystem. The topic on pollution can be handled beyond lecture method of teaching to become part of possible activity for hands-on activities and meeting the objectives of the curriculum. The EE themes considered in this study has the potential to introduce to the Zambian pupils: inquiry learning; discovery learning; problem based learning; and experiential and service learning. The study was designed to give a blueprint in curriculum reform by systematically tapping on the theories of instructional design (Gagné's theory) and other generally acceptable models of learning (the revised Bloom's taxonomy). In analysing the Zambian science curriculum, Chabalengula and Mumba (2012) reports that "…nearly all experiments in textbooks are at confirmation/verification level, with a few at structured inquiry level. For instance, 77% of experiments in chemistry books are confirmatory with only 14% and 5% at structured and guided inquiry, respectively" (p. 317). This study has the potential to introduce discovery learning in EE which can give way to experiential learning, and potentially reducing the number of confirmatory activities which pupils are required to do and increase on structured and guided inquiry.

By doing a detailed analysis of the water quality situation, the most problematic pollutants were established and instructions developed on how teaching objectives can be realised. By highlighting the relevant environment problems, the learner will be informed better about how to face and combat the environmental problems that affect them/or the people of Zambia. The hazards maps (appendix 1) are also meant to help the teacher give the learners a stimulus. Before the learners can start to process any new information, the instructor must gain the attention of the learners by showing the state of the environment in their neighbourhood and highlighting the problem(s) that needs to be taken care of. The visual images (hazard maps) generated were designed to present an appropriate stimulus; the maps give emphasis to distinctive features of the water pollution situation. Furthermore, the maps were designed to be elaborate about the makeup of the environment in a given location, similar to the way a labelled diagram of a plant cell is elaborate and narrative about the makeup of the cell. The images generated in this study managed to show the types of pollutants, where they are most acute and the probable cause (oil spill, failing sewer system, VOCs, heavy metals, mine effluent etc.); the impact on the pupils and society in general were extensively covered in this study; the location where the various types of pollutants are more pronounced are cited; the maps also gives insights about the concentration levels. The visual images further mention about seasonal variations of the pollutants.

The modules suggested in this study are intended to give a well organised and complete instructional package that can assist many educators in becoming more organized and staying focused on the instructional goals that will produce environmentally literate citizens that are aware of their environment and are equipped with the means of how to combat the environment woes in various regions of the country. The teaching objectives are also designed to achieve and conform to the high order thinking skills (HOTS) involving analysing, evaluating and creating information as explained in the revised blooms taxonomy  (Anderson et al., 2001). HOTS skills include analysing, evaluating and creating. This is in sharp contrast to the current Zambian EE practices which are mostly geared for learning of facts and concepts. The modules developed in this study were designed to help the teacher quickly and efficiently prepare a lesson plan which is relevant to the region or town where the EE lesson is to be conducted. The activities suggested are deliberately tailored to stimulate recall of prior learning; the teacher asks for recall of existing relevant knowledge (whether directly related or remotely connected) and in a stepwise fashion should build to higher order thinking skills such as application of the information which is taught.

Encoding of material to be stored in a long-term memory may take a number of forms, depending to a large extent on the learning outcome to be expected (Gagné, 1977). The process of encoding in this study utilised hazard maps showing several pollution parameters across a vast geographical region of Zambia. Gagné argues that diagrams and graphs, for example, may be presented to the learner to present rules and definitions, procedures, or a collection of information. In this particular study, the images were designed to give a collection of information about the nature, constitution and distribution of the pollutants, and the probable causes of the observed pollution. “The image that is stored as a result of viewing a picture can be, and is, retrieved in its specific form” (ibid, p. 308).  In addition, the images were designed to guide the process of learning according to Gagné and Briggs (1979) who argue that there are three aspects of leaning, these include: the performance to be acquired as a result of learning; the internal conditions that need to be present for learning to occur and; the external conditions which are established to bring essential stimulation to bear upon the leaner. Performance that indicates a fact has been learned consists of stating a relation between two or more named objects or events. The statements indicating performance are indicated in the module (Chapter 9); these statements may be made either orally (through the suggested group discussions) or in writing. To learn and remember about the water pollution situation, for example in Lusaka, a larger context of meaningful body of information needs to be recalled. An image of a pollutant of interest can be presented and link it with their residential areas and school and any other place frequently visited by the pupils. This new fact is associated by the learner with this information context. And externally, a visual image presenting pollution (source of pollution, extent of pollution, and type of pollution) in a given town is presented to stimulate the recall of the larger body of meaning information. The new fact is then presented, usually by means of a verbal statement or external communication. This communication may also suggest the association to be acquired, as in conveying that Lusaka city is predominantly polluted by manganese.

Furthermore, this study is suggesting that if there are skills that are part of a procedure and hence will be performed together in the future; these items may be grouped into a unit. Posner and Rudnitsky (1986) propose *the utilization-related basis for clustering* as a consideration of how the intended learning outcomes are to be used in future by the learner. Posner and Rudnitsky further argue that certain facts or theories may be expected to be used together in solving personal or society problems and that this may be a consideration for clustering. The utilization-related basis for clustering is probably most appropriate in EE because the future use of the learning outcomes is specific and even predictable, and this future use of the learnings is probably a prime. The following is an example of intended learning outcomes clustered on a utilization-related basis (the unit being water pollution as a societal problem): understands how industry in their localities and beyond augments pollution; understand how residential areas causes different forms of pollution; understand how private citizens cause pollution; understand the extent and type of pollution being contributed to the environment.

Conducting scientific inquiry requires that students have easy, equitable, and frequent opportunities to use a wide range of equipment, materials, supplies, and other resources for experimentation and direct investigation of phenomena (National Science Education Standards, 1996). Policy makers and curriculum developers need to bear in mind that equipment needs to be upgraded frequently and requires preventive maintenance. Given that materials appropriate for inquiry-based science teaching are central to achieving the educational goals set forth in the standards, it is critical that an effective infrastructure for material support be a part of any science program. This can be achieved by action research such as presented in this study.

With rampart pollution prevailing in Zambia, either from bacteria, chemical and/or physical contamination, there is a need to promote water based lesson activities in the curriculum. The activities, hitherto, in the Zambian curriculum do not demand that pupils delve into the water in their environment, albeit water quality issues are at the centre of not only the pupils' [human beings] lives but all living organisms. This study demonstrated that equipment or resources for such a task can be made available and affordably by any high school, and why it is appropriate to include such activities in the chemistry curriculum.

Through the visual images (maps) and water pollutant analysis methods developed in this study, it is hypothesised that learners will better understand their relation to other interlinking chains of natural systems and socio-ecological processes. Through the lessons (module) developed, it is further postulated that the learners should be able to interpret conditions into their own frameworks, since much of what we learn about 'reality' is determined and shaped by our individual worldviews and backgrounds. Overall, through the developed lessons, the learners should be able to critique conditions and uncover hidden ideologies or assumptions underlying specific environmental problems in their region and beyond. That which is learned must drive the learner towards attitudinal transformation. Knowledge of environmental issues must be built for the ultimate objective of action and practical change.

The lessons/module suggested in this study enable learners to have a role in planning their learning experiences and provide an opportunity for making decisions and accepting their consequences. This can done by allowing schools to determine levels of pollution in local environmental waters; effectively this can help learners discover the symptoms and real causes of environmental problems. The modules were also designed to utilise diverse learning environments and a broad array of educational approaches to teaching/learning about and from the environment with due stress on practical activities and first-hand experience. Furthermore, the four inquiry levels: Confirmation, Structured, Guided and Open were incorporated in the teaching modules and also recommended that the other topics in chemistry can be upgraded to meet these four criterions without any added cost and change in the existing science education program.

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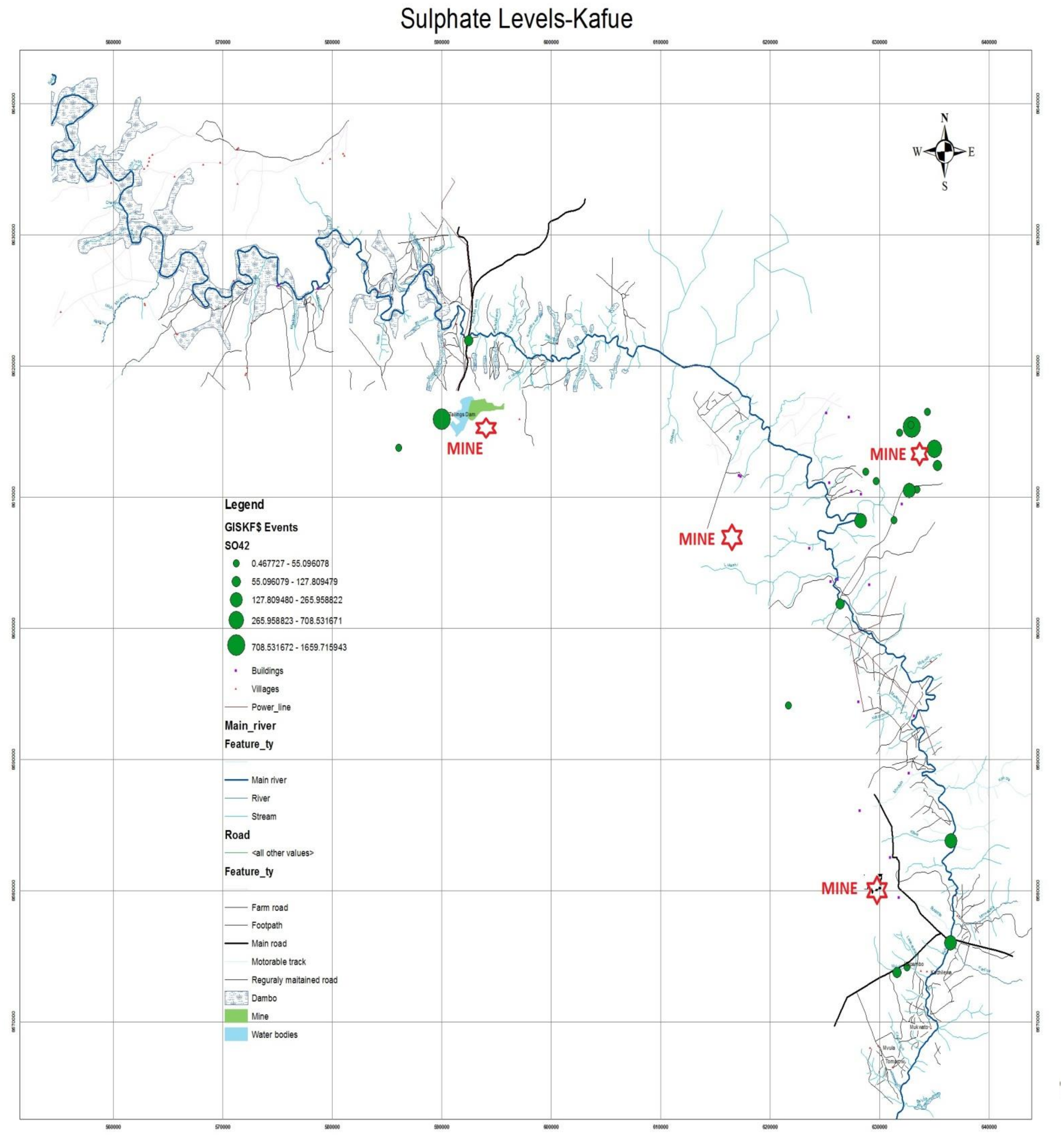
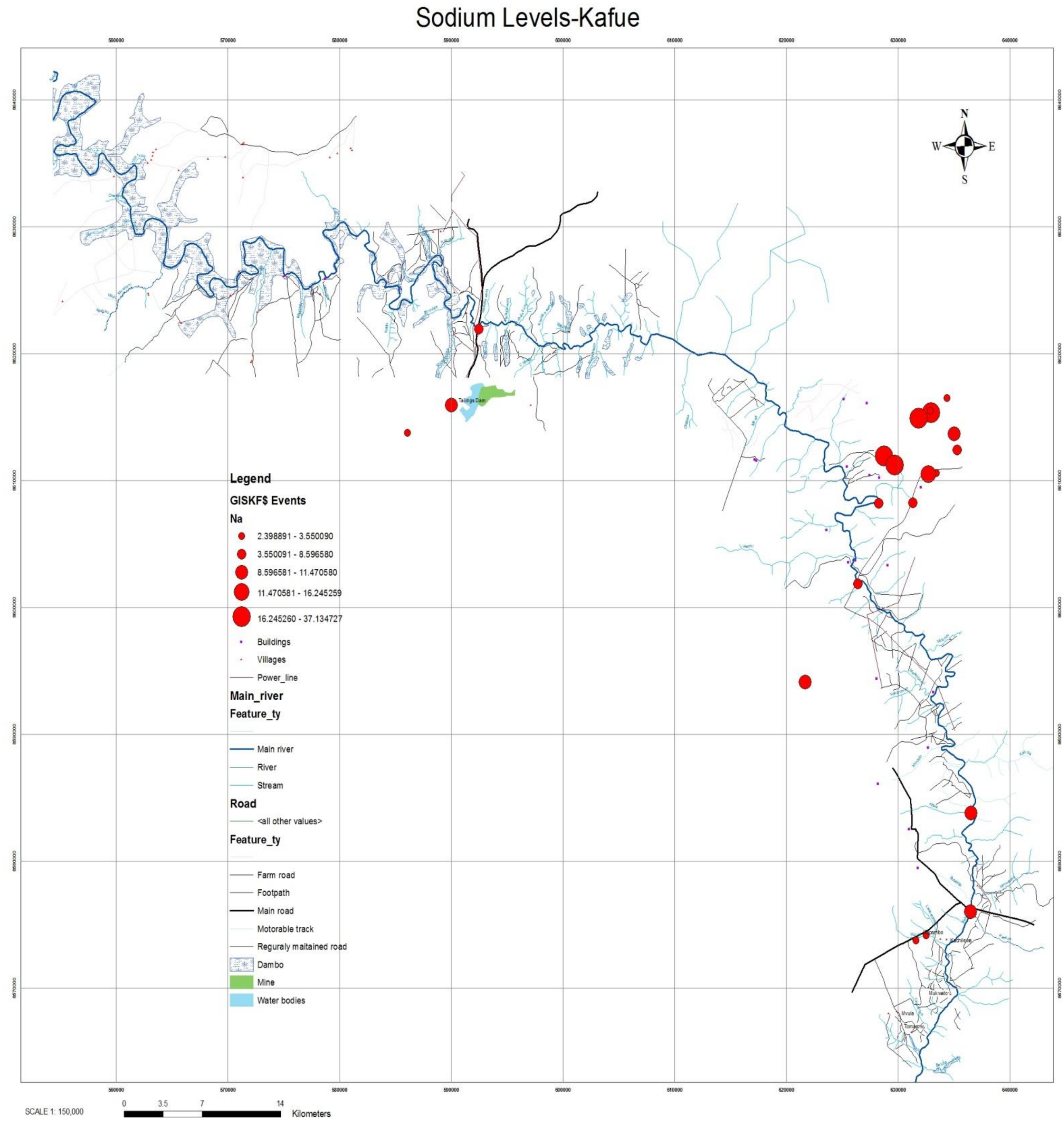
**Appendix 1.** Educational hazards maps

