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Foreword

The Environmental Management Act (CAP 20:27) mandates the Agency to undertake environmental research for purposes of providing guidance to environmental policy, legislation and decision making. Pursuant to this provision, the Environmental Management Agency (EMA) has provided a platform to all environmental researchers to publish their work in the Journal of Environmental Management in Zimbabwe (JEMZ). This is a great step in ensuring that environmental information is scientifically documented and made accessible in line with the dictates of our Constitution. Our first issues focus on stakeholder participation, environmental policies, laws and regulations, waste management, environmental and human health risk, environmental degradation assessment, water resources management, as well as earth observation techniques in environmental management.

This journal has been published in collaboration with technical partners from the University of Zimbabwe, Chinhoyi University of Technology and University of Energy and Natural Resources of Ghana. I would like to applaud them for cementing this collaboration between the academia and the Agency. This journal is partly a culmination of a long journey the Agency has taken sponsoring research at Master's Degree level in Zimbabwe.

The JEMZ offers a window to scientists to publish research that can influence policy. We are in an era where decisions should be science based as the Country is currently grappling with environmental challenges which include pollution and land degradation. Through this journal I call for innovation, new technologies and novel approaches for restoration of degraded lands, dealing with emerging issues on invasive alien species such as *vernonathura polyanthes*, air pollution abatement and efficient waste to energy solutions among others.

The Journal will take priority on publishing results of applied research so that the government can solve local challenges and uplift standard of living of communities. Let me also take this opportunity to appeal for increased collaboration in environmental research by stakeholders who include industry, commerce, and mining among others. I therefore challenge all scientists to make use of this platform offered by the Agency to proffer practical solutions to our local challenges.

A Chigona

Director General – Environmental Management Agency

Preface

An Overview Of Environmental Management In Zimbabwe

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This first issue of the Journal of Environmental Management in Zimbabwe (JEMZ) is a compilation of selected papers that were presented at two research symposia hosted in 2016 and 2019 by the Environmental Management Agency (EMA) in Harare, Zimbabwe, as well as contributions from multi and inter disciplinary studies carried out in the country in the last five years. It is our sincere hope that this issue marks the beginning of a new era in environmental research and dissemination in the country and beyond. JEMZ aims to offer researchers not only an opportunity to publish their work but also establish the current status of the environment and environmental management the country. More importantly, JEMZ aims to be an

authoritative source of environmental data in the country, and provides the basis for policy crafting and analysis.

This inaugural volume contains 13 peer-reviewed papers related to integrated environmental management in Zimbabwe and are a culmination of extensive research in six broad themes, namely, (1) stakeholder participation (2) environmental policies, laws and regulations (3) waste management, environmental and human health risk (4) environmental degradation assessment (5) water resources management, as well as (6) earth observation techniques in environmental management. As an environmentally concerned Southern African Development Community (SADC) member, Zimbabwe has endorsed concepts of Environmental Management, thus making these thematic areas critical for sustainable development. Issues addressed in this journal also contribute towards building knowledge to facilitate sustainable environmental actions aimed at fulfilling objectives of the Africa We Want (Agenda 2063).

Furthermore, by virtue of being a full member of the UN, Zimbabwe subscribes to the ideals of the Sustainable Development Goals (SDGs), and these thematic areas were selected in the light of their importance to sustainable development.

Zimbabwe, currently faces wide range of environmental challenges ranging from pollution (air, water, soil) from both point and non-point sources, environmental, wetland destruction and degradation, veld fires, invasive alien species, deforestation, illegal harvesting and trade in natural resources such as fish and wildlife, sand mining, soil erosion, rampant artisanal gold panning, waste management and inappropriate agricultural practices.

The country just like the rest of the world also suffers from a surge in plastic pollution. These environmental threats are on the increase in the country and have important implications for human welfare including public health. The aforementioned environmental threats are exacerbated by rapid population increase, illegal land occupations, human displacement and resettlement, urbanization, as well as climate change. These challenges require that the country join hands with the global scientific community, to find sustainable solutions. Therefore, this journal offers an opportunity for researchers to explore these environmental issues and contribute towards providing science based environmental solutions that are complemented by stakeholder engagement.

The volume provides a platform to share knowledge on contemporary environmental issues, not only for academics, but also for policy makers, local authorities, industry and relevant stakeholders. Ultimately the journal aims at contributing to knowledge and innovative approaches and models in environmental sciences that facilitate informed decision-making and policy formulation by environmental managers and

practitioners in the region. Whist the research themes have a wider scope to cater for diverse environmental aspects, the review process is stringent, rendering the papers and the research credible.

The editors wish to thank all the contributing authors for their efforts, EMA which facilitated and funded some of the research presented in this volume and the numerous reviewers who provided insightful comments made the production of high-quality papers and this journal possible.

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People's Attitude and Perceptions towards Biodiversity and Ecosystem Services in Cowdray Park, Bulawayo.

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Abstract

As urban areas in Zimbabwe continue to expand, biodiversity and ecosystem services have been exposed to unsustainable exploitation as citizens strive to earn a living. This study sought to investigate people's perceptions of ecosystem services in Cowdray Park because it is one of the biggest high-density suburbs in Bulawayo, Zimbabwe. The study used mixed methods of collecting data from 160 randomly selected residents of Cowdray Park and stratified according to age for easy focus group discussions. Participants from Bulawayo City Council, Environmental Management Agency and National Parks and Wildlife shared their knowledge on the current environmental issues in Cowdray Park through semi-structured interviews. Inspired by the Theory of Planned Behaviour (behaviours are determined by attitudes) the assumption was that a positive attitude should be indicative of sustainable environmental behaviour and practices. However, it was discovered that perceptions do not necessarily indicate behaviour. Results from the focus group discussion revealed that 51% of the participants value ecosystem services for their utilities more than one's willingness to conserve them. In as much as ecosystem

services are meant to be a source of livelihood in Cowdray Park, they are unsustainably exploited. Sand abstraction, quarry pounding and firewood selling have dominated the market while urban farming is done to fight poverty. The study, therefore, recommends a reaffirmation of social norms and strengthening of both formal and informal institutions to improve environmental management strategies.