Appendix 1A

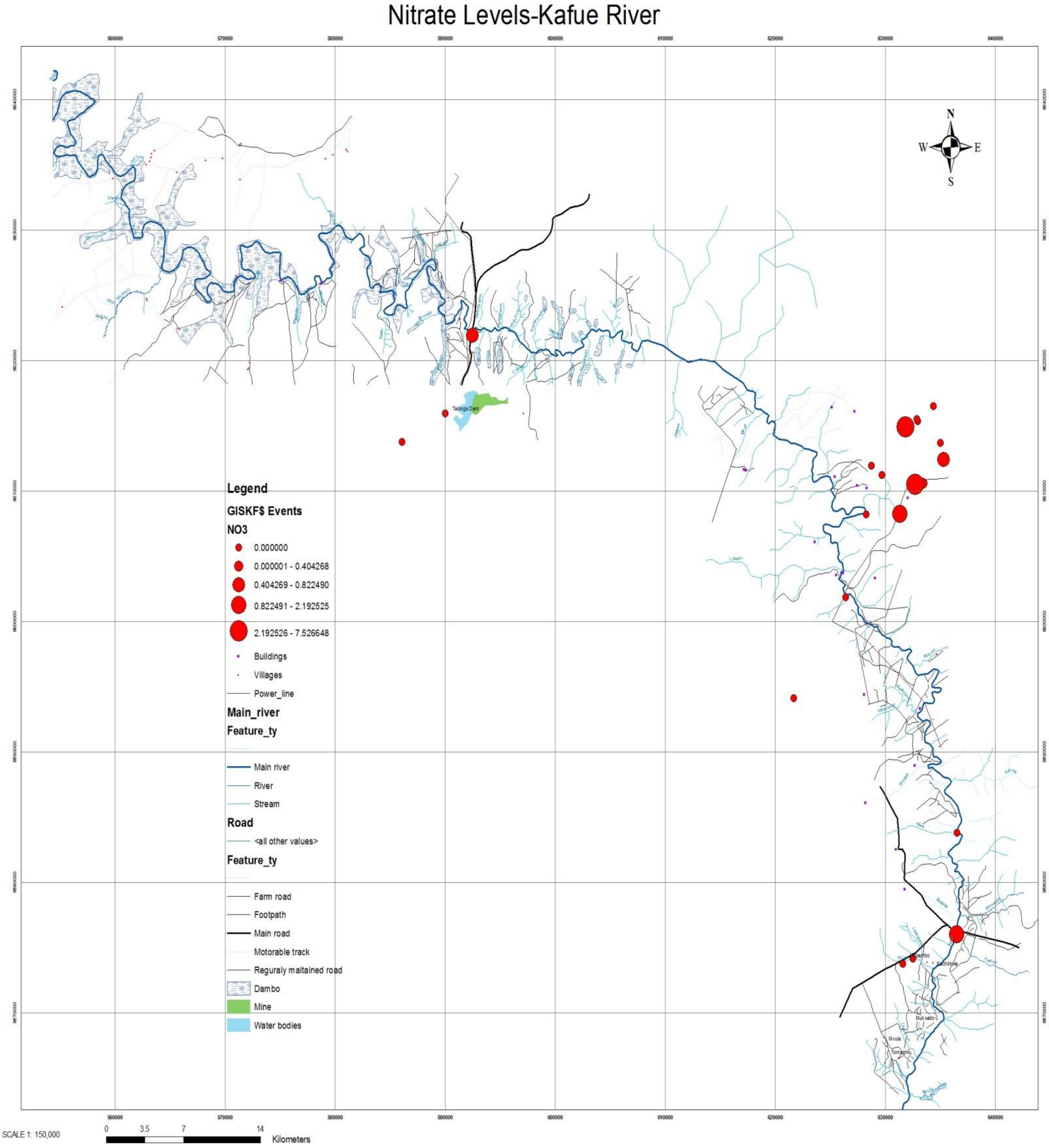


Appendix 1B

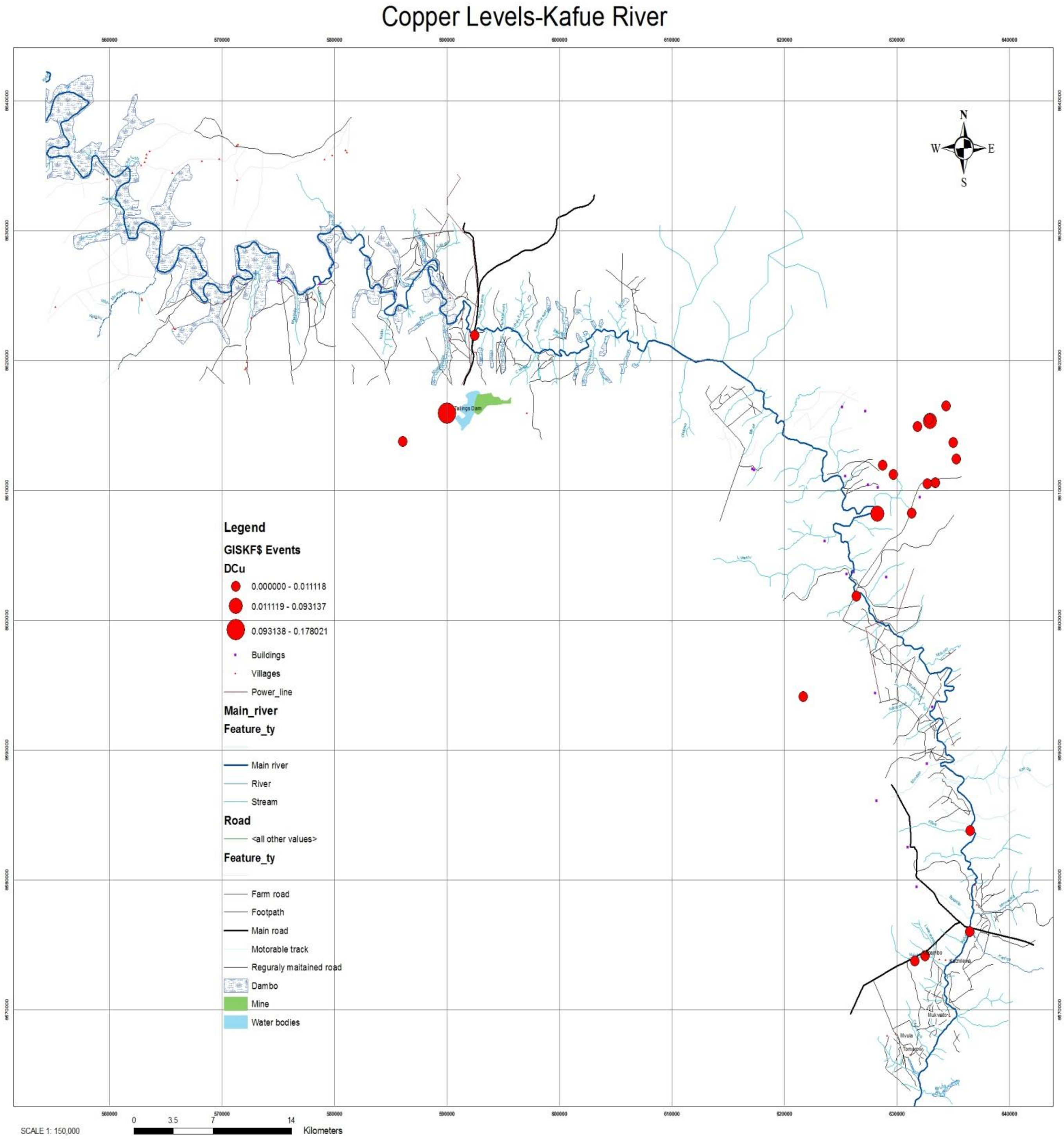


Sodium Levels-Kafue

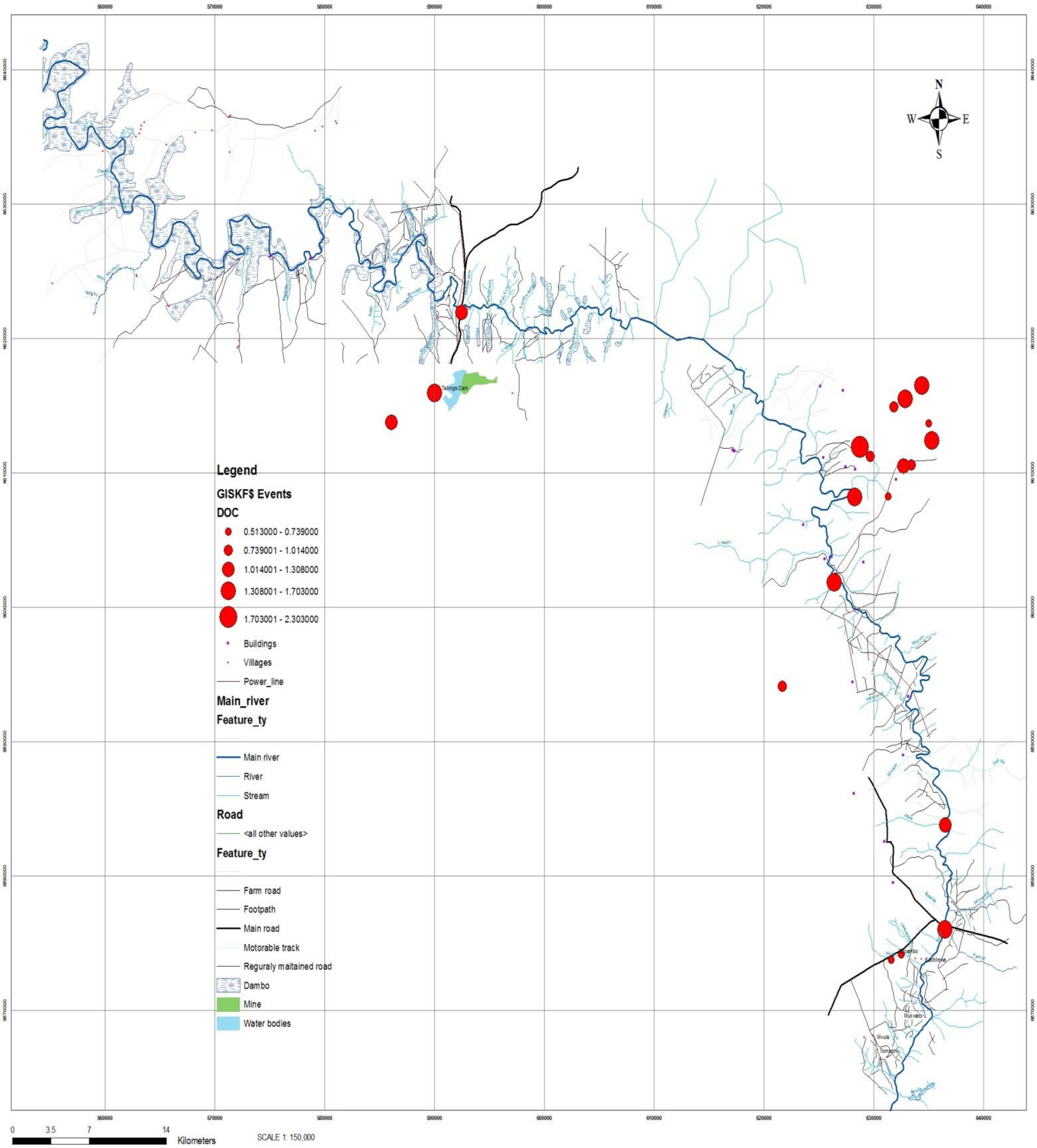
Appendix 1C


Nitrate Levels-Kafue River
560000
570000
580000
590000
600000
610000
620000
630000
640000
N
S
E
W
Tailings Dam
Legend
GISKF$ Events
NO3
0.000000
0.000001 - 0.404268
0.404269 - 0.822490
0.822491 - 2.192525
2.192526 - 7.526648
Buildings
Villages
Power_line
Main_river
Feature_ty
Main river
River
Stream
Road
<all other values>
Feature_ty
Farm road
Footpath
Main road
Motorable track
Reguraly maitained road
Dambo
Mine
Water bodies
Mukwato
Mvula
Kachinwe
SCALE 1: 150,000
0
3.5
7
14
Kilometers

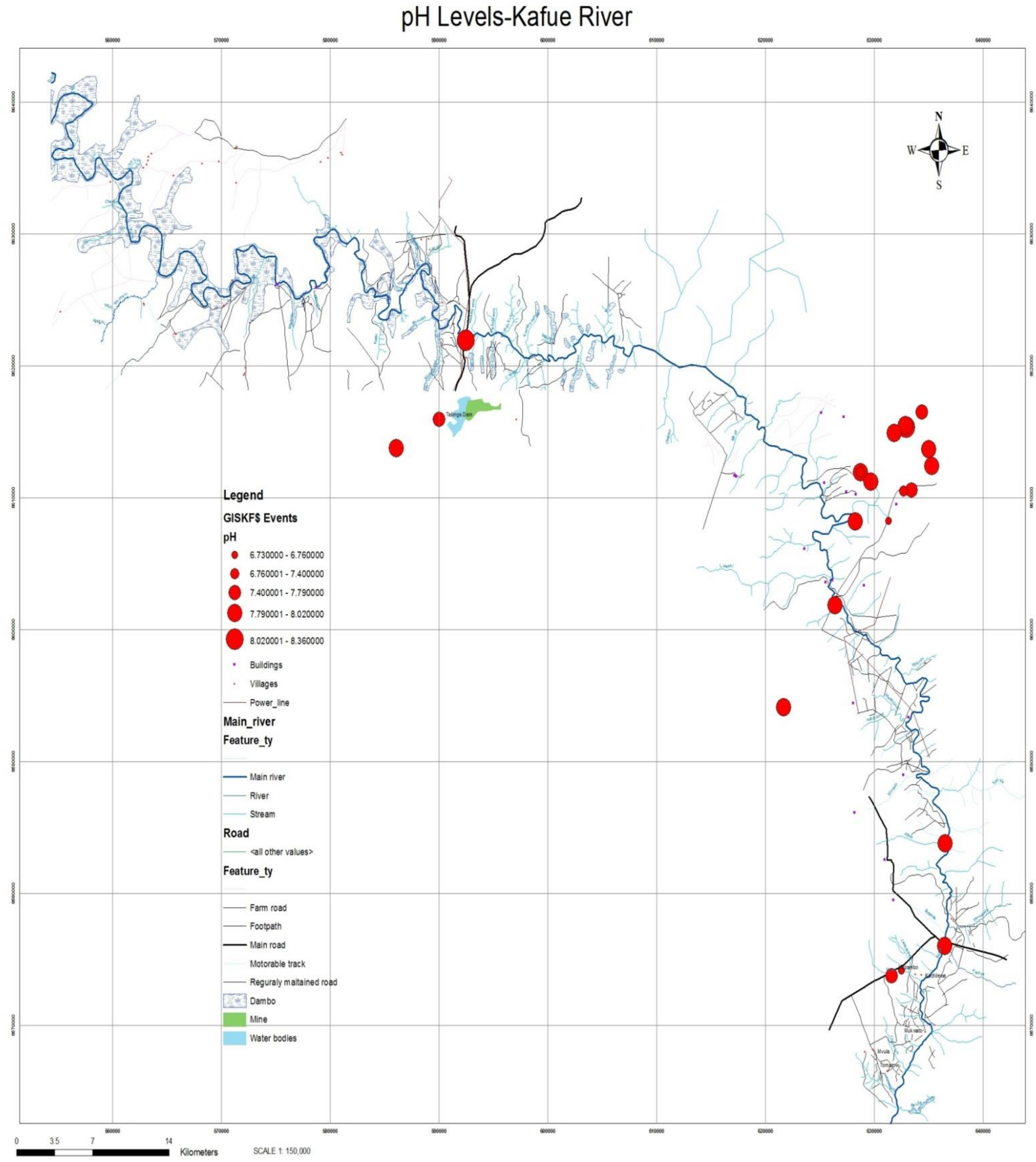
Appendix 1D


Copper Levels-Kafue River
N
W
E
S
Tailings Dam
Legend
GISKF$ Events
DCu
0.000000 - 0.011118
0.011119 - 0.093137
0.093138 - 0.178021
Buildings
Villages
Power_line
Main_river
Feature_ty
Main river
River
Stream
Road
<all other values>
Feature_ty
Farm road
Footpath
Main road
Motorable track
Reguraly maitained road
Dambo
Mine
Water bodies
SCALE 1: 150,000
0
3.5
7
14
Kilometers

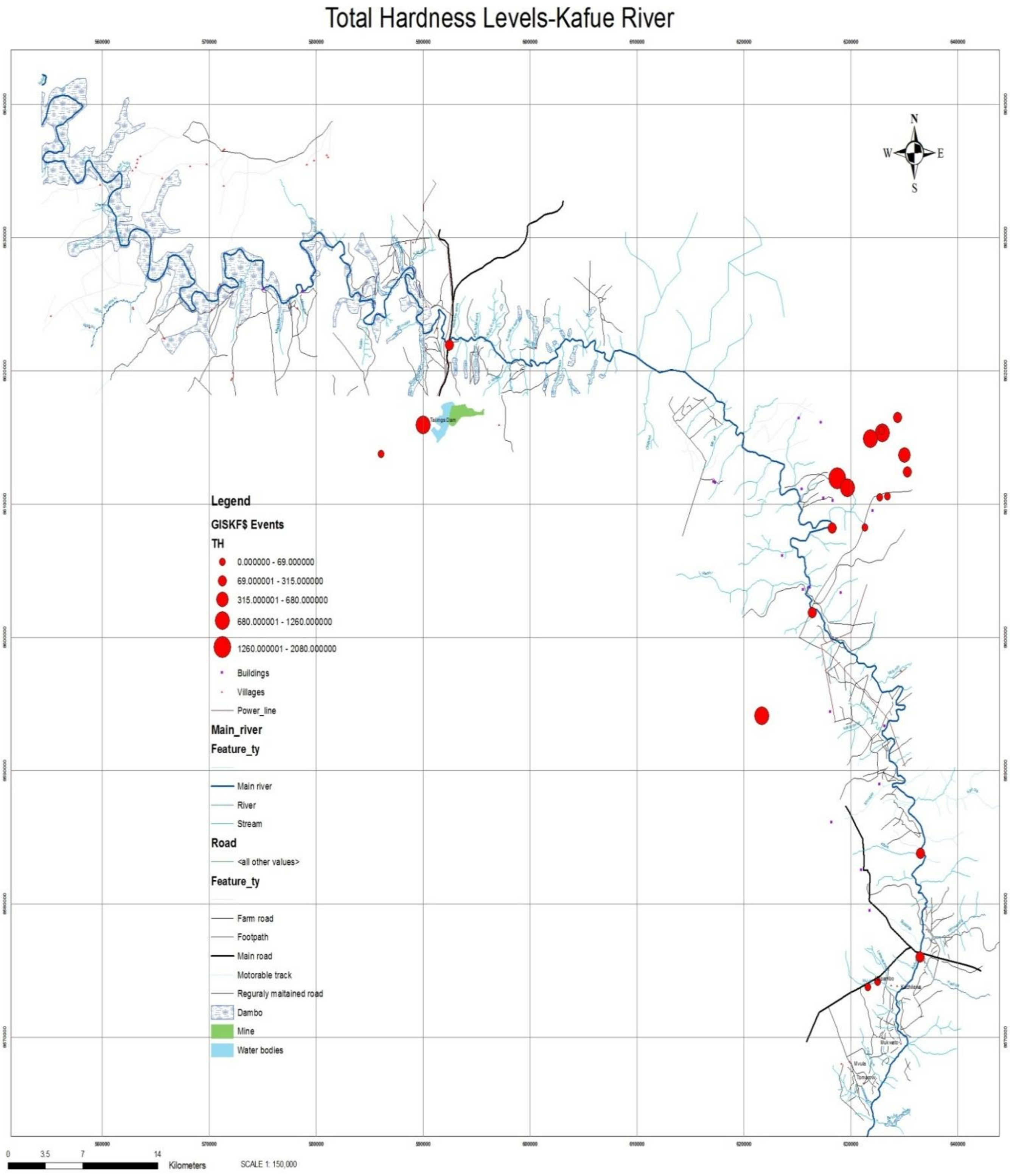
Appendix 1E


DOC Levels-Kafue River

Appendix 1F

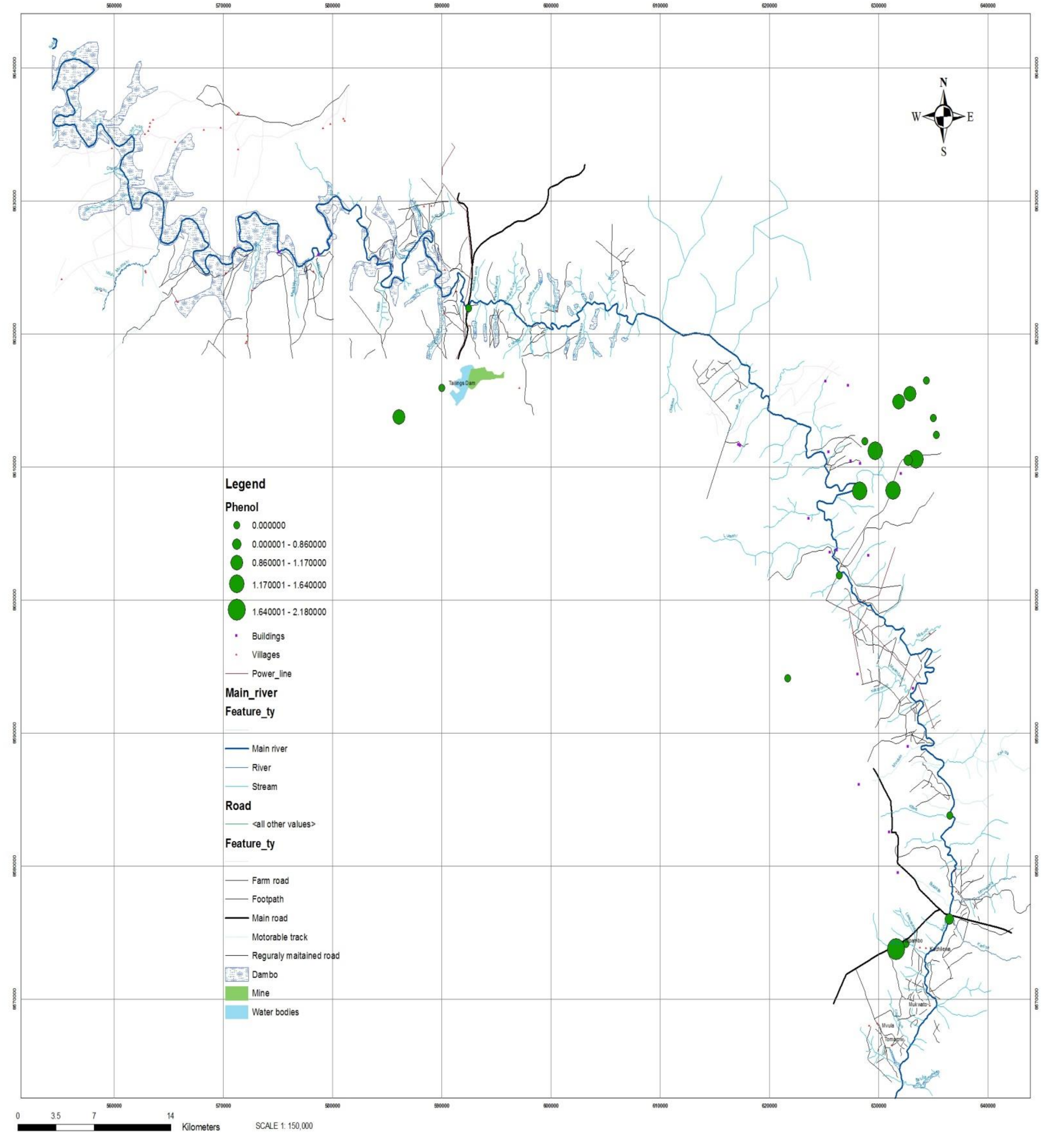

pH Levels-Kafue River
N
W
E
S
Tailings Dam
Legend
GISKF$ Events
pH
6.730000 - 6.760000
6.760001 - 7.400000
7.400001 - 7.790000
7.790001 - 8.020000
8.020001 - 8.360000
Buildings
Villages
Power_line
Main_river
Feature_ty
Main river
River
Stream
Road
<all other values>
Feature_ty
Farm road
Footpath
Main road
Motorable track
Reguraly maitained road
Dambo
Mine
Water bodies
0
3.5
7
14
Kilometers
SCALE 1: 150,000