Key Words: *Biodiversity, Cowdray Park, Ecosystem Services, New Environmental Paradigm, Perceptions.*

Introduction

Pinpointing the exact dates when the environment conservation debate started is very difficult but Nhamo and Inyang (2011) acknowledge that efforts to conserve the environment started as early as the 1880s. The first recognized effort was made by Switzerland to establish a regional agreement on the conservation of migrating birds and later in 1886, an agreement on regulating salmon fisheries was signed between The Netherlands, Luxembourg, Germany and Switzerland (Nhamo and Inyang, 2011). The internationalization of environmental management gained prominence in the 1970s stretching to the 1990s through the enactment of various conventions inclusive of Convention on Wetlands of International Importance (1971), Convention on International Trade in Endangered Species (1973), Convention on Biodiversity as well as Convention to Combat Desertification (1994), (World Bank, 2014).

The inevitability of urban expansion and development have subjected biodiversity and ecosystem services to stress as urbanites have proven to be the most consumers of ecosystem services, (Grimm *et al* 2008, Folke *et al*, 2011, Kay 2016,). In 1987 the Bruntland Commission published a report, *Our Common Future,* addressing the clashes between economic growth and environmental stability. It was underscored that development should meet the needs of today without compromising the needs of tomorrow, (Stoddart, 2011). In substantiation, Elmqvist *et al* (2013) observe that research has been silent on the governance of urban biodiversity and ecosystem services yet ignoring proper management of biodiversity and ecosystem services negatively affects the world which has been seen through climate change.

Biodiversity and Ecosystem services management in Zimbabwe is also informed by the need to balance it with economic growth and development. Mawere (2013), states that environmental conservation in Zimbabwe is disturbed by many factors inclusive of the introduction of scientific methods instead of indigenous knowledge systems. In aggravation, urban planners seem to be turning a blind eye towards the environment, (Chirisa and Matamanda, 2014).

In support of the above, Banga (2013) opines that not only does the environment suffer the aftermath of urbanisation, biodiversity is also lost due to unsustainable urban farming and animal husbandry. In as much as urban agriculture mitigates poverty,

its contribution to depletion of biodiversity is worth noting. This is an emphasis on Elmqvist *et al* (2013)'s argument that urban ecosystem services and biodiversity suffer a lot from human errors and actions. It was at the centre of this study to investigate the people's position in this environmental management discourse for the conservation of biodiversity and ecosystem services in Cowdray Park. The study was guided by the following objectives

Objectives

1. To investigate people's perceptions of the environment in Cowdray Park.
2. To assess people's value for ecosystem services in Cowdray Park
3. To establish methods to promote behavioural change in environmental management in Cowdray Park.

Literature Review

The Convention on Biological Diversity (1992), defines biodiversity as the diversification of living organisms and the complexities of the categories in which they are part. Mace *et al* (2012) observe that this definition leaves room for actors to set standards that differentiate human beings from the rest of biodiversity. In as much as research acknowledge that there is a difference between biodiversity and human beings, Houde (2007), is of the view that ecological complexities are further widened by social constructs. Bastian (2012) simply refers to biodiversity as a variety of life on earth, ranging from plants, animals or any other microorganisms, thus, biodiversity is all about life.

According to the CBD (1992), biodiversity is categorised in three main groups inclusive of genetic diversity, species diversity and ecosystem diversity. Under the genetic, all species are believed to be connected one way or the other through genes (Bastian 2012). Species diversity is a variety within a particular habitat or region (Bastian, 2012). These species vary depending on the conduciveness of the carrying environment. Ecological diversity has to be protected to maintain a healthy network, (Constanza *et al* (2007, Rhodes and Hockings, 2014).

Biodiversity and ecosystem services are intertwined concepts that are hard to study in isolation of each other, (Mace, 2012). MEA (2005), states that ecosystem services (*cultural, provisioning, regulatory and supporting services*) are benefits that individuals obtain from the environment. The link between the two is anchored on biodiversity as a facilitator of the provisioning of ecosystem services, thus ecosystem services are largely dependent on biodiversity.

The United Nations Earth Summit of 1992 has been credited for proposing the need to

conserve the environment at three levels inclusive of species, ecosystems and genetic diversity, (Kay, 2016). In Zimbabwe, the Environmental Management Agency was enacted in line with the provisions of Rio de Janeiro to facilitate the management of the environment and ecosystem services nationwide. Before that, numerous Acts were put in place to manage natural resources in Zimbabwe through the Natural Resources Board. Some of these include Natural Resources (1942), Forest Act (1948), Parks and Wildlife Act (1949), Parks and Wildlife Act (1975), (Murombedzi 2003). These Acts were blamed for inefficiency because of their lack of communal involvement in managing natural resources which later on necessitated the birth of Communal Based Natural Resources Management in line with the Kyoto Protocol Agenda 21.

In 2002 the Environmental Management Act (Chapter 20:27) was enacted and it annulled The Atmospheric Pollution Prevention Act (Chapter 20:03), The Hazardous Substances and Article Act (Chapter15:05), Natural Resources Act (Chapter 20:13) (Mutambara, 2005). This new Act ushered in an environmental management approach that is centred at 'intergenerational equity', harmful-free and clean environment through working together with all relevant stakeholders.

The State of biodiversity and urbanisation in Africa

Africa is believed to be rich in biodiversity with its living organisms constituting almost a quarter of global biodiversity, (UNEP-WCMC, 2016). However, a decline in species has been recorded in 2014 where it was noted that 6 419 animals and 3148 plants were under threat of extinction according to the IUCN Red List (UNEP-WCMC, 2016). 21% of freshwater species are also recorded to be under threat where 45% of freshwater species and 58% of freshwater plant species in Africa are also under threat due to overexploitation. These declines are said to be more in Western and Central Africa than in Southern or Eastern Africa, (Craigie, *et al* 2010). Although experienced at different levels, biodiversity loss is a common challenge in Africa.