Appendix 1G

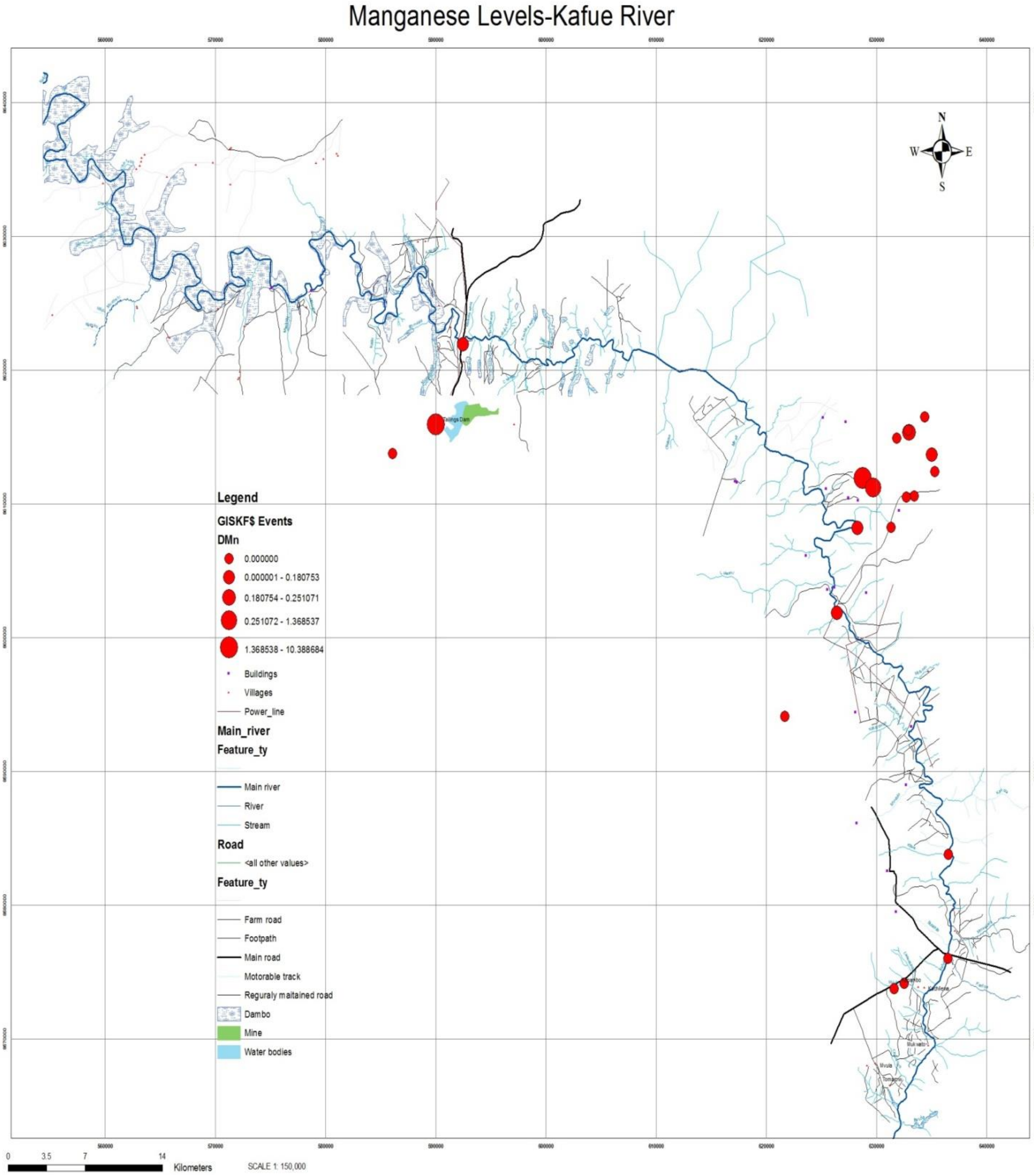

Total Hardness Levels-Kafue River
N
W
E
S
Taslinga Dam
Legend
GISKF$ Events
TH
● 0.000000 - 69.000000
● 69.000001 - 315.000000
● 315.000001 - 680.000000
● 680.000001 - 1260.000000
● 1260.000001 - 2080.000000
Buildings
Villages
Power_line
Main_river
Feature_ty
Main river
River
Stream
Road
<all other values>
Feature_ty
Farm road
Footpath
Main road
Motorable track
Reguraly maitained road
Dambo
Mine
Water bodies
0 3.5 7 14
Kilometers
SCALE 1: 150,000

Appendix 1H

## Phenol Levels-Kafue River

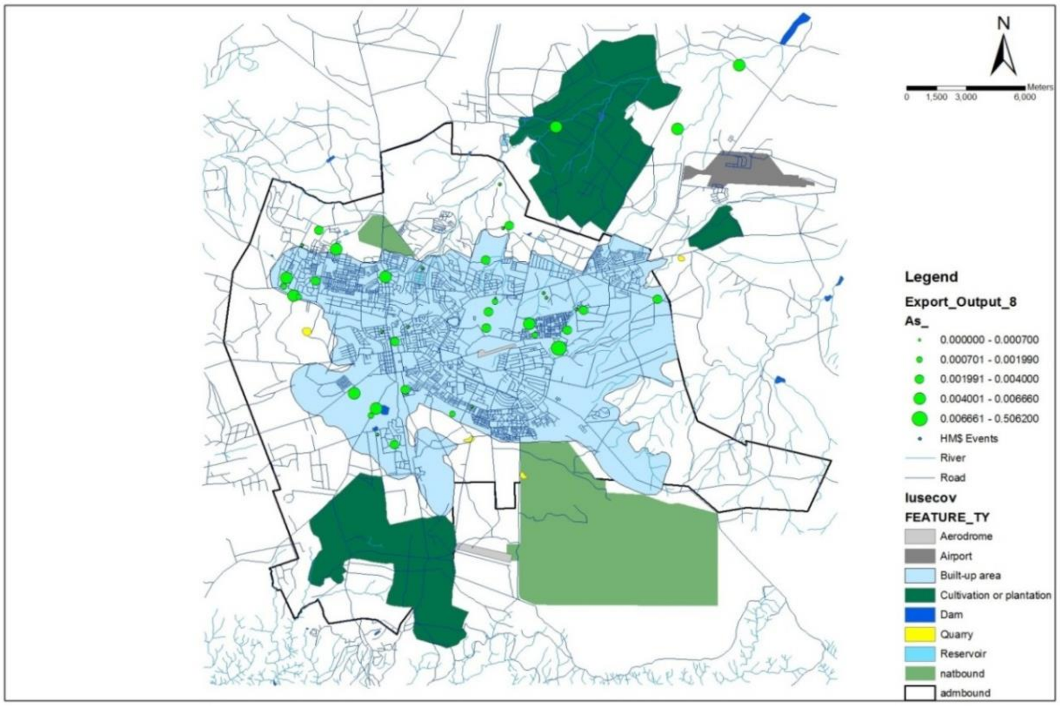


Appendix 1I


Manganese Levels-Kafue River
N
W
E
S
Tailings Dam
Legend
GISKF$ Events
DMn
0.000000
0.000001 - 0.180753
0.180754 - 0.251071
0.251072 - 1.368537
1.368538 - 10.388684
Buildings
Villages
Power_line
Main_river
Feature_ty
Main river
River
Stream
Road
<all other values>
Feature_ty
Farm road
Footpath
Main road
Motorable track
Reguraly maitained road
Dambo
Mine
Water bodies
0
3.5
7
14
Kilometers
SCALE 1: 150,000

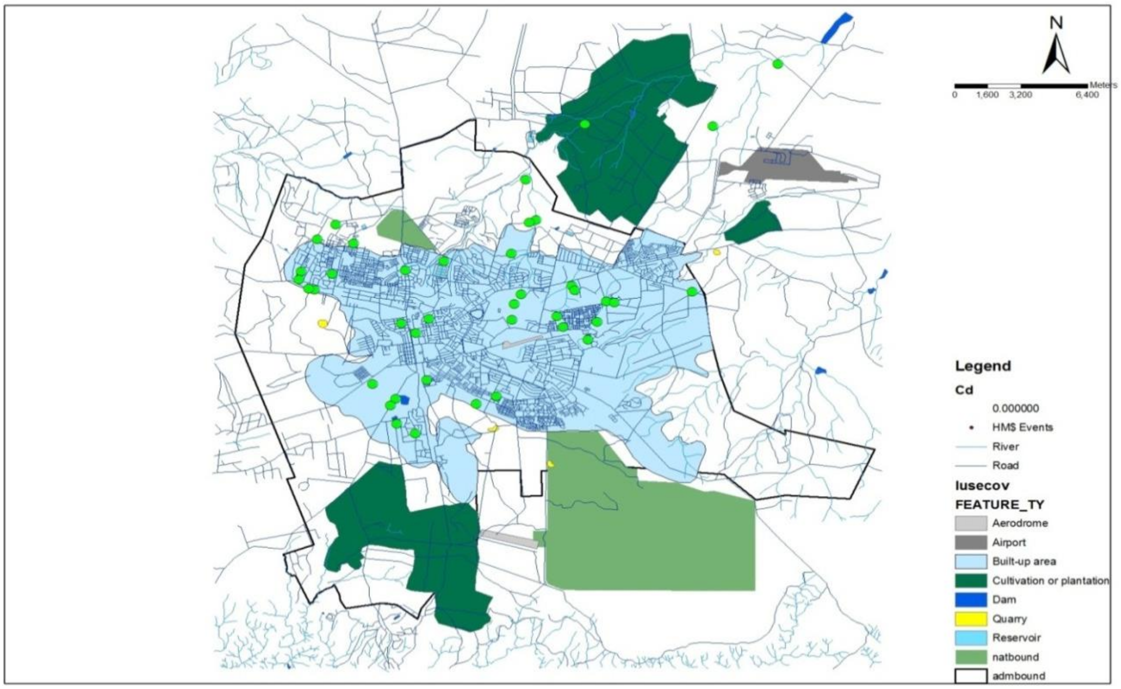
Appendix 1J

## Arsenic Levels-Lusaka



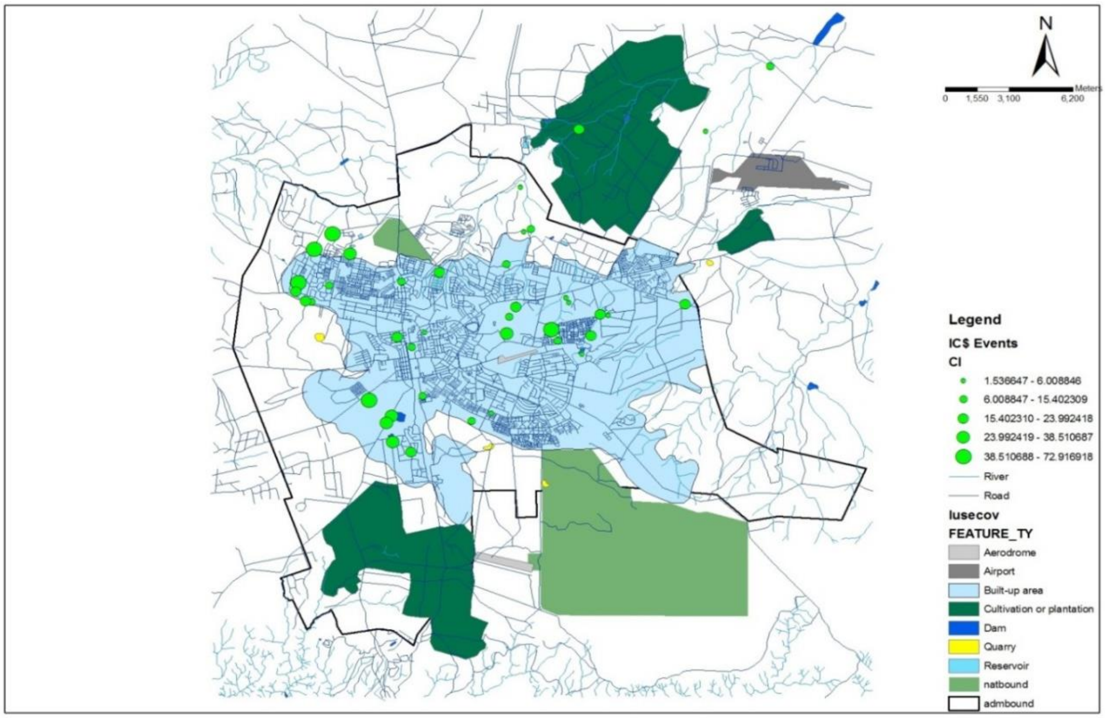
Appendix 1K

## Cadmium Levels-Lusaka



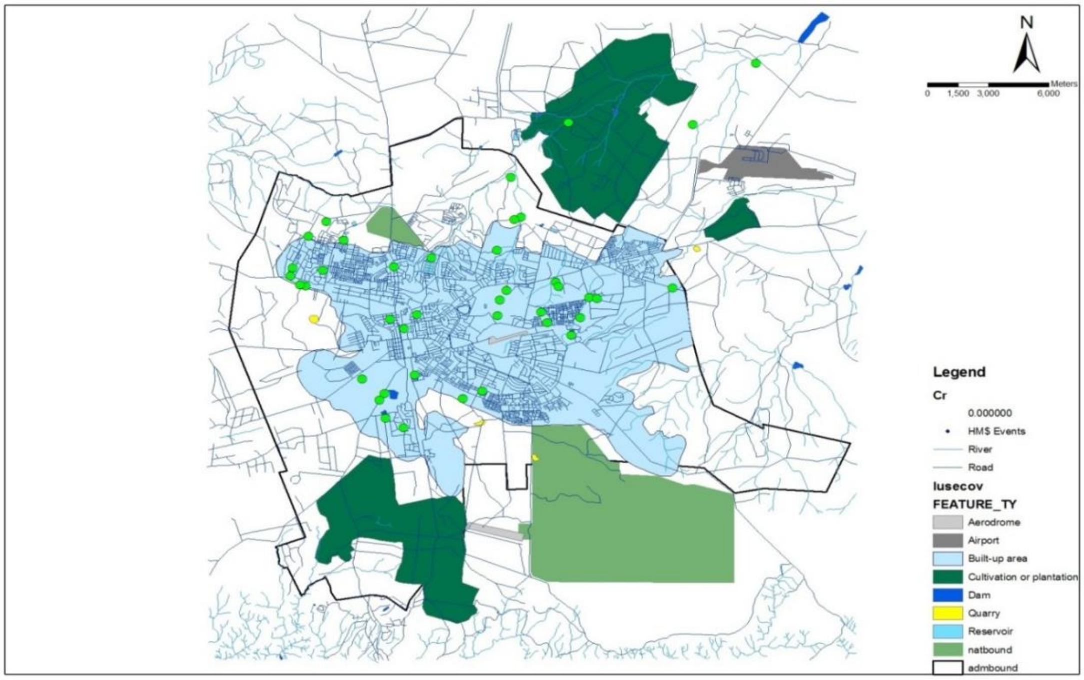
Appendix 1L

## Chloride Levels-Lusaka

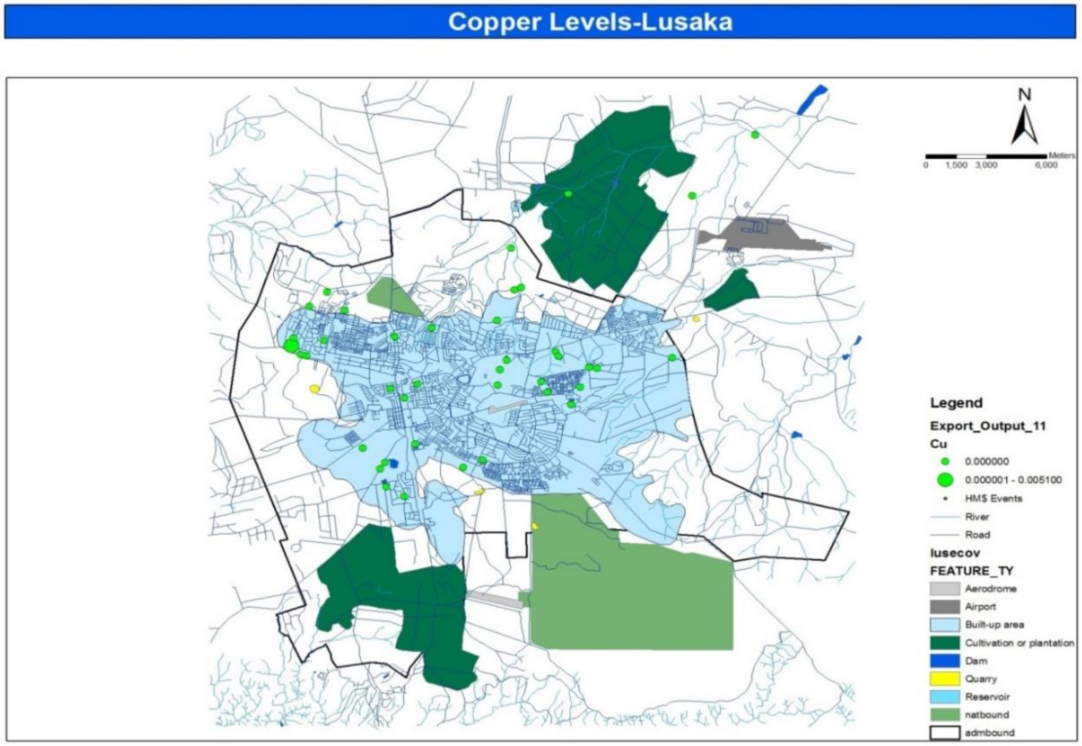


Appendix 1M

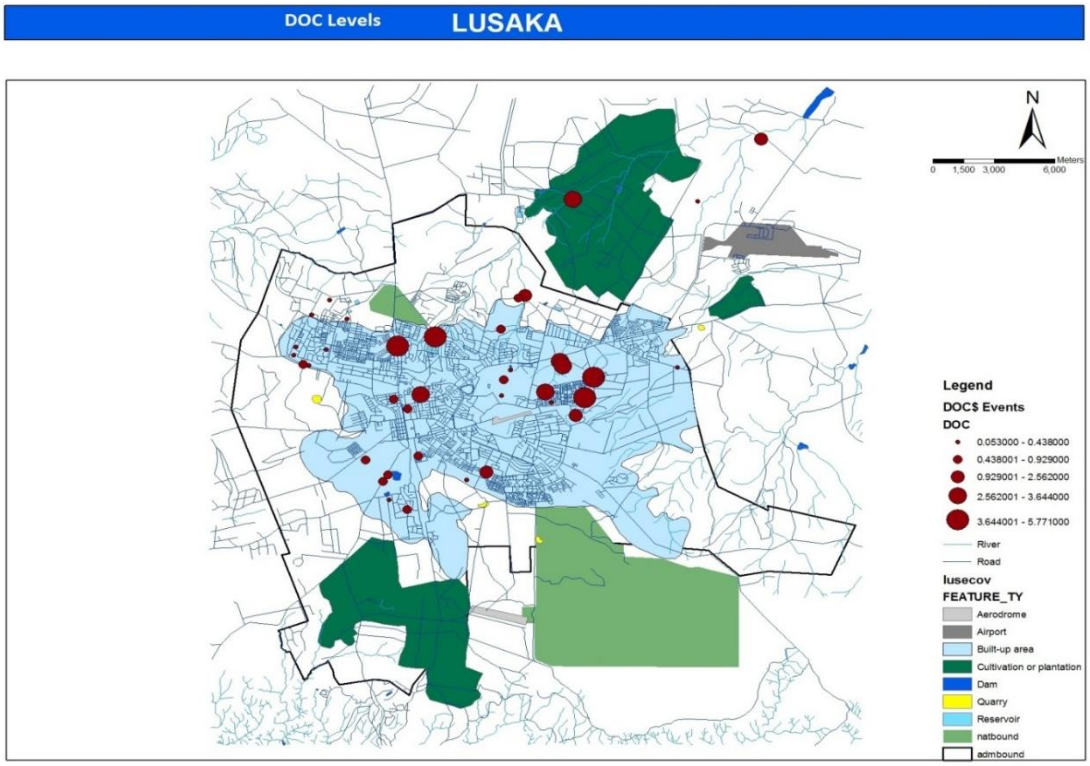
## Chromium Levels-Lusaka



Appendix 1N

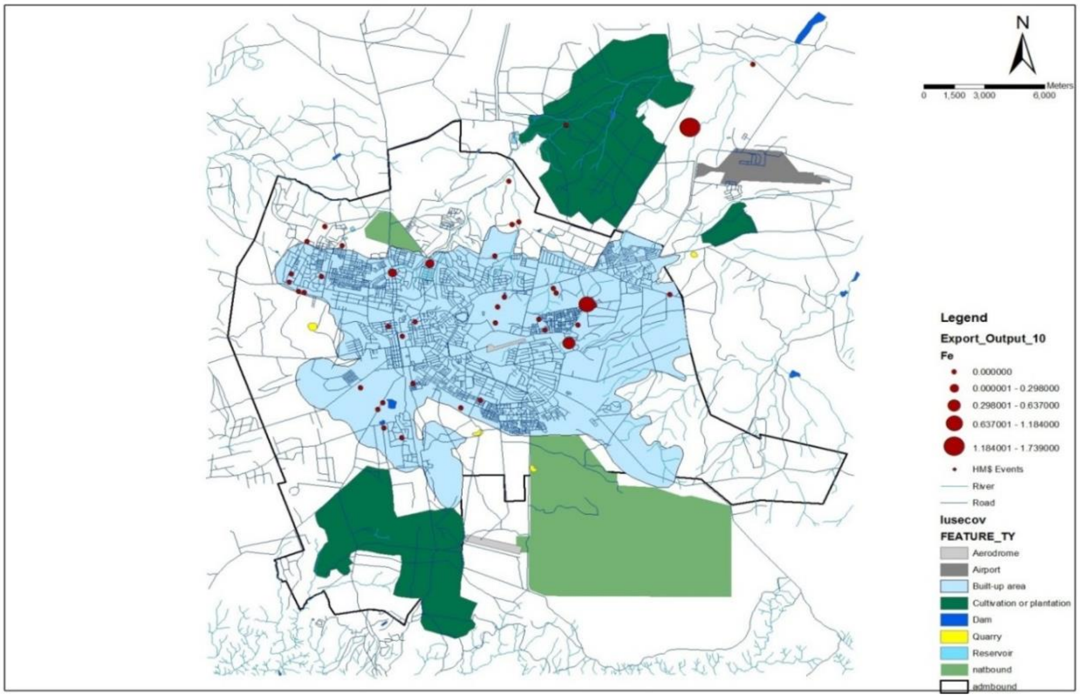


Appendix 1O



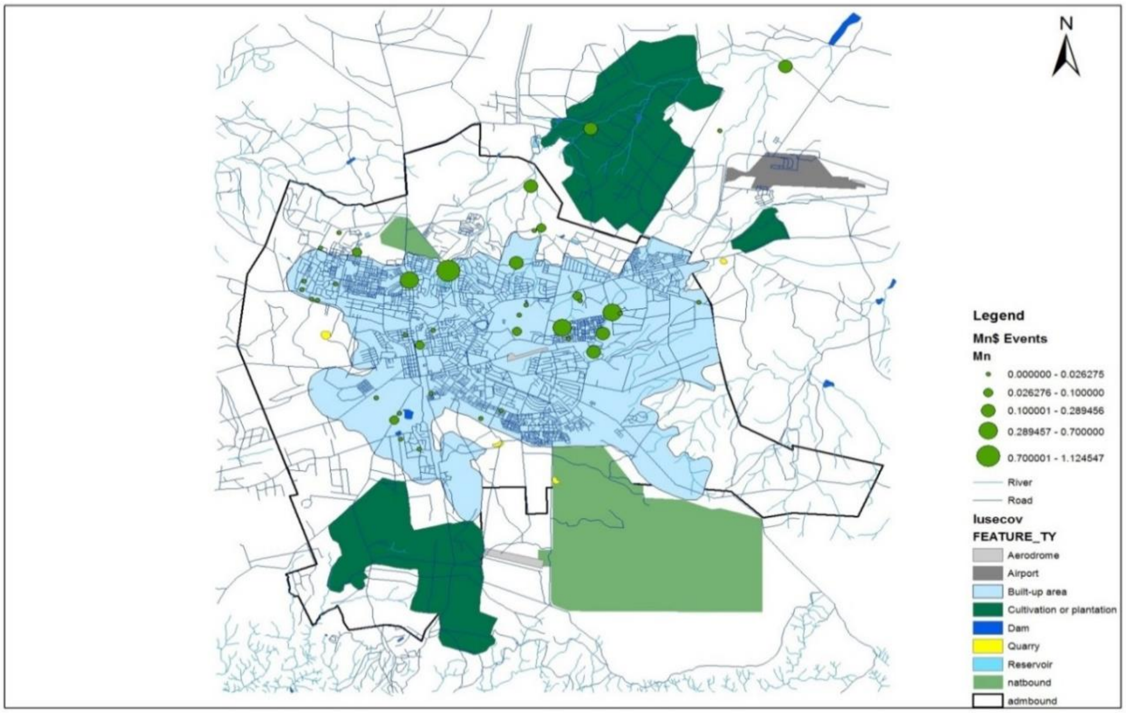
Appendix 1P

## Iron Levels-LUSAKA



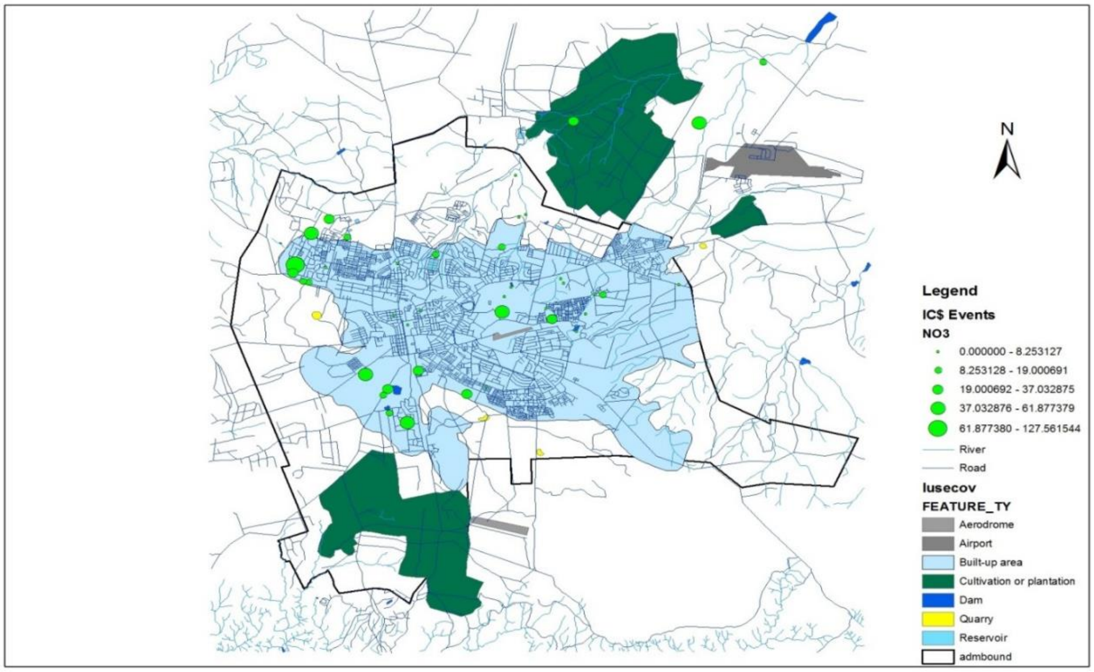
Appendix 1Q

## Manganese Levels-Lusaka



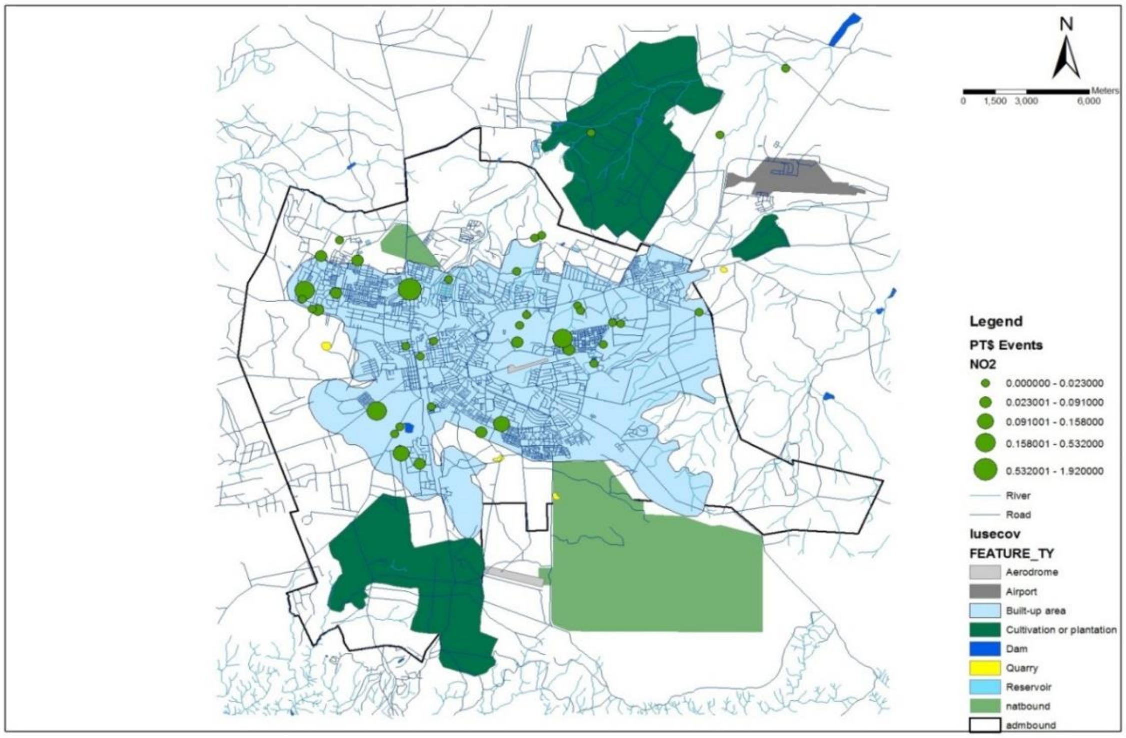
Appendix 1R

## Nitrate Levels-Lusaka



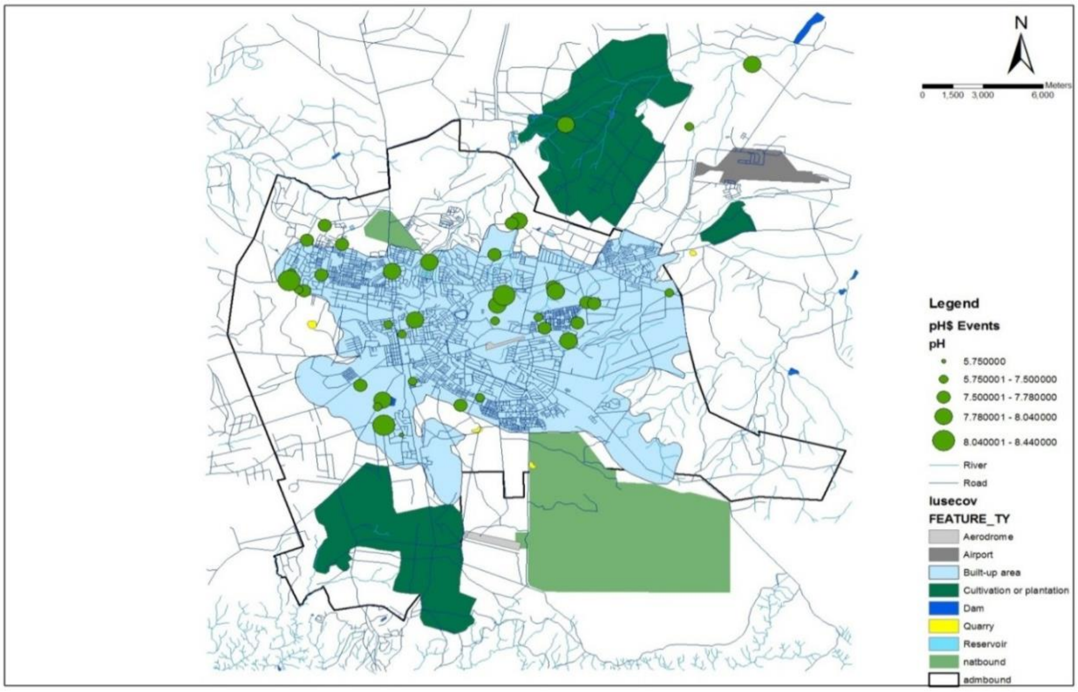
Appendix 1S

## Nitrite Levels-Luska



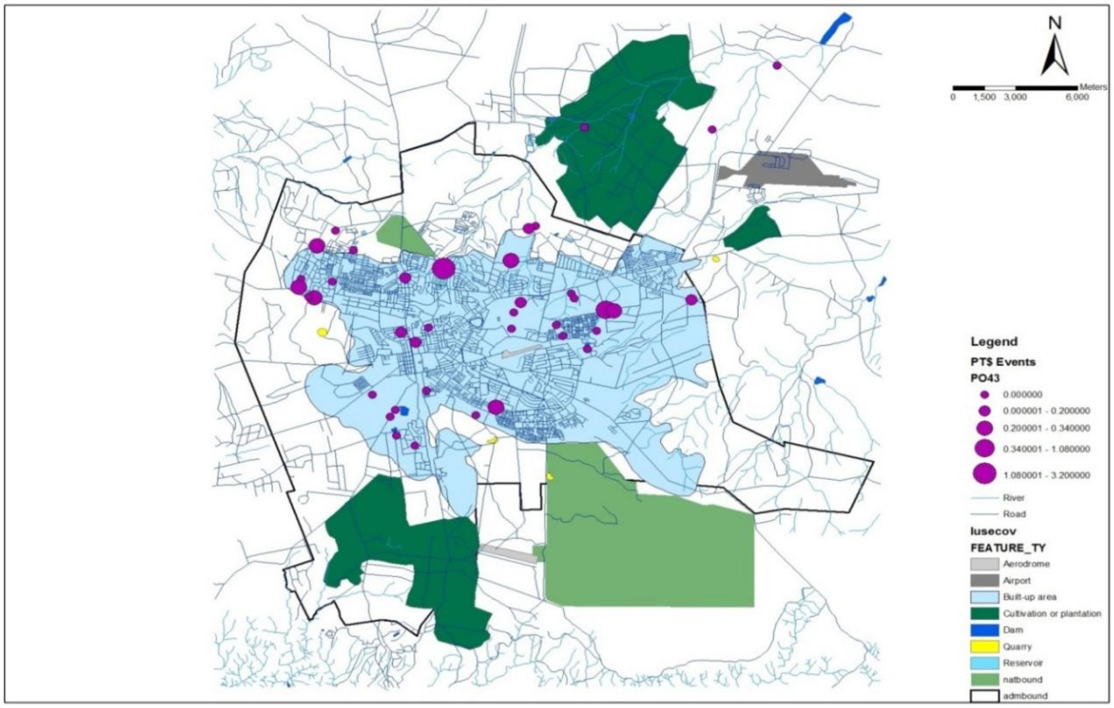
Appendix 1T

## pH Levels-Lusaka



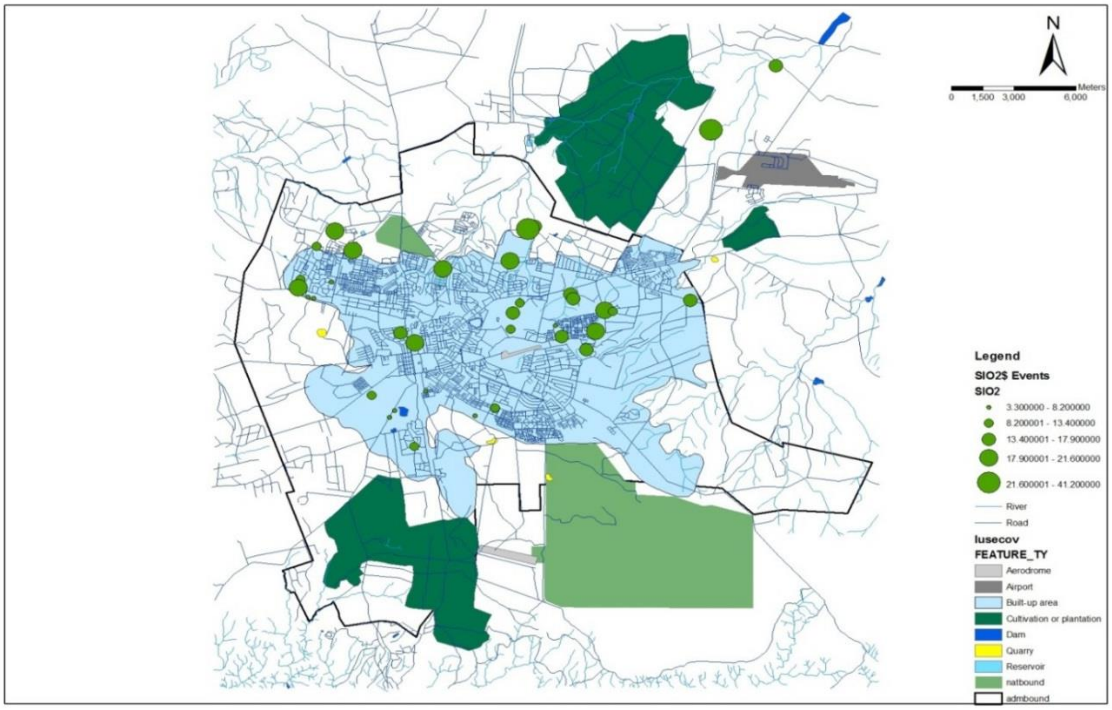
Appendix 1U

## Phosphate Levels-Lusaka



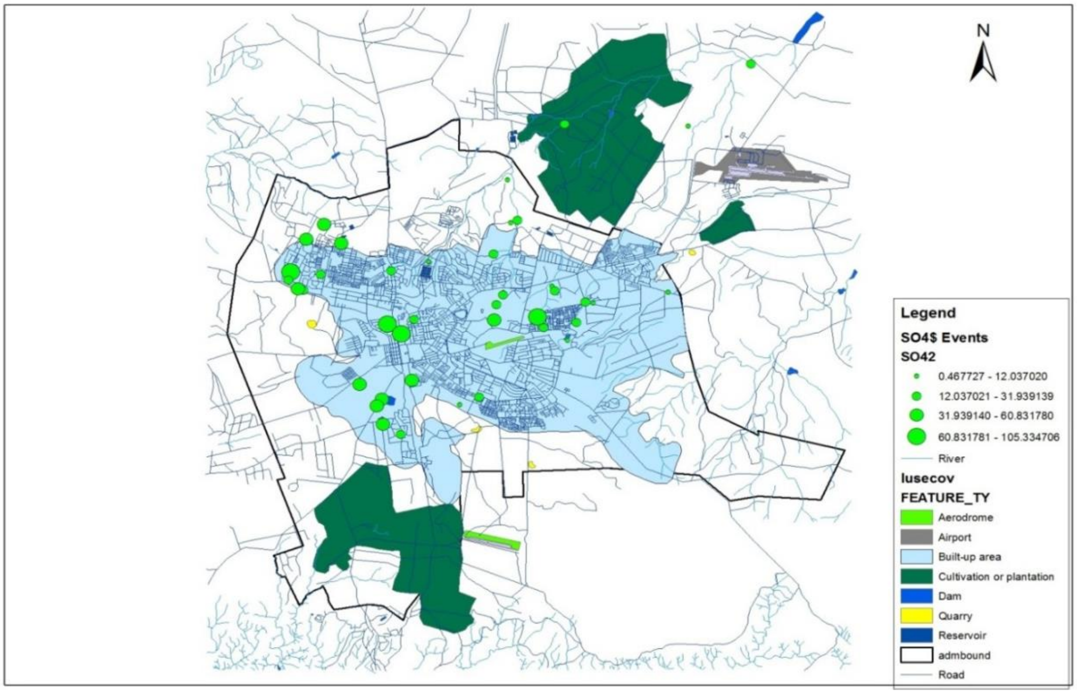
Appendix 1V

## Silicon Dioxide-Lusaka



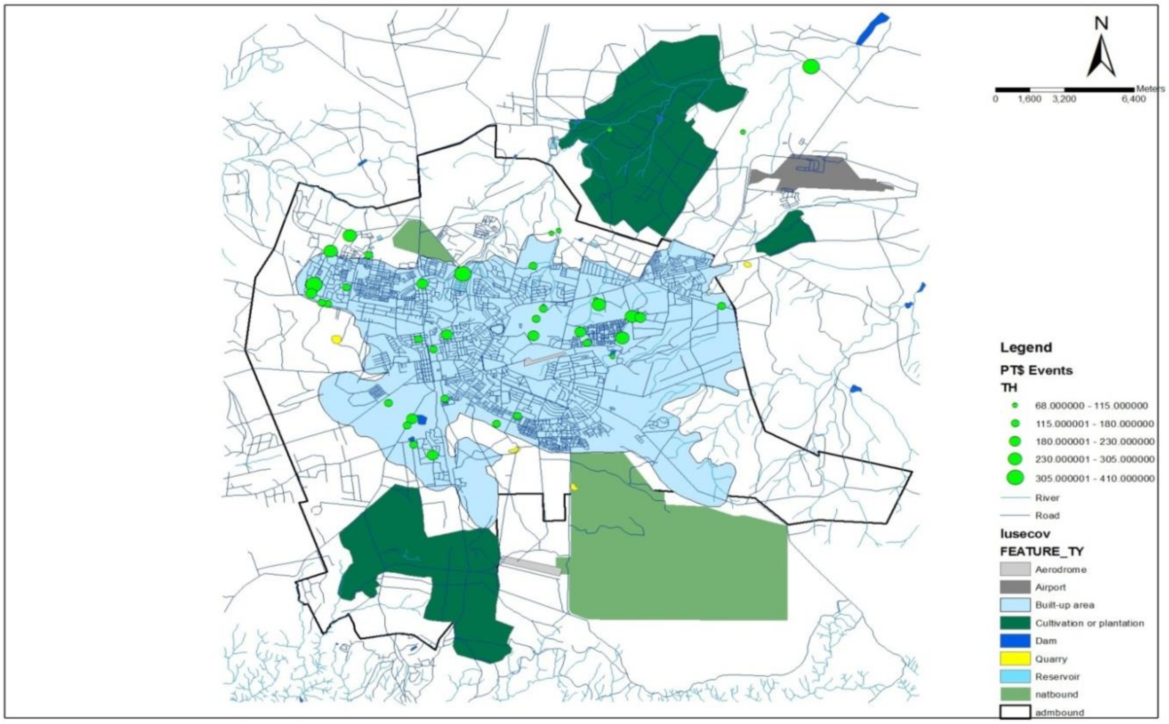
Appendix 1W

## Sulphate Levels-Lusaka



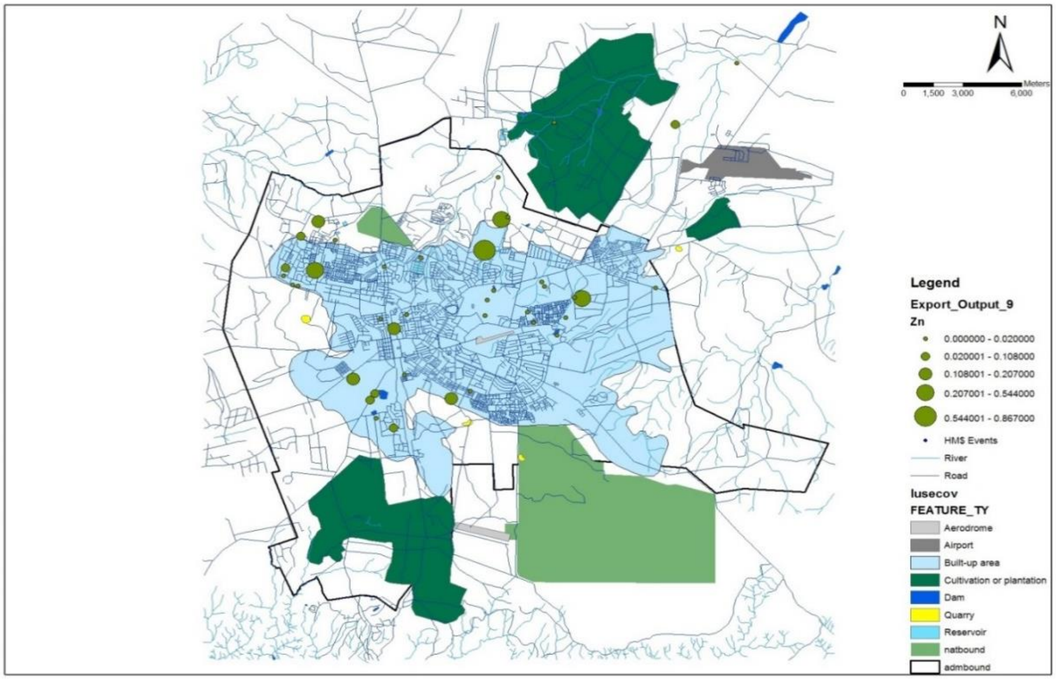
Appendix 1X

## Total Hardness Levels-Lusaka



Appendix 1Y

## Zinc Levels-Lusaka



## **Appendix 2.** Comparison of Water Quality Standards

| **Parameter** | **WHO Drinking Water Quality Guidelines, 1993** | **Zambia Standard Specification for Drinking Water Quality. Zambia Bureau of Standards** | **ECZ Waste Regulation into Aquatic Environment, 1993** | **Trade Effluent into a Public Sewer, Local Administration Regulation Act (No. 161), 1985** |
|---|---|---|---|---|
| Active Bromine | | | 0.10 ppm | 0.50 - 3.00 ppm |
| Active Chloride | | | 0.5 ppm | 0.50 - 3.00 ppm |
| Algae/ 100 ml | | | 1000 cells | |
| Aluminium Compounds | | 0.20 ppm | 2.5 ppm | < 20.00 ppm |
| Ammonia | 1.5 ppm | | 10.00 ppm | 30.00 ppm |
| Antimony | | | 0.50 ppm | 0.50 ppm |
| Arsenic | 0.01 ppm | 0.05 ppm | 0.05 ppm | 1.00 ppm |
| Barium | | | 0.50 ppm | 1.00 ppm |
| Beryllium Compounds | | | 0.50 ppm | 0.50 ppm |
| BOD | | | 50 ppm $O_2$/l | 1200 ppm |
| Boron | | | 0.50 ppm | < 50.00 ppm |
| Cadmium | | 0.005 ppm | 0.50 ppm | 1.50 ppm |
| Calcium | | 200 ppm | | |
| COD | | | 90 $O_2$/l (average for 24 hrs.) | 1800 ppm |
| Chlorides | | 250 ppm | 800 ppm | 1000 ppm |
| Chromium Hexavalent | | | 0.10 ppm | 5.00 ppm |
| Cobalt | | 0.50 ppm | 1.00 ppm | 0.50 ppm |
| Colour | 15 True Colour | 15 True Colour | 20 Hazen Units | Note 1 |
| Conductivity (EC) | | 2300 MS | 4300 MS | |
| Copper | 2.00 ppm | 1.00 ppm | 1.50 ppm | 3.00 ppm |
| Cyanides | 0.07 ppm | 0.10 ppm | 0.2 | 0.50 ppm |
| Dissolved Oxygen (DO) | | | after mixing > 5.00 ppm | no requirements |
| Fats & Saponification Oils | | | 20.00 ppm | install oil/water separators |
| Fluorides | 1.50 ppm | 1.50 ppm | 2.00 ppm | < 30.00 ppm |
| Iron | | 1.00 ppm | 2.00 ppm | 15.00 ppm |
| Lead | 0.01 ppm | 0.05 ppm | 0.50 ppm | 1.50 ppm |
| Magnesium | | 150 ppm | 500 ppm | < 1000 ppm |
| Manganese | 0.10 ppm | 0.10 ppm | 1.00 ppm | 10 ppm |
| Mercury | 2.00 ppm | 0.001 ppm | 0.002 ppm | 0.01 ppm |
| Molybdenum | | | 5.00 ppm | 5.00 ppm |
| Nickel | | | 0.50 ppm | 2.00 ppm |
| Nitrates | 50.00 ppm | 10.00 ppm | 50.00*ppm and 20.00**ppm | 80.00 ppm |

| **Parameter** | **WHO Drinking Water Quality Guidelines, 1993** | **Zambia Standard Specification for Drinking Water Quality. Zambia Bureau of Standards** | **ECZ Waste Regulation into Aquatic Environment, 1993** | **Trade Effluent into a Public Sewer, Local Administration Regulation Act (No. 161), 1985** |
|---|---|---|---|---|
| Nitrites | 3.00 ppm | 1.00 ppm | 2.00 $NO_2$ as N/l | 10.00 ppm $NO_2$ as N/l |
| Odour & Taste | | Unobjectionable | | No Nuisance |
| Oils | | | 5.00 ppm | 100 ppm |
| Organic Nitrogen | | | 5.00 ppm (mean) | 300 ppm N/I |
| Pesticides | | | 0.50 ppm | 1.00 ppm |
| pH | | | 6 to 9 | 6 to 10 |
| Phenols (Hydrocarbons) | | 0.002 ppm | 0.20 ppm | 5.0 ppm (1.0 ppm if by steam distillation) |
| Phosphates | | | | |
| Phosphorous | | | 1.00 ppm | 45.00 ppm |
| Salinity | | | | 7500 ppm |
| Selenium | 0.01 ppm | 0.01 ppm | 0.02 ppm | < 1.00 ppm |
| Silver | | 0.05 ppm | 0.10 ppm | 0.10 ppm |
| Sulphates | | 400 ppm | 1500 ppm | 500 ppm |
| Sulphide | | | 0.10 ppm | 1.00 ppm |
| Sulphite | | | 0.10 ppm | 10.00 ppm |
| Temperature | | | 40ºC at point of entry | 60ºC initially and after mixing < 40ºC |
| Thallium | | | 0.50 ppm | 1.00 ppm |
| Tin | | | 2.00 ppm | 2.00 ppm |
| Trihaloforms | | | 0.50 ppm | 1.00 ppm |
| Total Coliform/ 100ml | must not be detectable in 95 % of samples over 12 months | 0 | 5000 ppm | |