The growing demand for biodiversity and ecosystem services is attributed to population growth in Africa. World Bank (2011) projected that the population of Africa would grow at 2.3 % by 2015. Although Africa is still largely rural, it is urbanising faster with its urban population expected to triple from 395 million in 2010 to at least 1.339 billion in 2050, (Burak *et al,* 2017). Urban expansion in Africa is said to be associated with "unplanned and unregulated" growth further aggravated by "weak planning institutions" resulting in biodiversity loss, (Pieterse and Parnell, 2014 cited in Burak *et al* 2017: 2). Biodiversity loss negatively affects the availability of ecosystem services which consequently affects people at large (Cardinale *et al.* 2012). Brawn (2017) summarises the causes of biodiversity loss as climate change, invasive alien species, pollution and habitat loss caused by the transformation of the natural environment to meet the needs of the people. In a research done in Cape Town, South Africa, Holmes *et al* (2012), note that biodiversity in the low land was at the verge of getting extinct due to agricultural

habitat loss, urban development, mining, invasive plants as well as land degradation.

The same was also confirmed in a study conducted in Harare on *The effect of land-use change on the quality of urban wetland,* where Murungweni (2013) noted that housing development and crop cultivation in Harare have led to 13.4 % loss of wetland area in Monavale. This has consumed water logging areas that are used by wetland birds during breeding time. The scenic view is also affected when reeds, trees and grass are cleared destroying habitats for many bio-organisms. Murungweni (2013) further states that the Environmental Assessment Impact was not done because the Environmental Management Act was not yet in enacted, ironically the city was rapidly expanding to meet the government's target on housing for all by the year 2000. Both mentioned studies show a nexus between urban expansion and biodiversity loss aggravated by weak planning institutions.

Understanding Perceptions and Attitudes

Perceptions are a general overview of a particular object that determines an individual's attitude and ability to make a meaningful interpretation of the world, (Tanner-McAllister, 2014, Fischer *et al*, 2011). Psychologists argue that there is a tissue-thin difference between attitudes and perceptions. Perceptions determine one's attitude towards a given object. Attitude reflects the readiness of a person to act and hints on the manner one is to act. Similarly, Gordon (1935: 810) in Milfont and Duckitt (2010) defined attitudes as a '*mental and neural state of readiness, organised through experience and exerting a directive or dynamic influence upon individual's response to all objects and situations with which it is related*'.

A conclusion is, therefore, made that attitude is all about intention and behaviour. Regarding the environment, the behaviour is how people, either value or abuse their natural resources (Eden, 1993). Environmental behaviours are indicators of people's interaction with their environment and they are an outcome of attitude and perceptions, (Milfont and Duckitt 2010, Fischer, *et al.* 2011, Buckton 2014). They predict the future sustainability of the entire environment.

The Theory of Planned Behaviour (Ajzen and Fishbein, 1980)

This study was anchored on Ajzen and Fishbein 1980's Theory of Planned Behaviour. According to Ajzen and Fishbein (2012), an individual's behaviour is an output of a combination of attitude towards behaviour, subjective norm, and perceived behavioural control. Ajzen (2005) believes that when people have control over the performance of the behaviour, they tend to act per their intentions. Applying this theory, understanding people's subjective norms, attitude, behaviour as well as their ability to control perceived behaviour determined a general overview of people's attitude towards their environment.

Given that attitudes are a scale that weighs the behaviour of people, relevant and positive attitude results in a favourable behaviour, (Ferdous, 2010). Kim *et al.* (2013) argue that subjective norms include one's social beliefs on the limits one is expected to participate. This means that there are guiding social norms within every society which influence people's behaviour. To Fishbein and Ajzen (1980), beliefs or norms are acquired through direct observation, information received from external forces or by inferences made at personal levels. One can, then, argue that beliefs or norms are social constructs that individuals repeatedly consume until they become part of their everyday life. The third predictor of intention in this theory is perceived behavioural control, which gives an understanding of people's perceptions of their ability to partake in a behaviour (Ferdous, 2010). Sven (2010) posits that external hindrances can impede the performance of any behaviour. It is within an individual's capacity to control and suppress these impediments. Likewise, the study was based on the notion that he who has positive thoughts about the environment should have a positive attitude towards conserving it.

Methodology

Area of Study

The study was carried out in Cowdray Park, a high-density suburb of Bulawayo, the second-largest city of Zimbabwe which is also the capital of Bulawayo Metropolitan Province. Bulawayo falls under Ecological Region IV which is characterised with very low rainfall of between 450 and 600 millimetres per year. Its vegetation is dominated by acacias and mopane woodland. According to EMA (2018), this region is experiencing overexploitation and deforestation as people exploit Mopane trees for firewood and fencing poles around their properties. Bulawayo's population was on the rise since 1952 and the highest growth rate of 9.02% was recorded in 1962. As the economy dropped in early 2000 there was an increase in emigration which saw a decrease in the population. As of 2017, it decreased by -0.47% leaving it at 642000. Cowdray Park is located about eighteen kilometres north-west of Bulawayo Central Business District. The suburb was developed in the early 1990s and it is one of the largest high-density suburbs of Bulawayo, (Manyepa, 2014). In 2005 Cowdray Park experienced a massive extension due to the Live well/Garikai/Hlalani Kuhle housing scheme which was meant to accommodate the victims of Operation Restore Order (Murambatsvina) which saw the demolition of informal houses around urban cities of Zimbabwe. About 700 by 200m2 houses were built which translates to the exploration of around 14 hectares of virgin land and since then the suburb has been expanding, (Gumbo, 2014; Manyepa, 2014). It is because of this rapid and continuous growth that this study sought to investigate the state of biodiversity loss and ecosystem services in Cowdray Park.

Research Design

The study used a case of Cowdray Park. A case study was chosen because it is explorative and allows an in-depth investigation of the subject matter based on real-time experiences. Data were collected using both qualitative and quantitative methods to cure bias that usually emanates from the interference of the researcher's preconceived insights. Using a mixed-method approach helped in complementing the weaknesses of both methods, thereby giving holistic findings.

Population, Sample Size and Sampling Methods (Stratified and Purposive)

According to ZIMSTAT (2012), Cowdray Park has approximately 45,115 residents which constituted the target population for this study. In determining the sample size, Sekeran (2003)' sample size table was adopted where it was argued that for a total population of 50 000, the sample size should be at least 357 however the saturation point was at 160 participants. The population was stratified into four as follows: 19 – 29 years (Young), 30 – 39 years (Middle Age), 40 – 49 years (Adults) and over 50 years (Older adults). Per each stratum, 40 respondents were randomly sampled to give a total of 160 participants. Six key informants (two from each) were purposively sampled from Bulawayo City Council (department of housing and planning), the Environmental Management Agency and National Parks and Wildlife Management based on the researcher's judgement that they had professional knowledge required for the study.

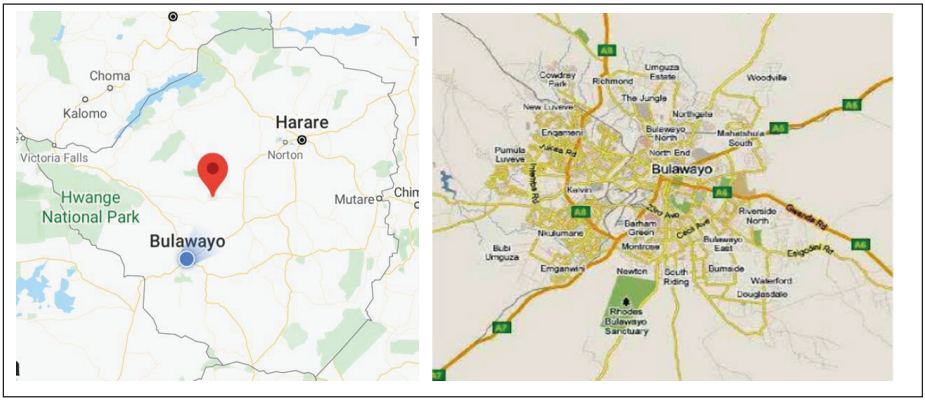


Figure 1: Map of Zimbabwe and Bulawayo

Data Collection Methods and analysis

Data was collected using semi-structured interviews with Key Informants from BCC staff, EMA and Parks officials. Questionnaires were distributed to gather information from the residents of Cowdray Park. Three focus group discussions were convened in

Cowdray Park where participants had an opportunity to discuss their opinions on the current environmental debate. It was justified to use focus group discussions in this study because they used open-ended questions which facilitated the gathering of more useful data. Quantitative data were analysed using SPSS while ATLAS. Ti was used for qualitative data analysis and presented thematically.

Results and Discussion

Respondents' general environmental attitude and perceptions

To gather data on perceptions, the New Environment Management Paradigm (NEP) scale constituted the greater part of the questionnaire. The NEP was developed by Dunlap and Van Liere (1978) and has its roots in the United States of America's environmental movement of the 1960s-1970s (Anderson, *et al*, 2012). It shifts from the Dominant Social Paradigm's core principles of treating human beings as independent from nature and envisions human beings as integral and dependent on the entire environment. This scale has15 statements which participants are expected to give their opinions on. Responding 'yes' to eight statements shows a positive attitude while responding yes to the other seven speaks of the negative perceptions towards the environment. Statements in red font confirm 'anti-environmental' attitude while those in black are pro-environmental management.

The NEP Scale Statements

1. *We are approaching the limit of the number of people the earth can support*
2. *Humans have the right to modify the natural environment to suit their needs*
3. *When humans interfere with nature it often produces disastrous consequences*
4. *Human ingenuity will ensure that we do not make the earth unliveable*
5. *Humans are seriously abusing the environment*
6. *The earth has plenty of natural resources if we just learn how to develop them*
7. *Plants and animals have as much right as humans to exist*
8. *The balance of nature is strong enough to cope with the impacts of modern industrial nations*
9. *Despite our special abilities, humans are still subject to the law of nature*

10. *The so-called 'ecological crisis' facing humankind has been greatly exaggerated*

11. *The earth is like a spaceship with very limited room and resources*

12. *Humans were meant to rule over the rest of nature*

13. *The balance of nature is very delicate*

14. *Humans will eventually learn enough about how nature works to be able to control it*

15. *If this continue on their present course, we will soon experience a major ecological catastrophe*

Collected data were coded into five main themes inclusive of Human Dominion (statements 2,7,12), Ecological Limits (1,6,11); Balance of Nature (5,8,9,13), Science and Technology (4,14) and Ecological Catastrophe (3,10,15).

The table below presents scores as per participants' responses.
Summary of results per age group (Agree/Strongly Agree)

	The young (19-29 years) N=40	The Middle Age (30-39 years) N=40	Adults (40-49 years) N=40	Older Adults (above 50 years) N=40
Human Dominion	19	13	17	36
Ecological Limits	40	40	20	8
Balance of Nature	15	18	20	25
Science and Technology	28	23	2-	9
Ecological Catastrophe	40	40	40	28

Opinions on Human Dominion over ES in Cowdray Park

53% of the participants agreed that humans had the authority to modify natural resources to meet their needs. It was noted that the Older Adults (Above 50 years) had the highest respondents who acknowledged human dominion over the environment with a total of 36, 8 of which strongly agreed. This was attributed to their belief in biblical teachings that people were given authority to rule nature. Ecosystem services are perceived as a gift from God awaiting people to consume them for their benefit.