| Faecal Coliform/100 ml | Must not be detectable in any 100 ml sample | 0 | 2500 ppm | |
| TDS | | | 3000 ppm | |
| TPH | | | 10.00 ppm | 20.00 ppm |
| TSS | | | 100.0 ppm | 1200 ppm |
| Turbidity | | 10 Nephelometer Turbidity Units | 15 NTU | |
| Vanadium | | | 1 ppm | 1.00 ppm |
| Zinc Compounds | | 5.00 ppm | 10.00 ppm | 25.00 ppm |

**Appendix 3.** Examples of overt verbs associated with the levels of Bloom's taxonomy

| **Remembering** | **Understanding** | **Applying** | **Analysing** | **Evaluating** | **Creating** |
|---|---|---|---|---|---|
| Count | Associate | Add | Analyse | Appraise | Categorize |
| Define | Compute | Apply | Arrange | Assess | Combine |
| Describe | Convert | Calculate | Breakdown | Compare | Compile |
| Draw | Defend | Change | Combine | Conclude | Compose |
| Identify | Discuss | Classify | Design | Contrast | Create |
| Labels | Distinguish | Complete | Detect | Criticize | Drive |
| List | Estimate | Compute | Develop | Critique | Design |
| Match | Explain | Demonstrate | Diagram | Determine | Devise |
| Name | Extend | Discover | Differentiate | Grade | Explain |
| Outlines | Extrapolate | Divide | Discriminate | Interpret | Generate |
| Point | Generalize | Examine | Illustrate | Judge | Group |
| Quote | Give examples | Graph | Infer | Justify | Integrate |
| Read | Infer | Interpolate | Outline | Measure | Modify |
| Recall | Paraphrase | Manipulate | Point out | Rank | Order |
| Recite | Predict | Modify | Relate | Rate | Organize |
| Recognize | Rewrite | Operate | Select | Support | Plan |
| Record | Summarize | Prepare | Separate | Test | Prescribe |
| Repeat |  | Produce | Subdivide |  | Propose |
| Reproduces |  | Show | Utilize |  | Rearrange |
| Selects |  | Solve |  |  | Reconstruct |
| State |  | Subtract |  |  | Related |
| Write |  | Translate |  |  | Reorganize |
|  |  | Use |  |  | Revise |
|  |  |  |  |  | Rewrite |
|  |  |  |  |  | Summarize |
|  |  |  |  |  | Transform |
|  |  |  |  |  | Specify |

Source: modified from http://www.asu.edu/oue/covertOvert.html

**Appendix 4.** Copperbelt river water quality

| No | Site Code | pH | As | Cd | Cr | Cu | Mn | Ni | Pb | D Zn |
|---|---|---|---|---|---|---|---|---|---|---|
| 19 | CB19 River | 7.92 | 0.0001 | 0.0000 | 0.0000 | 0.0348 | **0.1808** | 0.0000 | 0.0000 | 0.0000 |
| 20 | CB20 Tap | 7.87 | 0.0006 | 0.0000 | 0.0000 | 0.0510 | **0.1694** | **0.0899** | **0.0941** | 0.0999 |
| 21 | CB21 Effluent | 8.36 | 0.0054 | 0.0000 | 0.0000 | 0.1450 | **0.2511** | **0.1259** | 0.0000 | 0.0027 |
| 22 | CB22 Tap | 7.83 | 0.0000 | 0.0000 | 0.0000 | 0.0188 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 23 | CB23 River | 7.79 | 0.0000 | 0.0000 | 0.0000 | 0.0072 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 24 | CB24 River | 8.02 | 0.0027 | 0.0000 | 0.0000 | 0.0158 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 25 | CB25 River | 7.95 | 0.0025 | 0.0000 | **0.0892** | 0.0038 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 26 | CB26 River | 7.93 | 0.0002 | 0.0000 | **0.0889** | 0.0084 | **0.2490** | 0.0053 | 0.0000 | 0.0000 |
| 27 | CB27 Effluent | 7.31 | 0.0012 | 0.0000 | **0.0892** | 0.0256 | **9.5453** | **0.6984** | 0.0000 | 0.0000 |
| 28 | CB28 River | 8.14 | 0.0000 | 0.0000 | **0.0889** | 0.0950 | **0.1631** | 0.0000 | 0.0000 | 0.0000 |
| 29 | CB29 Effluent | 7.63 | 0.0039 | 0.0000 | 0.0000 | 0.2698 | **10.3887** | **0.0284** | 0.0000 | 0.0211 |
| 30 | CB30 River | 6.73 | 0.0000 | 0.0000 | 0.0000 | 0.0072 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 32 | CB32 River | 7.91 | 0.0013 | 0.0000 | **0.0892** | 0.0064 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 33 | CB33 River | 7.85 | 0.0045 | 0.0000 | 0.0000 | 0.0227 | 0.0000 | **0.0761** | 0.0000 | 0.0000 |
| 34 | CB34 River | 7.99 | 0.0008 | 0.0000 | **0.0892** | 0.0131 | 0.0000 | 0.0000 | 0.0000 | 0.0165 |
| 35 | CB35 River | 7.56 | 0.0000 | 0.0000 | **0.0892** | 0.0039 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 36 | CB36 River | 7.97 | 0.0000 | 0.0000 | 0.0000 | 0.0037 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 37 | CB37 River | 7.89 | 0.0049 | 0.0000 | 0.0000 | 0.0079 | **1.3685** | **0.0830** | 0.0000 | 0.0000 |
| 38 | CB38 Ground Tap | 7.69 | 0.0000 | 0.0000 | 0.0000 | 0.0205 | 0.0000 | 0.0000 | 0.0000 | **1.2098** |
| 39 | CB39 River | 7.40 | 0.0000 | 0.0000 | **0.0890** | 0.0060 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 40 | CB40 River | 7.90 | 0.0002 | 0.0000 | 0.0000 | 0.0559 | **0.1046** | 0.0000 | 0.0000 | 0.0000 |
| 44 | CB44 River | 6.76 | 0.0001 | 0.0000 | 0.0000 | 0.0031 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

## **Appendix 5.** Useful reactions for qualitative and quantitative analysis

| Item | | Range(mg/L) | Reaction Time | Reagent Model | Colour Change | LED colour |
|---|---|---|---|---|---|---|
| Al | Aluminium | 0.050〜0.400 | 5min. | Eriochrome Cyanine R (ECR)Hexamethylenetetramine Buffer Reagent Powder Pillows | Yellow→Orange→Red | **G** |
| B | Boron (High Range) | 5.0〜40.0 | 12min. | Azomethine-H monosodium salt hydrate | Light Yellow→Yellow | **B** |
| Ca | Calcium | 0.5〜15.0 | 2min. | Phthalein Complexone | Yellow→Reddish Purple→Purple | **G** |
| ClO | Residual Chlorine (High Range) | 2〜320 | 1min. | Potassium Iodide | None→Yellow→Orange→Red brown | **G** |
| $ClO_2$ | Chlorine Dioxide | 0.20〜6.00 | 1min. | N,N-diethyl-p-phenylenediamine sulphate with Glycine | None→Pink | **G** |
| CN | total Cyanide | 0.10〜3.00 | 18min. | Picric acid | Yellow→Orange→Brown | **R** |
| COD | Chemical Oxygen Demand | 2.0〜10.0 | 10min. | Oxidation by potassium permanganate in alkaline | Red Purple→Green | **B** |
| Colour | Colour | 100〜1000deg. | 0min. | No reagent (Calibration by Platinum Cobalt Colour standard) | | **B** |
| Cr | Total Chromium | 0.050〜1.400 | 12min. | Oxidation and Diphenylcarbazide | None→Light Red→Red→Red Purple | **G** |
| Cu | Copper | 0.10〜5.00 | 1min. | Bathocuproine | None→Light Orange→Orange | **B** |
| DO | Dissolved Oxygen | 2.0〜11.0 | 2min. | Indigo Carmine | None → Blue | **R** |
| F | Fluoride (Free) | 0.40〜1.50 | 15min. | Lanthanum-Alizarin Complexon | Red→Purple | **B** |
| Fe | Iron | 0.20〜5.00 | 3min | Reduction and o-Phenanthroline | None→Light Orange→Orange | **B** |
| FOR | Formaldehyde | 0.20〜1.00 | 5min. | 3-methyl-2-benzothiazoline hydrazone (MBTH) | Yellow→Yellow Green→Green | **R** |
| $H_2O_2$ | Hydrogen Peroxide (High Range) | 3〜200 | 1min. | Potassium Iodide | None → Yellow → Orange → Red brown | **G** |
| Mn | Manganese | 0.6〜20.0 | 3min. | Potassium Periodate | None→Light Red→Red | **G** |
| $NH_4$ | Ammonium | 0.20〜5.00 | 10min. | Indophenol Blue | None→Light Blue→Blue | **R** |
| Ni | Nickel | 1.00〜8.00 | 5min. | Dimethylglyoxime | None→Light Pink→Pink | **G** |
| $NO_2$ | Nitrite | 5〜100 | 3min. | Griess Romijin | None→Light Yellow → Red Brown | **G** |
| $NO_3$ | Nitrate ($NO_2 = 0$) | 1.0〜25.0 | 5min. | Reduction and Naphthylethylenediamine | None→Light Red→Red | **G** |
| $O_3$ | Ozone | 0.25〜6.00 | 2min. | 4-Aminoantipyrine with enzyme | None→Light Purple→Purple | **G** |
| Phenol | Phenol | 0.20〜5.00 | 8min. | 4-Aminoantipyrine with enzyme | Light Yellow → Orange → Red | **G** |
| $PO_4$ | Phosphate | 0.10〜5.00 | 3min. | Molybdenum blue | None→Light Blue→Blue | **R** |
| S | Sulphide(Hydrogen sulphide) | 0.050〜0.800 | 3min. | Methylene blue | None→Light Blue→Blue | **R** |
| $SiO_2$ | Silica | 3.0〜60.0 | 8.5min. | Molybdenum blue | None→Light Blue→Blue | **R** |
| $SO_4$ | Sulphate | 1.0〜100 | 3min. | Barium sulphate turbidimetry | Transparent→Turbid White | **R** |
| TH | Total Hardness | 20〜100 | 2min. | Phthalein Complexone | Light Purple→Purple | **G** |
| Turbid | Turbidity | 10.0〜100.0deg. | 0min. | No reagent (Calibration by Polysthylene standard solution) | | **R** |
| Zn | Zinc | 0.10〜2.00 | 5min. | Zincon | Orange → Brown → Blue | **R** |

**Source**: Compiled from Kyoritsu Chemical-Check Lab., Corp (2010)

## **Appendix 6.** The taxonomy table

| Major Types and Subtypes Examples | |
|---|---|
| A. Factual Knowledge: The basic elements students must know to be acquainted with a discipline or solve problems in it | |
| AA. Knowledge of terminology | Technical vocabulary, music symbols |
| AB. Knowledge of specific details and elements | Major natural resources, reliable sources of information |
| B. Conceptual Knowledge: The interrelationships among the basic elements within a larger structure that enable them to function together | |
| BA. Knowledge of classifications and categories | Periods of geological time, forms of business ownership |
| BB. Knowledge of principles and generalizations | Pythagorean theorem, law of supply and demand |
| BC. Knowledge of theories, models, and structures | Theory of evolution, structure of Congress |
| C. Procedural Knowledge: How to do something, methods of inquiry, and criteria for using skills, algorithms, techniques, and methods | |
| CA. Knowledge of subject-specific skills and algorithms | Skills used in painting with water colours, whole-number division algorithm |
| CB. Knowledge of subject-specific techniques and methods | Interviewing techniques, scientific method |
| CC. Knowledge of criteria for determining when to use appropriate procedures | Criteria used to determine when to apply a procedure involving Newton’s second law, criteria used to judge the feasibility of using a particular method to estimate business costs |
| D. Metacognitive Knowledge: Knowledge of cognition in general as well as awareness and knowledge of one’s own cognition | |
| DA. Strategic Knowledge | Knowledge of outlining as a means of capturing the structure of a unit of subject matter in a text book, knowledge of the use of heuristics |
| DB. Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge | Knowledge of the types of tests particular teachers administer, knowledge of the cognitive demands of different tasks |
| DC. Self-knowledge | Knowledge that critiquing essays is a personal strength, whereas writing essays is a personal weakness; awareness of one’s own knowledge level |

Source: Adapted from Anderson et al. (2001)

# **Appendix 7.** Analysis of Zambian water samples for heavy metals (Ground, River & Portable Water)

**Parameters in ppm**

| | | | | | | **ICP** | **ICP** | **AAS** | **AAS** | **AAS** | **AAS** | **AAS** | **AAS** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **No** | **Site Name** | **pH** | **Temperature** | **latitude** | **longitude** | **As** | **Cd** | **Cr** | **D Cu** | **D Mn** | **D Ni** | **D Pb** | **D Zn** |
| 1 | Mutendere Dam | 7.90 | 26.2 | -15.410223 | 28.359895 | **0.506** | 0.000 | 0.000 | 0.000 | **0.180** | 0.000 | 0.000 | 0.000 |
| 2 | Chipata/Marapodi at Garden Park (stream) | 7.95 | 26.3 | -15.372142 | 28.295329 | 0.000 | 0.000 | 0.000 | 0.000 | **1.125** | 0.000 | 0.000 | 0.000 |
| 3 | Mutendere River upstream | 7.75 | 25.9 | -15.391525 | 28.368023 | 0.000 | 0.000 | 0.000 | 0.000 | **0.555** | 0.000 | 0.000 | 0.000 |
| 4 | Mumana Pleasure Resort (stream) | 7.78 | 26.1 | -15.383759 | 28.352576 | 0.000 | 0.000 | 0.000 | 0.000 | 0.070 | 0.000 | 0.000 | 0.000 |
| 5 | Ngombe East Stream | ND | ND | -15.331788 | 28.331507 | ND | ND | 0.000 | 0.000 | **0.258** | 0.000 | 0.000 | 0.000 |
| 6 | Ngwerere Stream (near kasisi) | 7.94 | 24.3 | -15.274562 | 28.443934 | 0.005 | 0.000 | 0.000 | 0.000 | **0.191** | 0.000 | 0.000 | 0.000 |
| 7 | Mutendere/Maplot midstream | 7.78 | 23.9 | -15.401413 | 28.363931 | 0.003 | 0.000 | 0.000 | 0.000 | **0.289** | 0.000 | 0.000 | 0.000 |
| 8 | Malimba Ngwerere Stream | 7.93 | 24.0 | -15.304456 | 28.358026 | 0.006 | 0.000 | 0.000 | 0.000 | **0.158** | 0.000 | 0.000 | 0.000 |
| 9 | Ngombe Basic school Stream | 7.90 | 23.7 | -15.351697 | 28.336484 | 0.003 | 0.000 | 0.000 | 0.000 | 0.081 | 0.000 | 0.000 | 0.000 |
| 10 | New N'gombe Basic Tap (underground) | 7.55 | 24.6 | -15.353020 | 28.333349 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.320 |
| 11 | Kafue River at Motor Bridge | 7.72 | 24.8 | -15.837317 | 28.237336 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 12 | Lumumba/Great North Road Junction (stream) | 7.87 | 23.6 | -15.376825 | 28.278027 | 0.006 | 0.000 | 0.000 | 0.000 | **0.477** | 0.000 | 0.000 | 0.000 |
| 13 | Chawama Compound Tap Water (LWSC) | 5.75 | 23.9 | -15.456692 | 28.282890 | 0.004 | 0.000 | 0.000 | 0.000 | 0.026 | 0.000 | 0.000 | 0.073 |
| 14 | John Laing Tap (ground water) | 7.84 | 24.5 | -15.439694 | 28.273929 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | **0.094** | 0.108 |
| 15 | Matero Petroda Station Tap Water (LWSC) | 7.76 | 24.0 | -15.378768 | 28.245407 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.544 |
| 16 | Roma/Garden Township Stream | 8.04 | 23.9 | -15.400353 | 28.288776 | 0.000 | 0.000 | 0.000 | 0.000 | 0.004 | 0.000 | 0.000 | 0.000 |
| 17 | Blue Water Dam | 8.44 | 23.1 | -15.451925 | 28.274606 | 0.001 | 0.000 | 0.000 | 0.000 | 0.015 | 0.000 | 0.000 | 0.000 |
| 18 | Train Bridge (Kafue River) | 7.26 | 22.9 | -15.788075 | 28.176641 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 19 | Kafue River Mufulira/Kitwe Road | 7.92 | 24.1 | -12.644862 | 28.164142 | 0.000 | 0.000 | 0.000 | 0.000 | **0.181** | 0.000 | 0.000 | 0.000 |
| 20 | Mine Water Mulonga Tap (Entebe) | 7.87 | 24.8 | -12.537643 | 28.242702 | 0.001 | 0.000 | 0.000 | 0.000 | **0.169** | 0.000 | **0.094** | 0.100 |
| 21 | West Shaft Effluent Water | 8.36 | 23.6 | -12.522426 | 28.223604 | 0.005 | 0.000 | 0.000 | 0.049 | **0.251** | **0.141** | 0.000 | 0.003 |
| 22 | Tap Water - Mufulira Town Centre (Mulonga Water) | 7.83 | 22.0 | -12.599024 | 28.245121 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 23 | Boating Club Dam (Mufulira) | 7.79 | 24.9 | -12.511877 | 28.236845 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 24 | Kafue River, Nkana East Waterworks | 8.02 | 25.0 | -12.807693 | 28.258129 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 25 | River Near Sabina | 7.95 | 24.1 | -12.714874 | 28.120857 | 0.003 | 0.000 | **0.089** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 26 | Before Tailings Damp (Butondo Stream) | 7.93 | 23.7 | -12.553647 | 28.185016 | 0.000 | 0.000 | **0.089** | 0.000 | **0.249** | 0.000 | 0.000 | 0.000 |
| 27 | Tailings Damp Effluent) | 7.31 | 23.5 | -12.553693 | 28.185199 | 0.001 | 0.000 | **0.089** | 0.000 | **9.545** | **0.842** | 0.000 | 0.000 |
| 28 | Chingola/Chililabobwe Road Kafue River | 8.14 | 23.8 | -12.464392 | 27.851051 | 0.000 | 0.000 | **0.089** | 0.011 | **0.163** | 0.000 | 0.000 | 0.000 |
| 29 | Chingola Mine Effluent | 7.63 | 24.6 | -12.518766 | 27.828553 | 0.004 | 0.000 | 0.000 | 0.178 | **10.389** | **0.040** | 0.000 | 0.021 |
| 30 | Malembeka Stream into Kafue (1st site) | 6.73 | 24.7 | -12.895048 | 28.221352 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 31 | Kafubu River | 8.20 | 23.9 | -12.985817 | 28.643193 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 32 | West Mine Shaft - Butondo Stream (at Bridge) | 7.91 | 23.4 | -12.521083 | 28.222888 | 0.001 | 0.000 | **0.089** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 33 | Butondo Stream at Road Near Butondo High | 7.85 | 23.7 | -12.526616 | 28.213540 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 | **0.040** | 0.000 | 0.000 |
| 34 | Ndola Kitwe Dual Carriage Kafue River | 7.99 | 24.9 | -12.878078 | 28.257839 | 0.001 | 0.000 | **0.089** | 0.000 | 0.000 | 0.000 | 0.000 | 0.017 |
| 35 | Malembeka Stream into Kafue (2nd site) | 7.56 | 23.8 | -12.898804 | 28.213170 | 0.000 | 0.000 | **0.089** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 36 | Chingola River Upstream | 7.97 | 23.1 | -12.538535 | 27.792312 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 37 | Tailings Damp (TD 11) | 7.89 | 24.3 | -12.559898 | 28.193978 | 0.005 | 0.000 | 0.000 | 0.000 | **1.369** | 0.000 | 0.000 | 0.000 |
| 38 | Eagle High School Tap Water (Groundwater) | 7.69 | 23.8 | -12.565491 | 28.228285 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | **1.210** |
| 39 | Kawama stream - Mufulira | 7.40 | 24.1 | -12.566172 | 28.221736 | 0.000 | 0.000 | **0.089** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 40 | Kafue Water Treatment Plant - Mulonga WSC | 7.90 | 23.8 | -12.587270 | 28.181009 | 0.000 | 0.000 | 0.000 | 0.093 | **0.105** | **0.034** | 0.000 | 0.000 |
| 41 | Kabwe City Council Tap Water (Lukanga WSC) | 7.63 | 20.8 | -14.443449 | 28.446066 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.011 |
| 42 | Jack & Jill School - Lukanga WSC | 7.74 | 21.3 | -14.447442 | 28.439063 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.030 |
| 43 | Kafubu Upstream | 8.22 | 24.9 | -12.976014 | 28.655871 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | **0.034** | 0.000 | 0.000 |
| 44 | Kansuswa Stream (at Mufulira/Kitwe Road) | 6.76 | 25.9 | -12.586698 | 28.208937 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 45 | Laka Petroluem Filling Station Tap Water - Ndola | 7.26 | 27.0 | -12.969959 | 28.620696 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.804 |
| 46 | Kafubu Downstream | 7.92 | 24.6 | -12.996526 | 28.606989 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 47 | Chainama Lusaka General Hospital | 7.80 | 21.8 | -15.386093 | 28.353912 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 48 | Kamwala Remand Prison Borehole Water | 7.39 | 22.1 | -15.430534 | 28.287962 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 49 | Libala Basic School Tap from the Ground | 7.66 | 22.1 | -15.441930 | 28.310054 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.033 | 0.000 | 0.179 |
| 50 | Vera Chiluba Basic School Tap from tap ground | 7.63 | 23.0 | -15.404121 | 28.348721 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.033 | 0.000 | 0.000 |
| 51 | UNZA Tap Water - Groundwater | 7.91 | 21.9 | -15.392944 | 28.326775 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 |
| 52 | Femag Garden John Laing Tap Water from the Ground | 7.12 | 23.6 | -15.442982 | 28.271762 | 0.001 | 0.000 | 0.000 | 0.000 | **0.100** | 0.000 | 0.000 | 0.067 |
| 53 | Kanyama Ground Water-Borehole-Filling Station | 7.74 | 21.2 | -15.432462 | 28.263631 | 0.007 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.132 |
| 54 | Gospel Outreach Tap Water-ground | 7.49 | 22.0 | -15.400639 | 28.325940 | 0.003 | 0.000 | 0.000 | 0.000 | **0.100** | 0.000 | 0.000 | 0.002 |
| 55 | Zingalume Police Tap Water from the Ground | 7.5 | 22.6 | -15.377411 | 28.231461 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.049 |
| 56 | Mutendere Near Chainama Golf Club Well Water | 7.31 | 22.2 | -15.398798 | 28.346059 | 0.006 | 0.000 | 0.000 | 0.000 | **0.700** | 0.000 | 0.000 | 0.000 |
| 57 | Chunga, Africa Methodist Episcopal Church Ground Water Borehole | 7.63 | 22.6 | -15.354280 | 28.246764 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.207 |
| 58 | Entrace of Chunga - Ground Water | 7.61 | 23.6 | -15.363683 | 28.254743 | 0.005 | 0.000 | 0.000 | 0.000 | **0.100** | 0.000 | 0.000 | 0.000 |
| 59 | Twikatane Area Ground Water | 7.62 | 24.3 | -15.361812 | 28.238413 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.086 |
| 60 | Avondale River Side Street Tap Water from the Ground | 7.49 | 23.7 | -15.386479 | 28.406418 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 61 | Ngome tap Water from Ground Aquifer | 7.71 | 24.0 | -15.368317 | 28.325356 | 0.003 | 0.000 | 0.000 | 0.000 | **0.200** | 0.000 | 0.000 | 0.867 |
| 62 | George Compound Borehole | 7.65 | 23.9 | -15.386337 | 28.237312 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.011 |
| 63 | Ndeke Village | 7.27 | 23.8 | -15.305062 | 28.415264 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.058 |
| 64 | Chisengalumbwe Basic School | 7.37 | 24.6 | -15.438116 | 28.319137 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 65 | Zeko Camp Borehole | 7.41 | 24.1 | -15.385867 | 28.234715 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 66 | NRDC Borehole Tap | 7.55 | 24.3 | -15.392026 | 28.371629 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.355 |
| 67 | Villa Elizabetha | 7.46 | 23.5 | -15.402727 | 28.276492 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.011 |
| 68 | Thornpark Construction Centre Borehole | 7.37 | 23.9 | -15.407415 | 28.282778 | 0.003 | 0.000 | 0.000 | 0.000 | **0.100** | 0.000 | 0.000 | 0.151 |
| 69 | Mazabuka Tap water | 8.02 | 20.7 | -15.847400 | 27.757810 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 |
| 70 | Goam lakes | 8.25 | 20.8 | -15.388241 | 28.329970 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 71 | Magoye borehole water - main compound | 8.13 | 20.9 | -15.999180 | 27.608409 | 0.003 | 0.000 | ND | ND | ND | ND | ND | ND |
| 72 | Zingalume borehole water | 8.17 | 21.4 | -15.381474 | 28.230375 | 0.001 | 0.000 | ND | ND | ND | ND | ND | ND |
| 73 | Solwezi well water | 6.23 | 21.1 | -12.394657 | 26.232585 | 0.000 | 0.000 | ND | ND | ND | ND | ND | ND |
| 74 | Magoye boreholewater- school | 7.63 | 20.5 | -15.997282 | 27.607620 | 0.005 | 0.000 | ND | ND | ND | ND | ND | ND |