Opinions on Ecological limits and Ecological Catastrophe in Cowdray Park

78% (n=128) of the participants acknowledged that the earth was fast approaching the

Table 1: Respondents' scores to the NEP Scale (Number of participants-100)

	strongly agree		Agree		not sure		disagree		strongly disagree	
	Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %	Count	Row N %
Humans have the right to modify the natural environment to suit their needs	8	5.0%	77	48.1%	0	0.0%	75	46.9%	0	0.0%
We are approaching the limit of the number of people the earth can support	28	17.5%	100	62.5%	0	0.0%	32	20.0%	0	0.0%
The balance of Nature is strong enough to cope with the impacts of modern industrial nations	0	0.0%	82	51.2%	0	0.0%	78	48.8%	0	0.0%
Human ingenuity will ensure that we do not make the earth unlivable	0	0.0%	80	50.0%	23	14.4%	57	35.6%	0	0.0%
If this continue on their present course, we will soon experience a major ecological catastrophe	32	20.0%	106	66.3%	14	8.8%	8	5.0%	0	0.0%

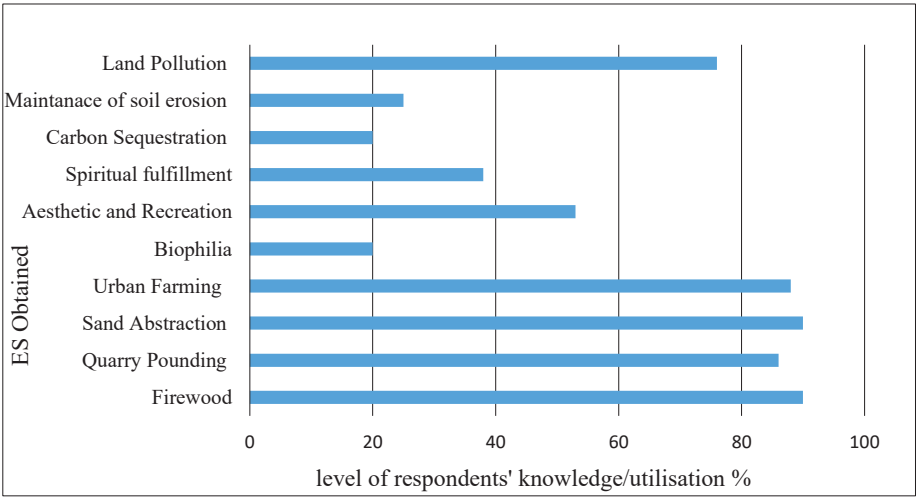
limits of its carrying capacity. The greater percentage of this came from the age groups 19-29 and 30-40 years where all 80 participants agreed. This was attributed to their exposure to current environmental debates presented via formal education, social platforms as well as electronic and print media. On the other hand, the older adults (above 50 years), dismissed the idea and argued that the earth was big enough to accommodate everyone and most people within the ages 40 and above 50 expressed interest in acquiring more land for building their houses. This speaks to a pro-development attitude at the expense of the environment. It also shows ignorance of the dangers associated with environmental degradation in the area. In support of this, BCC acknowledged the inevitability of development and stated that '*we cannot stop development, we can only try to control it'*. This response, however, is silent on the implications of continuous development on the environment.

Opinions on the Balance of Nature and faith in Science and Technology

With regards to the balance of nature, people expressed ignorance of the catastrophic consequences of human interference with nature. 82 people (51%) agreed that the balance of nature was strong enough to cope with the impacts of modern industrial nations. This shows the distance that exists in Cowdray Park, between people and environmental management efforts. Failure to realise catastrophic results of human error and actions explains continuous depletion of biodiversity in Cowdray Park. Furthermore, people indicated their trust in modern technology and science to mitigate the effects of biodiversity loss within the area and the country at large. 78 (49%) people agreed that human innovations or ingenuity can mitigate the effects of environmental loss and make the earth liveable. It is important to note that the NEP scale was a bit confusing to the participants such that in some instances they either agreed or disagreed to contradicting statements. To address this gap, FGDs were convened and results are presented below.

ES Obtained in Cowdray Park and their value

The first FDG focused on ascertaining the ecosystem services derived from the surrounding area. It was discovered that provisioning (*Urban farming, sand abstraction, quarry pounding and firewood*) and cultural ES (*Aesthetic and recreation, spiritual fulfilment*) dominated the list of ecosystem services obtained as presented in the graph below.



The graph above shows less interest in the connection people have with nature (*biophilia*), knowledge on the maintenance of soil erosion as well as knowledge on carbon sequestration. Building on Milfont and Duckitt (2010)'s argument that environmental attitudes are either utilitarian or preservation, results show that perceptions in Cowdray Park are biased towards the utilitarian approach. Most participants mentioned that they built their houses using sand abstracted from surrounding places in Cowdray Park. Some residents have since identified a business opportunity in sand abstraction where they sell it to other people within Bulawayo, but are very discrete to evade the law.

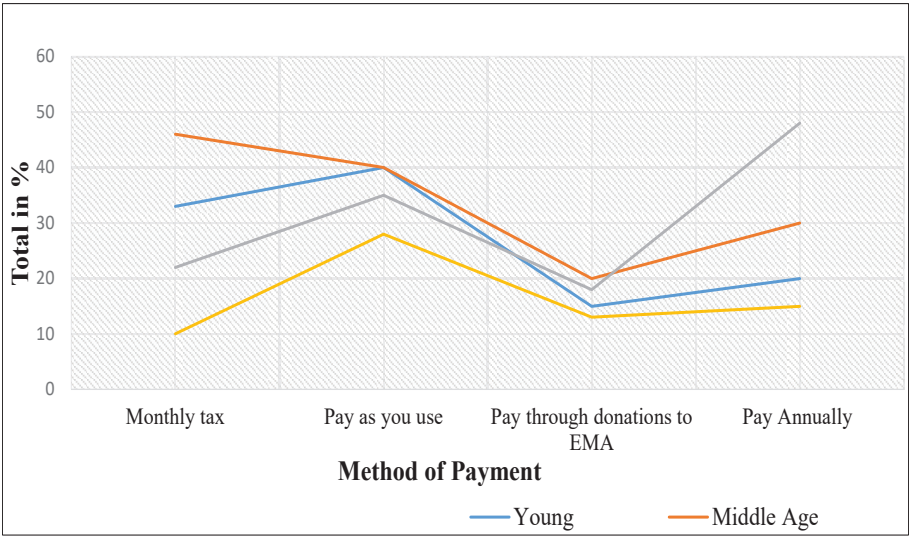
The FDG also gathered that construction has led to quarry pounding in Cowdray Park. However, it has exposed soil to erosion during rainy seasons which exposes biodiversity to more risk. It was revealed that one can pay from as little as US$3 per wheelbarrow of the quarry to US$180- $200 per 7 tonnes which is far less than the official market price of US$250-US$320 per 7 tones. With the increasing construction taking place in Bulawayo, the worst is feared in sand abstraction and quarry pounding. Although BCC revealed that there are designated places from which people can legally abstract sand only if they are licensed, EMA stated that people are not forthcoming in terms of applying for licenses, probably because they want to avoid payment of taxes involved to maximise on their profits.

Unavailability of electricity in new parts of Cowdray Park leaves residents with no choice but to solely rely on firewood for energy. Some participants in areas with electricity preferred firewood to electricity "……*because it is cheaper and readily available'* and has also turned into a source of livelihood as they sell it for survival. Urban farming and allotment gardens are also rampant in the area. While Mabhena and Sithole (2014) argue that urban agriculture is a master weapon adopted by women to

fight poverty it causes more damage to biodiversity than good.

People's value for Ecosystem Services in CP through a willingness to pay

FDG 2 and 3 investigated people's willingness to pay for ecosystem services. Participants were asked to choose a method of payment suitable for them from the following; (a) *Pay monthly tax* (b) *pay as they use* (c) *pay through donations to EMA* (d) *pay annually*. Results were as follows,



The above graphical presentation shows that the majority of the residents of Cowdray Park are not willing to pay for Ecosystem Services. Respondents failed to understand why they should do that as they believed that natural resources were free so no one should claim ownership. The highest percentage was 48 (N = 19) of adults willing to pay tax annually to relevant authorities. Results reveal that older adults above the age of 50 years are less interested in paying with only 12.5% of the sampled willing to make donations to EMA towards environment management projects, only when they have something to donate. These results confirm the information given by BCC and EMA interviewees that people in Cowdray Park are not willing to pay as indicated by their defaulting in paying monthly stipulated rates of $10.00 per household. This money was meant to carter for refuse collection since water is not yet connected rather people preferred dumping garbage within the area. Results from this study agree with James (2015)'s view that valuation of ecosystem services has a monetary connotation such that people risk selling nature and further states that confusion in valuing ecosystem services arises when trying to account for non-monetary value services. Similarly, people failed to express the monetary value of various benefits they get in Cowdray Park. Therefore, conserving ES from a utilitarian viewpoint stood out to be a complex and less effective

method because it focuses on attaching value to a selected few aspects considered important to individuals.

Conclusion and Recommendations

Participants argued that people lacked knowledge of environmental management issues because of limited communication between relevant authorities and the residents. Bylaws and social norms are undermined thereby worsening the situation. Awareness and dissemination of knowledge were suggested cited as major strategies that can promote behavioural change in Cowdray Park.

From the Theory of Planned Behaviour, perceptions should determine behaviour, that is, positive attitude should, ultimately, indicate one's willingness to value and conserve the environment. As such, with an average of 51% pro-environment perceptions, one would expect to have more or less the same percentage of people willing to pay for ES, however, only 22% were willing to pay for the main ecosystem services enjoyed in Cowdray Park. Therefore, it is concluded that perceptions are not necessarily predictors of behaviour. There is a significant gap that exists among perceptions/attitudes and behaviour while utilitarian framing has proven to be less credible in determining the value of ecosystem services. The study recommends that,

- Future research should consider focusing on quantifying and characterising ES across Cowdray Park through keeping an ES inventory using tools such as Ecological Footprint to assist in keeping track on the utilisation and conservation of ES for sustainability.
- Local authorities should be given autonomy to run and deliver services without outside influence.
- Policies made should be implemented and practised as per their provisions. Information should be effectively disseminated to people using relevant channels to improve awareness.
- Deterrent penalties should be charged to promote biodiversity conservation.
- Affirmation of social norms and the establishment of viable formal and informal institutions is encouraged. A four-step-path towards **Sustainable Behaviours** is proposed: (1) ***adequate and comprehensible knowledge*** – an individual should know the benefits of managing the environment as well as dangers associated with mismanagement of ES. (2) ***viable formal and informal institutions*** – An individual should be governed by viable bylaws, policies and social norms to maintain sanity and these should be complementary (3) ***stimulus*** – knowing the benefits of conserving the environment, an individual is motivated to use natural resources sparingly and have (4) **positive *attitude/ perceptions*** *towards the environment.*

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Profit versus Environmentalism: A Study Of Policies And Institutional Framework Affecting Wetland Management And Conservation In Harare, 2000-2017

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Abstract

This article investigate and analyze policies and institutional frameworks affecting the management and wetland conservation, trace the debates between capital and environmentalists and answer the question of whether economic development and environment protection are compatible in Zimbabwe using Harare, the capital city of Zimbabwe (member of the Ramsar Convention on Wetlands) as a case study. A mixed research methodology, comprising review of literature, interviews and document analysis forms the key methodology used in this study. The research made two important findings. Firstly, wetlands in Harare have been severely degraded by anthropogenic activities, with housing and commercial development as the major contributors to this degradation. Secondly, the research found that wetland degradation is closely linked to a lack of clear and harmonized policies and institutional framework both at national and local level which is caused by overlapping roles and functions among the

various institutions and legislations. The study concludes that clear boundaries and harmonization of key policies and institutional arrangements is needed to promote the sustainability of wetlands in Harare.

Keywords: *Institutional framework, Wetland Conservation, Wetland Governance, Wetland management, Harare.*

1. Introduction and Background

Wetlands are among the most productive ecosystems on earth and functions as the "kidneys" of the earth, which play an important role in maintaining ecological service functions. They offer important functions for hydrological and biogeochemical cycles. They are also among the world's most productive environments in terms of biodiversity and primary productivity and, therefore, offer natural resources that are often directly or indirectly exploited by humans for economic benefit (Barbier, 1993). Important ecosystem services provided by wetlands include storm prevention, flood control, water supply, maintenance of the water table and groundwater recharge as well as nutrient and pollution retention in flood-plains (Barbier, 1993). Wetlands also support rich wildlife, fisheries, fertile soil for agriculture, timber and energy supply as well as recreation and tourist opportunities. In the context of climate change, natural wetlands may act as important carbon sink, while the degradation and draining of wetland areas generally increases greenhouse emissions and accelerates global warming further (Barbier, 1993).