ND - not determined

# **Appendix 8.** Analysis of Zambian water samples for miscellaneous pollutants (Ground, River & Portable Water)

| | Sampled Sites | | | A | B | TOC Analyzer (ppm) | Pack Test (ppm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Site Name | pH | Temperature | latitude | longitude | DOC | $PO_4^{2-}$ | $C\ell O^-$ | $O_3$ | $H_2O_2$ | $CN^-$ | Pheno | TH | $CH_2O$ | $NO_2^-$ | B | $SIO_2$ |
| 1 | Mutendere Dam | 7.9 | 26.2 | -15.410223 | 28.359895 | 1.708 | <0.1 | <0.1 | <0.25 | <0.1 | <0.02 | <0.2 | 71 | <0.20 | <0.02 | <0.02 | 14.8 |
| 2 | Chipata/Marapodi at Garden Park (stream) | 7.95 | 26.3 | -15.372142 | 28.295329 | 5.053 | **3.2** | <0.1 | <0.25 | <0.1 | <0.02 | <0.2 | 360 | **0.2** | <0.02 | <0.02 | 18.6 |
| 3 | Mutendere River upstream | 7.75 | 25.9 | -15.391525 | 28.368023 | 4.466 | **1.08** | <0.1 | <0.25 | <0.1 | <0.02 | <0.2 | 270 | **0.19** | <0.02 | <0.02 | 18.6 |
| 4 | Mumana Pleasure Resort (stream) | 7.78 | 26.1 | -15.383759 | 28.352576 | 3.598 | <0.1 | <0.1 | <0.25 | <0.1 | <0.02 | <0.2 | 100 | **0.21** | <0.02 | <0.02 | 16.9 |
| 5 | Ngombe East Stream | ND | ND | -15.331788 | 28.331507 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| 6 | Ngwerere Stream (near kasisi) | 7.94 | 24.3 | -15.274562 | 28.443934 | 2.249 | <0.1 | <0.1 | <0.25 | <0.1 | <0.02 | **0.49** | 410 | **0.2** | <0.02 | <0.02 | 16.7 |
| 7 | Mutendere/Maplot midstream | 7.78 | 23.9 | -15.401413 | 28.363931 | 5.771 | <0.1 | <0.1 | <0.25 | <0.1 | <0.02 | <0.2 | 290 | **0.2** | <0.02 | <0.02 | 18.4 |
| 8 | Malimba Ngwerere Stream | 7.93 | 24 | -15.304456 | 28.358026 | 3.246 | <0.1 | <0.1 | <0.25 | <0.1 | <0.02 | <0.2 | 100 | **0.23** | <0.02 | 0.72 | ND |
| 9 | Ngombe Basic school Stream | 7.9 | 23.7 | -15.351697 | 28.336484 | 2.562 | <0.1 | <0.1 | <0.25 | <0.1 | **0.058** | <0.2 | 115 | <0.20 | <0.02 | 1.39 | 15 |
| 10 | New N'gombe Basic Tap (underground) | 7.55 | 24.6 | -15.353020 | 28.333349 | 0.499 | **0.17** | <0.1 | <0.25 | <0.1 | **0.03** | <0.2 | 80 | <0.20 | <0.02 | 1.57 | 41.2 |
| 11 | Kafue River at Motor Bridge | 7.72 | 24.8 | -15.837317 | 28.237336 | 3.951 | **0.25** | **0.25** | <0.25 | <0.1 | <0.02 | <0.2 | 89 | <0.20 | **0.054** | <0.02 | ND |
| 12 | Lumumba/Great North Road Junction (stream) | 7.87 | 23.6 | -15.376825 | 28.278027 | 4.561 | **0.12** | <0.1 | <0.25 | <0.1 | **0.04** | **0.89** | 185 | **0.22** | **1.92** | <0.02 | ND |
| 13 | Chawama Compound Tap Water (LWSC) | 5.75 | 23.9 | -15.456692 | 28.282890 | 0.712 | <0.1 | <0.1 | <0.25 | <0.1 | <0.02 | <0.2 | 190 | <0.20 | **0.049** | <0.02 | 10.8 |
| 14 | John Laing Tap (ground water) | 7.84 | 24.5 | -15.439694 | 28.273929 | 0.575 | <0.1 | <0.1 | <0.25 | <0.1 | <0.02 | <0.2 | 215 | <0.20 | <0.02 | <0.02 | 6.6 |
| 15 | Matero Petroda Station Tap Water (LWSC) | 7.76 | 24 | -15.378768 | 28.245407 | 0.235 | <0.1 | **0.2** | <0.25 | <0.1 | <0.02 | <0.2 | 180 | <0.20 | **0.051** | <0.02 | 7.5 |
| 16 | Roma/Garden Township Stream | 8.04 | 23.9 | -15.400353 | 28.288776 | 2.924 | <0.1 | **0.23** | <0.25 | <0.1 | <0.02 | <0.2 | 205 | <0.20 | <0.02 | <0.02 | ND |
| 17 | Blue Water Dam | 8.44 | 23.1 | -15.451925 | 28.274606 | 0.053 | <0.1 | **0.53** | <0.25 | <0.1 | <0.02 | <0.2 | 150 | <0.20 | **0.158** | <0.02 | ND |
| 18 | Train Bridge (Kafue River) | 1.9 | 22.9 | -15.788075 | 28.176641 | 3.974 | <0.1 | **0.14** | <0.25 | <0.1 | <0.02 | **0.36** | 110 | <0.20 | <0.02 | <0.02 | ND |
| 19 | Kafue River Mufulira/Kitwe Road | 7.92 | 24.1 | -12.644862 | 28.164142 | 1.398 | <0.1 | <0.10 | <0.25 | <0.1 | <0.02 | <0.2 | 225 | <0.20 | <0.02 | ND | ND |
| 20 | Mine Water Mulonga Tap (Entebe) | 7.87 | 24.8 | -12.537643 | 28.242702 | 0.708 | <0.1 | <0.10 | <0.25 | <0.1 | <0.02 | <0.2 | 670 | <0.20 | <0.02 | ND | ND |
| 21 | West Shaft Effluent Water | 8.36 | 23.6 | -12.522426 | 28.223604 | 0.597 | <0.1 | <0.10 | **0.32** | <0.1 | <0.02 | <0.2 | 1030 | <0.20 | <0.02 | ND | ND |
| 22 | Tap Water - Mufulira Town Centre (Mulonga Water) | 7.83 | 22 | -12.599024 | 28.245121 | 1.41 | <0.1 | <0.10 | <0.25 | <0.1 | <0.02 | <0.2 | 220 | <0.20 | **0.02** | ND | ND |
| 23 | Boating Club Dam (Mufulira) | 7.79 | 24.9 | -12.511877 | 28.236845 | 1.582 | <0.1 | <0.10 | <0.25 | <0.1 | <0.02 | <0.2 | 145 | <0.20 | **0.03** | ND | ND |
| 24 | Kafue River, Nkana East Waterworks | 8.02 | 25 | -12.807693 | 28.258129 | 1.308 | <0.1 | <0.10 | <0.25 | <0.1 | <0.02 | <0.2 | 275 | <0.20 | **0.024** | ND | ND |
| 25 | River Near Sabina | 7.95 | 24.1 | -12.714874 | 28.120857 | 0.908 | <0.1 | <0.10 | <0.25 | <0.1 | <0.02 | <0.2 | 930 | <0.20 | <0.02 | ND | ND |
| 26 | Before Tailings Damp (Butondo Stream) | 7.93 | 23.7 | -12.553647 | 28.185016 | 0.801 | <0.1 | <0.10 | <0.25 | <0.1 | <0.02 | <0.2 | 680 | <0.20 | <0.02 | ND | ND |
| 27 | Tailings Damp Effluent) | 7.31 | 23.5 | -12.553693 | 28.185199 | 2.303 | <0.1 | <0.10 | <0.25 | <0.1 | <0.02 | <0.2 | 2080 | <0.20 | **0.021** | ND | ND |
| 28 | Chingola/Chililabobwe Road Kafue River | 8.14 | 23.8 | -12.464392 | 27.851051 | 1.21 | <0.1 | <0.10 | <0.25 | <0.1 | <0.02 | <0.2 | 190 | <0.20 | **0.035** | ND | ND |
| 29 | Chingola Mine Effluent | 7.63 | 24.6 | -12.518766 | 27.828553 | 1.703 | **0.18** | <0.10 | <0.25 | <0.1 | <0.02 | <0.2 | 1260 | <0.20 | <0.02 | ND | ND |
| 30 | Malembeka Stream into Kafue (1st site) | 6.73 | 24.7 | -12.895048 | 28.221352 | 0.513 | <0.1 | <0.10 | **0.7** | <0.1 | <0.02 | <0.2 | <20 | <0.20 | <0.02 | ND | ND |
| 31 | Kafubu River | 8.2 | 23.9 | -12.985817 | 28.643193 | 2.273 | <0.1 | <0.10 | <0.25 | <0.1 | <0.02 | **1.47** | 180 | <0.20 | <0.02 | ND | ND |
| 32 | West Mine Shaft - Butondo Stream (at Bridge) | 7.91 | 23.4 | -12.521083 | 28.222888 | 1.632 | **0.55** | <0.10 | <0.25 | <0.1 | <0.02 | **1.17** | 54 | <0.20 | <0.02 | ND | ND |
| 33 | Butondo Stream at Road Near Butondo High | 7.85 | 23.7 | -12.526616 | 28.213540 | 0.82 | **0.4** | <0.10 | <0.25 | <0.1 | <0.02 | **1.02** | 920 | <0.20 | <0.02 | ND | ND |
| 34 | Ndola Kitwe Dual Carriage Kafue River | 7.99 | 24.9 | -12.878078 | 28.257839 | 1.437 | **0.2** | <0.10 | <0.25 | <0.1 | <0.02 | **0.77** | 315 | <0.20 | <0.02 | ND | ND |
| 35 | Malembeka Stream into Kafue (2nd site) | 7.56 | 23.8 | -12.898804 | 28.213170 | 0.739 | <0.1 | <0.10 | <0.25 | <0.1 | <0.02 | **2.18** | 67 | <0.20 | <0.02 | ND | ND |
| 36 | Chingola River Upstream | 7.97 | 23.1 | -12.538535 | 27.792312 | 1.14 | **0.24** | <0.10 | <0.25 | <0.1 | <0.02 | **1.08** | 42 | <0.20 | <0.02 | ND | ND |
| 37 | Tailings Damp (TD 11) | 7.89 | 24.3 | -12.559898 | 28.193978 | 0.913 | <0.1 | <0.10 | **0.36** | <0.1 | <0.02 | **1.46** | 1260 | <0.20 | <0.02 | ND | ND |
| 38 | Eagle High School Tap Water (Groundwater) | 7.69 | 23.8 | -12.565491 | 28.228285 | 1.014 | **0.35** | <0.10 | <0.25 | <0.1 | <0.02 | **1.64** | <20 | <0.20 | **0.065** | ND | ND |
| 39 | Kawama stream - Mufulira | 7.4 | 24.1 | -12.566172 | 28.221736 | 1.253 | **0.16** | <0.10 | <0.25 | <0.1 | <0.02 | **0.86** | 69 | <0.20 | <0.02 | ND | ND |
| 40 | Kafue Water Treatment Plant - Mulonga WSC | 7.9 | 23.8 | -12.587270 | 28.181009 | 1.574 | <0.10 | <0.10 | <0.25 | <0.1 | <0.02 | **1.32** | 210 | <0.20 | **0.02** | ND | ND |
| 41 | Kabwe City Council Tap Water (Lukanga WSC) | 7.63 | 20.8 | -14.443449 | 28.446066 | 0.265 | <0.10 | <0.10 | <0.25 | <0.1 | <0.02 | <0.2 | 94 | <0.20 | <0.02 | ND | ND |
| 42 | Jack & Jill School - Lukanga WSC | 7.74 | 21.3 | -14.447442 | 28.439063 | 0.389 | <0.10 | <0.10 | <0.25 | <0.1 | <0.02 | <0.2 | 66 | <0.20 | <0.02 | ND | ND |
| 43 | Kafubu Upstream | 8.22 | 24.9 | -12.976014 | 28.655871 | 2.436 | <0.10 | <0.10 | <0.25 | <0.1 | <0.02 | <0.2 | 26 | <0.20 | <0.02 | ND | ND |
| 44 | Kansuswa Stream (at Mufulira/Kitwe Road) | 6.76 | 25.9 | -12.586698 | 28.208937 | 0.699 | <0.10 | <0.10 | <0.25 | <0.1 | <0.02 | **1.46** | <20 | <0.20 | <0.02 | ND | ND |
| 45 | Laka Petroluem Filling Station Tap Water - Ndola | 7.26 | 27 | -12.969959 | 28.620696 | 0.186 | <0.10 | **0.32** | <0.25 | **0.25** | <0.02 | **1.84** | <20 | <0.20 | **0.278** | ND | ND |
| 46 | Kafubu Downstream | 7.92 | 24.6 | -12.996526 | 28.606989 | 2.324 | **1** | <0.10 | <0.25 | <0.1 | <0.02 | <0.2 | 62 | <0.20 | <0.02 | ND | ND |
| 47 | Chainama Lusaka General Hospital | 7.8 | 21.8 | -15.386093 | 28.353912 | 3.203 | <0.1 | **0.28** | <0.25 | <0.1 | <0.02 | <0.2 | 275 | <0.20 | <0.20 | <0.02 | 14.2 |
| 48 | Kamwala Remand Prison Borehole Water | 7.39 | 22.1 | -15.430534 | 28.287962 | 0.562 | <0.1 | **0.21** | <0.25 | <0.1 | <0.02 | **0.27** | 175 | <0.20 | **0.023** | <0.02 | 8.1 |
| 49 | Libala Basic School Tap from the Ground | 7.66 | 22.1 | -15.441930 | 28.310054 | 0.278 | <0.1 | <0.1 | <0.25 | <0.1 | <0.02 | <0.2 | 140 | <0.20 | **0.043** | <0.02 | 7.5 |
| 50 | Vera Chiluba Basic School Tap from tap ground | 7.63 | 23 | -15.404121 | 28.348721 | 0.343 | <0.1 | **0.43** | <0.25 | <0.1 | <0.02 | <0.2 | 145 | <0.20 | **0.051** | <0.02 | 17.9 |
| 51 | UNZA Tap Water - Groundwater | 7.91 | 21.9 | -15.392944 | 28.326775 | 0.9 | <0.1 | **0.51** | <0.25 | <0.1 | <0.02 | <0.2 | 170 | <0.20 | <0.02 | <0.02 | 16.7 |
| 52 | Femag Garden John Laing Tap Water from the Ground | 7.12 | 23.6 | -15.442982 | 28.271762 | 0.714 | <0.1 | **0.32** | <0.25 | <0.1 | <0.02 | <0.2 | 160 | <0.20 | <0.02 | <0.02 | 3.3 |
| 53 | Kanyama Ground Water-Borehole-Filling Station | 7.74 | 21.2 | -15.432462 | 28.263631 | 0.783 | <0.1 | **0.14** | <0.25 | <0.1 | <0.02 | <0.2 | 149 | <0.20 | **0.497** | <0.02 | 10.8 |
| 54 | Gospel Outreach Tap Water-ground | 7.49 | 22 | -15.400639 | 28.325940 | 0.379 | <0.1 | **0.2** | <0.25 | <0.1 | <0.02 | <0.2 | 210 | <0.20 | **0.056** | <0.02 | 12.6 |
| 55 | Zingalume Police Tap Water from the Ground | 7.5 | 22.6 | -15.377411 | 28.231461 | 0.078 | <0.1 | **0.33** | <0.25 | <0.1 | **0.025** | <0.2 | 385 | <0.20 | **0.396** | <0.02 | 10.2 |
| 56 | Mutendere Near Chainama Golf Club Well Water | 7.31 | 22.2 | -15.398798 | 28.346059 | 3.644 | <0.1 | <0.1 | <0.25 | <0.1 | **0.027** | <0.2 | 215 | <0.20 | **0.532** | <0.02 | 7.6 |
| 57 | Chunga, Africa Methodist Episcopal Church Ground Water Borehole | 7.63 | 22.6 | -15.354280 | 28.246764 | 0.371 | <0.1 | **0.36** | <0.25 | <0.1 | <0.02 | <0.2 | 305 | <0.20 | <0.02 | <0.02 | 21.1 |
| 58 | Entrace of Chunga - Ground Water | 7.61 | 23.6 | -15.363683 | 28.254743 | 0.438 | <0.1 | **0.27** | <0.25 | <0.1 | <0.02 | <0.2 | 165 | <0.20 | **0.091** | <0.02 | 21.2 |
| 59 | Twikatane Area Ground Water | 7.62 | 24.3 | -15.361812 | 28.238413 | 0.328 | **0.34** | **0.23** | <0.25 | <0.1 | <0.02 | <0.2 | 290 | <0.20 | **0.064** | <0.02 | 12.9 |
| 60 | Avondale River Side Street Tap Water from the Ground | 7.49 | 23.7 | -15.386479 | 28.406418 | 0.301 | **0.14** | <0.10 | <0.25 | <0.1 | <0.02 | <0.2 | 167 | <0.20 | <0.02 | <0.02 | 17 |
| 61 | Ngome tap Water from Ground Aquifer | 7.71 | 24 | -15.368317 | 28.325356 | 0.5 | **0.34** | **0.25** | <0.25 | <0.1 | **0.025** | <0.2 | 150 | <0.20 | <0.02 | <0.02 | 21.3 |
| 62 | George Compound Borehole | 7.65 | 23.9 | -15.386337 | 28.237312 | 0.257 | **0.24** | **0.17** | <0.25 | <0.1 | <0.02 | <0.2 | 155 | <0.20 | **0.073** | <0.02 | 8.1 |
| 63 | Ndeke Village | 7.27 | 23.8 | -15.305062 | 28.415264 | 0.206 | <0.1 | **0.14** | <0.25 | <0.1 | <0.02 | <0.2 | 68 | <0.20 | <0.02 | <0.02 | 34.2 |
| 64 | Chisengalumbwe Basic School | 7.37 | 24.6 | -15.438116 | 28.319137 | 1.946 | **0.28** | **0.18** | **0.34** | <0.1 | <0.02 | <0.2 | 165 | <0.20 | **0.132** | <0.02 | 12 |
| 65 | Zeko Camp Borehole | 7.41 | 24.1 | -15.385867 | 28.234715 | 0.475 | <0.1 | **0.17** | **0.38** | **0.22** | <0.02 | <0.2 | 160 | <0.20 | <0.02 | <0.02 | 8.2 |
| 66 | NRDC Borehole Tap | 7.55 | 24.3 | -15.392026 | 28.371629 | 0.152 | **0.26** | **0.18** | **0.27** | <0.1 | <0.02 | **0.46** | 200 | <0.20 | <0.02 | <0.02 | 13.4 |
| 67 | Villa Elizabetha | 7.46 | 23.5 | -15.402727 | 28.276492 | 0.929 | **0.2** | **0.28** | **0.39** | **0.2** | <0.02 | <0.2 | 170 | <0.20 | **0.021** | <0.02 | 16.8 |
| 68 | Thornpark Construction Centre Borehole | 7.37 | 23.9 | -15.407415 | 28.282778 | 0.67 | **0.1** | **0.24** | <0.25 | <0.1 | <0.02 | <0.2 | 180 | <0.20 | <0.02 | <0.02 | 18.2 |
| 69 | Mazabuka Tap water | 8.02 | 20.7 | -15.847400 | 27.757810 | 3.268 | **0.25** | <0.10 | <0.25 | <0.1 | <0.02 | **0.21** | 130 | <0.20 | <0.02 | <0.02 | ND |
| 70 | Goam lakes | 8.25 | 20.8 | -15.388241 | 28.329970 | 0.096 | **0.16** | **0.29** | <0.25 | **0.19** | <0.02 | **1.03** | 155 | <0.20 | <0.02 | <0.02 | 10.9 |
| 71 | Magoye borehole water - main compound | 8.13 | 20.9 | -15.999180 | 27.608409 | 5.388 | **0.1** | **0.15** | <0.25 | **0.36** | <0.02 | **0.44** | 200 | 0.41 | **6** | <0.02 | ND |
| 72 | Zingalume borehole water | 8.17 | 21.4 | -15.381474 | 28.230375 | 0.307 | **0.25** | **0.16** | <0.25 | **0.11** | <0.02 | **0.29** | 230 | <0.20 | <0.02 | <0.02 | 21.6 |
| 73 | Solwezi well water | 6.23 | 21.1 | -12.394657 | 26.232585 | 0.181 | <0.10 | <0.10 | <0.25 | **0.16** | <0.02 | <0.2 | <20 | <0.20 | **0.022** | <0.02 | ND |
| 74 | Magoye boreholewater- school | 7.63 | 20.5 | -15.997282 | 27.607620 | 0.356 | <0.10 | <0.10 | <0.25 | <0.10 | <0.02 | <0.2 | 74 | <0.20 | **0.023** | <0.02 | ND |

ND - not determined

# **Appendix 9.** Analysis of Zambian water samples for common ions (Ground, River & Portable Water)

| | Sampled Sites | | | A | B | Parameters By Ion Chromatography (ppm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Site Name | pH | Temperature | latitude | longitude | $SO_4^{2-}$ | $Cl^-$ | $NO_3^-$ | $Na^+$ | $NH_4^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
| 1 | Mutendere Dam | 7.9 | 26.2 | -15.410223 | 28.359895 | 1.890 | 1.547 | NR | 7.333 | NR | 1.759 | 30.645 | 78.589 |
| 2 | Chipata/Marapodi at Garden Park (stream) | 7.95 | 26.3 | -15.372142 | 28.295329 | 12.037 | 21.134 | 16.032 | 48.507 | NR | 16.268 | 28.856 | 108.981 |
| 3 | Mutendere River upstream | 7.75 | 25.9 | -15.391525 | 28.368023 | 19.272 | 19.450 | NR | 52.028 | **3.469** | 20.437 | NR | 67.094 |
| 4 | Mumana Pleasure Resort (stream) | 7.78 | 26.1 | -15.383759 | 28.352576 | 9.529 | 1.537 | NR | 7.413 | **6.493** | 2.308 | 11.299 | 36.520 |
| 5 | Ngombe East Stream | ND | ND | -15.331788 | 28.331507 | 9.519 | 1.537 | NR | 7.232 | **6.332** | 1.766 | 12.089 | 36.552 |
| 6 | Ngwerere Stream (near kasisi) | 7.94 | 24.3 | -15.274562 | 28.443934 | 16.148 | 15.402 | 12.203 | 36.947 | NR | 3.123 | 25.668 | NR |
| 7 | Mutendere/Maplot midstream | 7.78 | 23.9 | -15.401413 | 28.363931 | 31.939 | 22.713 | NR | 58.158 | **2.246** | 20.096 | 37.947 | 63.595 |
| 8 | Malimba Ngwerere Stream | 7.93 | 24 | -15.304456 | 28.358026 | 14.882 | 17.364 | 30.078 | 41.202 | NR | 5.685 | 32.658 | 2.212 |
| 9 | Ngombe Basic school Stream | 7.9 | 23.7 | -15.351697 | 28.336484 | 13.380 | 11.159 | NR | 26.054 | NR | 2.680 | 32.885 | 83.620 |
| 10 | New N'gombe Basic Tap (underground) | 7.55 | 24.6 | -15.353020 | 28.333349 | 0.872 | 6.009 | 1.836 | 41.650 | NR | 2.445 | 23.271 | 27.495 |
| 11 | Kafue River at Motor Bridge | 7.72 | 24.8 | -15.837317 | 28.237336 | 10.407 | 0.857 | NR | 6.582 | NR | 1.373 | 11.436 | 34.675 |
| 12 | Lumumba/Great North Road Junction (stream) | 7.87 | 23.6 | -15.376825 | 28.278027 | 15.870 | 12.109 | 7.164 | 31.083 | NR | 4.578 | 0.211 | 60.983 |
| 13 | Chawama Compound Tap Water (LWSC) | 5.75 | 23.9 | -15.456692 | 28.282890 | 20.263 | 17.344 | 48.002 | 36.323 | NR | 1.928 | 22.236 | 96.865 |
| 14 | John Laing Tap (ground water) | 7.84 | 24.5 | -15.439694 | 28.273929 | 44.307 | 29.945 | 25.508 | 48.817 | NR | 0.923 | 30.683 | 86.282 |
| 15 | Matero Petroda Station Tap Water (LWSC) | 7.76 | 24 | -15.378768 | 28.245407 | 28.048 | 10.361 | 5.902 | 14.644 | NR | 0.926 | 21.320 | 103.826 |
| 16 | Roma/Garden Township Stream | 8.04 | 23.9 | -15.400353 | 28.288776 | 14.212 | 3.832 | 1.320 | 11.545 | NR | 1.861 | 19.795 | 65.733 |
| 17 | Blue Water Dam | 8.44 | 23.1 | -15.451925 | 28.274606 | 49.110 | 34.423 | 12.241 | 75.888 | NR | 10.701 | 20.387 | 62.321 |
| 18 | Train Bridge (Kafue River) | 1.9 | 22.9 | -15.788075 | 28.176641 | 12.462 | 0.085 | NR | NR | NR | 0.009 | NR | 2.154 |
| 19 | Kafue River Mufulira/Kitwe Road | 7.92 | 24.1 | -12.644862 | 28.164142 | 127.809 | 0.085 | NR | 7.623 | NR | 3.063 | 19.130 | 58.557 |
| 20 | Mine Water Mulonga Tap (Entebe) | 7.87 | 24.8 | -12.537643 | 28.242702 | 708.532 | 0.085 | NR | 10.543 | NR | 6.965 | 63.933 | NR |
| 21 | West Shaft Effluent Water | 8.36 | 23.6 | -12.522426 | 28.223604 | 1261.114 | 2.768 | NR | 31.934 | NR | 7.418 | 90.795 | NR |
| 22 | Tap Water - Mufulira Town Centre (Mulonga Water) | 7.83 | 22 | -12.599024 | 28.245121 | 115.267 | 3.207 | 0.759 | 7.831 | NR | 3.576 | 19.104 | 58.345 |
| 23 | Boating Club Dam (Mufulira) | 7.79 | 24.9 | -12.511877 | 28.236845 | 20.039 | 0.515 | NR | 3.550 | NR | 1.155 | 20.782 | 43.038 |
| 24 | Kafue River, Nkana East Waterworks | 8.02 | 25 | -12.807693 | 28.258129 | 256.170 | 0.085 | NR | 9.584 | NR | 4.916 | 35.378 | 78.964 |
| 25 | River Near Sabina | 7.95 | 24.1 | -12.714874 | 28.120857 | 0.468 | 211.325 | NR | 11.471 | NR | 9.365 | NR | NR |
| 26 | Before Tailings Damp (Butondo Stream) | 7.93 | 23.7 | -12.553647 | 28.185016 | 0.468 | 220.135 | NR | 29.788 | NR | 0.009 | NR | NR |
| 27 | Tailings Damp Effluent) | 7.31 | 23.5 | -12.553693 | 28.185199 | 0.468 | 598.244 | NR | 37.135 | NR | 51.325 | 341.964 | NR |
| 28 | Chingola/Chililabobwe Road Kafue River | 8.14 | 23.8 | -12.464392 | 27.851051 | 83.166 | 1.673 | 0.822 | 6.306 | NR | 3.636 | 18.350 | 54.427 |
| 29 | Chingola Mine Effluent | 7.63 | 24.6 | -12.518766 | 27.828553 | 1659.716 | 0.085 | NR | 10.155 | NR | 20.310 | NR | NR |
| 30 | Malembeka Stream into Kafue (1st site) | 6.73 | 24.7 | -12.895048 | 28.221352 | 1.673 | 0.217 | NR | 2.399 | NR | 4.540 | 1.845 | 4.449 |
| 31 | Kafubu River | 8.2 | 23.9 | -12.985817 | 28.643193 | 12.539 | 0.934 | 0.170 | 5.039 | NR | 0.786 | 34.394 | 86.237 |
| 32 | West Mine Shaft - Butondo Stream (at Bridge) | 7.91 | 23.4 | -12.521083 | 28.222888 | 20.679 | 0.506 | NR | 3.402 | NR | 0.877 | 22.009 | 45.232 |
| 33 | Butondo Stream at Road Near Butondo High | 7.85 | 23.7 | -12.526616 | 28.213540 | 0.468 | 258.511 | 7.527 | 35.342 | NR | 11.028 | NR | NR |
| 34 | Ndola Kitwe Dual Carriage Kafue River | 7.99 | 24.9 | -12.878078 | 28.257839 | 265.959 | 0.085 | 1.992 | 10.319 | NR | 4.940 | 34.723 | 80.071 |
| 35 | Malembeka Stream into Kafue (2nd site) | 7.56 | 23.8 | -12.898804 | 28.213170 | 107.611 | 0.085 | NR | 3.038 | NR | 3.921 | 14.642 | 51.386 |
| 36 | Chingola River Upstream | 7.97 | 23.1 | -12.538535 | 27.792312 | 9.975 | 0.358 | NR | 2.615 | NR | 1.770 | 17.535 | 34.683 |
| 37 | Tailings Damp (TD 11) | 7.89 | 24.3 | -12.559898 | 28.193978 | 0.468 | 276.150 | NR | 33.483 | NR | 14.135 | NR | NR |
| 38 | Eagle High School Tap Water (Groundwater) | 7.69 | 23.8 | -12.565491 | 28.228285 | 55.096 | 1.517 | 0.404 | 3.410 | NR | 7.088 | NR | 33.223 |
| 39 | Kawama stream - Mufulira | 7.4 | 24.1 | -12.566172 | 28.221736 | 193.047 | 5.976 | 6.225 | 16.245 | NR | 5.910 | 26.454 | 58.241 |
| 40 | Kafue Water Treatment Plant - Mulonga WSC | 7.9 | 23.8 | -12.587270 | 28.181009 | 181.973 | 0.607 | NR | 8.597 | NR | 3.070 | 22.826 | 74.848 |
| 41 | Kabwe City Council Tap Water (Lukanga WSC) | 7.63 | 20.8 | -14.443449 | 28.446066 | 4.145 | 0.703 | 4.462 | 3.550 | NR | 0.009 | 50.234 | 43.625 |
| 42 | Jack & Jill School - Lukanga WSC | 7.74 | 21.3 | -14.447442 | 28.439063 | 11.006 | 2.776 | 10.159 | 5.916 | NR | 0.009 | 45.646 | 66.646 |
| 43 | Kafubu Upstream | 8.22 | 24.9 | -12.976014 | 28.655871 | 13.095 | 0.817 | NR | 4.711 | NR | 0.606 | 34.087 | 86.780 |
| 44 | Kansuswa Stream (at Mufulira/Kitwe Road) | 6.76 | 25.9 | -12.586698 | 28.208937 | 8.929 | 2.092 | 2.193 | 7.116 | NR | 2.188 | 4.457 | 9.222 |
| 45 | Laka Petroluem Filling Station Tap Water - Ndola | 7.26 | 27 | -12.969959 | 28.620696 | 2.713 | 2.066 | 1.145 | 5.413 | NR | 1.390 | 0.396 | 24.796 |
| 46 | Kafubu Downstream | 7.92 | 24.6 | -12.996526 | 28.606989 | 17.666 | 3.734 | 11.539 | 15.622 | NR | 3.854 | 44.783 | 93.215 |
| 47 | Chainama Lusaka General Hospital | 7.8 | 21.8 | -15.386093 | 28.353912 | 16.136 | 2.725 | NR | 9.424 | NR | 1.243 | 15.729 | 51.263 |
| 48 | Kamwala Remand Prison Borehole Water | 7.39 | 22.1 | -15.430534 | 28.287962 | 45.852 | 13.799 | 32.490 | 38.256 | NR | 43.483 | 41.665 | 36.993 |
| 49 | Libala Basic School Tap from the Ground | 7.66 | 22.1 | -15.441930 | 28.310054 | 10.890 | 9.120 | 37.033 | 17.097 | NR | 1.267 | 39.238 | 45.992 |
| 50 | Vera Chiluba Basic School Tap from tap ground | 7.63 | 23 | -15.404121 | 28.348721 | 15.442 | 10.051 | 25.332 | 16.921 | NR | 0.009 | 20.640 | 64.719 |
| 51 | UNZA Tap Water - Groundwater | 7.91 | 21.9 | -15.392944 | 28.326775 | 24.016 | 12.456 | 6.863 | 13.977 | NR | 0.009 | 38.919 | 50.780 |
| 52 | Femag Garden John Laing Tap Water from the Ground | 7.12 | 23.6 | -15.442982 | 28.271762 | 35.558 | 27.188 | 17.038 | 50.262 | NR | 6.416 | 34.423 | 51.969 |
| 53 | Kanyama Ground Water-Borehole-Filling Station | 7.74 | 21.2 | -15.432462 | 28.263631 | 55.433 | 48.205 | 61.877 | 92.166 | NR | 11.386 | 49.148 | 52.387 |
| 54 | Gospel Outreach Tap Water-ground | 7.49 | 22 | -15.400639 | 28.325940 | 35.827 | 28.596 | 48.815 | 33.199 | NR | 0.009 | 48.466 | 59.427 |
| 55 | Zingalume Police Tap Water from the Ground | 7.5 | 22.6 | -15.377411 | 28.231461 | 105.335 | 72.917 | 127.562 | 102.705 | NR | 0.009 | NR | NR |
| 56 | Mutendere Near Chainama Golf Club Well Water | 7.31 | 22.2 | -15.398798 | 28.346059 | 75.215 | 61.733 | NR | 108.771 | NR | 4.824 | 53.672 | 49.085 |
| 57 | Chunga, Africa Methodist Episcopal Church Ground Water Borehole | 7.63 | 22.6 | -15.354280 | 28.246764 | 60.832 | 55.858 | 32.634 | 44.160 | NR | 0.009 | NR | 37.196 |
| 58 | Entrace of Chunga - Ground Water | 7.61 | 23.6 | -15.363683 | 28.254743 | 58.455 | 38.511 | 17.577 | 66.398 | NR | 5.945 | 28.808 | 51.320 |
| 59 | Twikatane Area Ground Water | 7.62 | 24.3 | -15.361812 | 28.238413 | 50.954 | 48.695 | 54.387 | 38.656 | NR | 0.009 | 71.356 | 60.425 |
| 60 | Avondale River Side Street Tap Water from the Ground | 7.49 | 23.7 | -15.386479 | 28.406418 | 0.468 | 16.323 | NR | 13.831 | NR | 0.339 | 66.846 | 26.253 |
| 61 | Ngome tap Water from Ground Aquifer | 7.71 | 24 | -15.368317 | 28.325356 | 16.295 | 14.768 | 16.868 | 30.535 | NR | 1.084 | 47.532 | 45.364 |
| 62 | George Compound Borehole | 7.65 | 23.9 | -15.386337 | 28.237312 | 26.289 | 13.121 | 19.001 | 24.406 | NR | 0.926 | 35.408 | 45.629 |
| 63 | Ndeke Village | 7.27 | 23.8 | -15.305062 | 28.415264 | 0.991 | 1.848 | 46.095 | 59.899 | NR | 3.344 | 13.811 | 32.726 |
| 64 | Chisengalumbwe Basic School | 7.37 | 24.6 | -15.438116 | 28.319137 | 19.795 | 3.558 | 5.326 | 9.824 | NR | 2.213 | 21.033 | 81.614 |
| 65 | Zeko Camp Borehole | 7.41 | 24.1 | -15.385867 | 28.234715 | 37.598 | 16.446 | 10.979 | 29.730 | NR | 4.318 | 33.525 | 45.911 |
| 66 | NRDC Borehole Tap | 7.55 | 24.3 | -15.392026 | 28.371629 | 3.401 | 3.847 | 14.972 | 14.734 | NR | 1.331 | 44.975 | 39.739 |
| 67 | Villa Elizabetha | 7.46 | 23.5 | -15.402727 | 28.276492 | 93.460 | 23.992 | 8.253 | 48.835 | NR | 1.626 | 47.659 | 48.561 |
| 68 | Thornpark Construction Centre Borehole | 7.37 | 23.9 | -15.407415 | 28.282778 | 69.394 | 14.724 | 5.711 | 18.764 | NR | 0.009 | 37.183 | 49.302 |
| 69 | Mazabuka Tap water | 8.02 | 20.7 | -15.847400 | 27.757810 | 21.499 | 2.572 | NR | 10.641 | NR | 2.898 | 16.928 | 55.875 |
| 70 | Goam lakes | 8.25 | 20.8 | -15.388241 | 28.329970 | 24.781 | 17.191 | NR | 17.560 | NR | 0.670 | 37.910 | 59.653 |
| 71 | Magoye borehole water - main compound | 8.13 | 20.9 | -15.999180 | 27.608409 | 62.080 | 12.441 | 48.406 | 49.640 | NR | 5.851 | 49.079 | 58.188 |
| 72 | Zingalume borehole water | 8.17 | 21.4 | -15.381474 | 28.230375 | 31.676 | 20.360 | 31.935 | 21.997 | NR | 0.009 | 55.574 | 63.381 |
| 73 | Solwezi well water | 6.23 | 21.1 | -12.394657 | 26.232585 | 0.468 | 0.630 | NR | 0.534 | **0.169** | 0.009 | 0.446 | 0.835 |
| 74 | Magoye boreholewater- school | 7.63 | 20.5 | -15.997282 | 27.607620 | 55.601 | 5.724 | 28.326 | 81.018 | NR | 9.661 | 38.041 | 30.996 |

NR - not recordable