In spite of the important role of wetlands to the planet, it is clear that these ecosystems have been forgotten and often been abused. They are under intense pressure from anthropogenic factors that lead to their exploitation and, quite often, degradation. Some wetlands have been degraded by either reclaiming or changing the ecosystem to other land uses. Economic development and inconsistencies of the policies of the government also play an important role in this regard.

Kristen D. Schuyt (2005), R.K. Turner (1998), and other researches on wetland loss have concluded that wetland loss and degradation are due to economic development and inconsistencies of the policies of the government. Their findings reveal that over the past 40 years, approximately 90 percent of wetlands have been changed to other land-uses such as agriculture, residential complexes and industrial areas. In developed places such as California, New Zealand and Australia, it is estimated that socio-economic developments such as the erection of different infrastructure have damaged more than 90% of the wetlands (Chiras, 2001). Africa is also estimated to have lost more than 30% of these ecosystems (Chenje and Johnson, 1999). In Harare, over 30 wetlands have come under threat due to different uses such as housing, waste dumping, infrastructural development and agriculture (*The Daily News*, July 20, 2014). However, some countries through the Ramsar Convention[1] have realized the potential of wetlands

1 The Convention took place in 1971 in the Iranian city of Ramsar. The Convention on Wetlands' broad aims were to halt the loss of wetlands and raising awareness about the important role that wetlands play in the economy,

to the environment. For instance, Uganda, a developing country, values wetlands for the products they offer such as green bananas and wild fruits and have instituted policies that favour the management and conservation of these ecosystems (Emerton et al, 1999). In Rwanda, the government made a decision of relocating an industry that was constructed on a wetland area in order to rehabilitate and protect wetland areas (Mbambazi, 2011).

In Zimbabwe, many wetlands have been lost despite the commitments and obligations under the Ramsar Convention which clearly advocate the wise use and avoidance of wetland loss and degradation in the first instance. Across the country, there has been an illegal invasion of wetlands by groups and individuals who have ignored a statutory requirement to carry out an Environmental Impact Assessment (EIA) before any development takes place in the country. In most urban centres such as Harare, iconic wetlands have been turned into residential areas with some now a hive of commercial activities such as service stations and shopping malls. In most urban centres such as Harare, iconic wetlands have been turned into residential areas with some now a hive of commercial activities such as service stations and shopping malls. In Epworth, for instance, a wetland area has been invaded by a population of up to twenty thousand and put up very substandard residential structures, not even meeting the minimum of the expected standards and without proper infrastructure (Chirisa, Matamanda and Skiyi, 2016).

Environmental organisations in Harare such as Local Environment Action Plans (LEAP) and the Harare Wetlands Trust have been constantly complaining about the construction of shopping malls and residential housing on wetlands, which they say will affect water supplies in urban areas in the future. In actual fact, the effects of wetlands loss are already taking place. For instance, the city of Harare is constantly experiencing water shortages with some areas going for more than two months without water since the city's major water source originates from the vleis (Birdlife Zimbabwe, 2015). Another effect that can be seen is the constant change in climate. Since wetlands act as a carbon sink,[2] their constant loss and degradation has accelerated global warming and in turn changed the weather patterns of Zimbabwe. Also, over the past years, rapid population growth in Harare has made people see wetlands as food security nets, readily available to the urban poor and this has resulted in the change of municipal responses to urban agriculture from making it illegal, to supportive programs resulting in establishment of domestic gardens on wetlands (Mandishona, 2011).

Environmentalists have become concerned about the disappearance of wetlands, but without the tools to enforce by-laws, treaties and conventions which Zimbabwe is signatory to, they cannot do much to protect these cradles of biological diversity that provide the water and productivity upon which countless species of plants and animals

climate change and survival of humankind in general to enhance their wise use.

2 A carbon sink is a natural or artificial reservoir that accumulates and stores some carbon-containing chemical compound for an indefinite period.

depend on for survival. Against this background, the thrust of this research sought to investigate and analyze policies and institutional frameworks affecting the management and wetland conservation, trace the debates between capital and environmentalists and answer the question of whether economic development and environment protection are compatible in Zimbabwe using Harare as a case study. The research also focused on determining possible intervention measures to minimise loss of these wetlands. This was done by examining policies and actions implemented by the Environmental Management Agency, the government and other institutional frameworks vis-à-vis the initiatives by capital. The nature and extension of contribution of ventures embarked on wetlands was also investigated. The study of institutional frameworks and policies in wetland management is of significance in maintaining and reinstating wetland integrity as appropriate measures can be put in place to improve the existing institutional and policies structures as expected under Ramsar guidelines for wise use of wetlands.

This article is structured as follows: Section 1 is an introductory and background which highlights the importance of examining institutional frameworks and policies affecting wetland conservation and management in Harare. Section 2 gives a description of the study area and outlines the methods of data collection and analysis. In Section 3, the research findings are presented and discussed. Finally, Section 4 concludes the research and highlights the implications of the research for wetland policy, especially in Zimbabwe. Other developing countries where wetlands are managed under multi-institutional systems should also benefit.

2. Materials and Methods

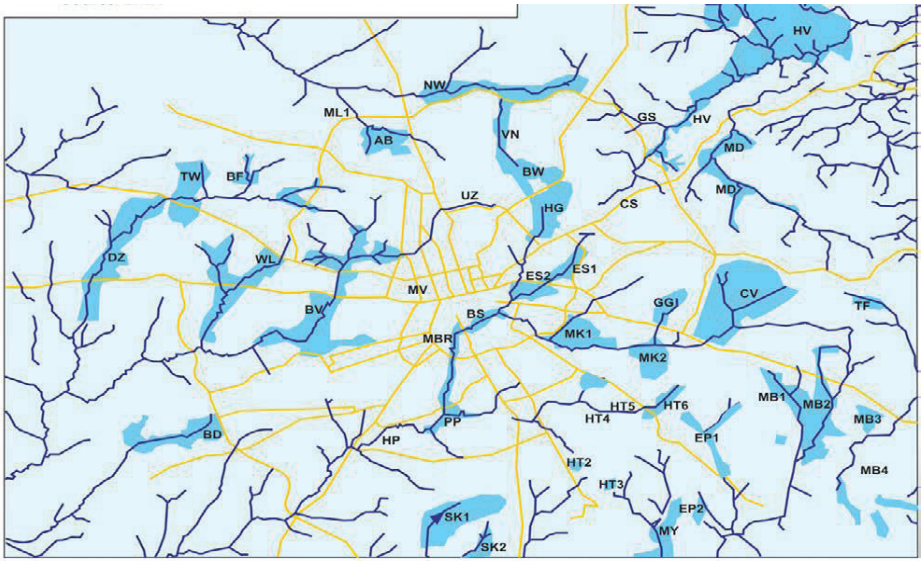
2.1 Description of the study area

The study focuses on Harare wetlands. Harare is in the middle veld with an elevation of 1488m (T. Muronda, 2008). Founded in 1890 as Salisbury by Cecil Rhodes' mercenary[3] group (the Pioneer Column), Harare became a city in 1935. The area is covered by greenstone (Harare Shamva greenstone) and is surrounded by granite from which greyish brown sandy loams and coarse textured sandy soils are derived (Nyamapfene, 1991). The study area has a tropical climate and lies in agro-ecological region 2 with the total rainfall for the year ranging from 800-1000 mm (Nyamapfene, 1991). Temperatures for the day range between 7-22ºC especially in winter and 15-29ºC in summer (Nyamapfene, 1991). Different types of wetlands are found in the study area. Riverine and palustrine are most common and these include floodplains, riverine systems, dambos, vleis, pans, swamp and artificial impoundments such as Lake Chivero (Matiza and Crafter, 1997). The main riverine systems include Mukuvisi, Manyame and Marimba rivers (Matiza and Crafter, 1997). Vleis which are waterlogged seasonally are the most common wetlands in Harare.

3 A small military force of the British South Africa Company.

Over the past decades population growth in Zimbabwe has inexorably increased the demand of land. According to Mr Mhofu (a worker at Mabelreign Municipality), Harare's population has more than doubled in the past years and is now estimated to be more than 2 million. This population growth has put pressure on Zimbabwe's urban land posing a threat to wetlands as people build on wetlands. Houses and upscale shopping malls have covered swampy areas (The Chronicle, 17 December 2016). For example, in Harare areas such as Kuwadzana, Glen Norah, Waterfalls, Belvedere, Borrowdale and Malbereign have housing developments on marshlands (The Chronicle, 17 December 2016).

Harare has a large inventory of wetlands of which 26 were declared as protected areas through the Government Gazette 380 of 2013. However, the gazette is constantly withdrawn by the government due to its interest in socio-economic development rather than wetlands protection and conservation. In brief, the study included wetlands showing different ecological states, that is, relatively pristine wetlands and those that are degraded. The focus is on understanding how policies and institutional frameworks have affected wetland conservation and management in the urban area with different ecological conditions and trace the debates between capital and environmentalists. Wetlands being affected by policies and institutional framework in Harare include Monavale wetland, Borrowdale wetland (opposite race course), Budiriro 3 and 4 wetlands, Tynwald, Eastlea, Chisipite, Glenview, Glen Norah, Kuwadzana and Belvedere wetlands and these areas are shown in figure 1.



WETLAND CODE				
AB – Ashbrittle	CV – Cleveland	HP – Houghton	MD – Mandara	TF – Tafara
BD – Budiriro	DZ – Dzivarasekwa	HT – Hatfield	MV – Monavale	TW – Tynwald
BF – Bluffhill	EP – Epworth	HV – Helensvale	MY – Manyame	VN – Vainona
BS – Braeside	ES – Eastlea	MBR – Mbare	NS – National Sports	WS – Westlea
BV – Belvedere	GG – Greengrove	MK – Mukuvisi	NW – Northwood	
BW – Borrowdale West	GS – Greystone Park	ML – Marlborough	PP – Prospect	
CS – Chisipite	HG – Highlands	MB – Mabvuku	SK – Seke	

Figure 1: *Wetland map of Harare*
Source: *EMA*

2.2 Data Collection

The lens through which my analysis was made was largely informed by economic history. Economic history is the academic study of economies or economic events of the past focusing on the institutional dynamics of systems of production, labour, and capital, as well as the economy's impact on society, culture and environment. It is both a quantitative and qualitative discipline which elevates economic processes and places premium on case study analysis. For this particular study, qualitative research methodology was employed. The qualitative methodology involved the use of interviews, government documents, policy documents and newspapers.

Documents produced by various sources were reviewed and analyzed. The review

considered information relating to the use and management of wetlands. Content analysis was then used to analyze the information from the document review. The documents that informed the study include The Constitution of Zimbabwe (CoZ) Amendment No. 20 of 2013, Environmental Management Act (EM Act) [Chapter 20: 27], The Regional, Town and Country Planning Act [Chapter 29: 12] (RTCP), and Urban Councils Act [Chapter 29: 15] (UCA).

Structured in-depth interviews were held with key informants to collect information on conflicts and discord between institutions involved in wetland management and conversation due to divergent institutional mandates torn between socio-economic and environmental considerations. Key informants were selected from the Ministry of Environment, Climate Change, Tourism and Hospitality Industry, local authorities, environmental management officers, community leaders, and The Harare Wetlands Trust.

3. Results and Discussion

3.1 Institutions Governing and Managing Urban Wetlands in Harare (Zimbabwe)

Wetlands management and conservation in Zimbabwe since independence has been exposed to multi- institutional management. Central government departments, local district authorities, private players, Non-Governmental Organizations (NGOs) and local people participate in wetland management as shown in figure 2. The participation of the institutions is mainly influenced by their diverse institutional mandate.

The Ministry of Environment, Climate Change, Tourism and Hospitality Industry has overall responsibility for the environment, water and climate related issues in the country. MEWC aligns its aims and its objectives with the provisions of the Ramsar Convention of 1971. The management of wetlands is mandated to Environmental Management Agency (EMA), which is responsible for ensuring sustainable use of the country's natural resources for the benefit of all Zimbabweans. To fulfill its responsibility, the Agency plans, formulates, reviews, coordinates policy with a view of achieving sustainable development in the country. The Agency environmental

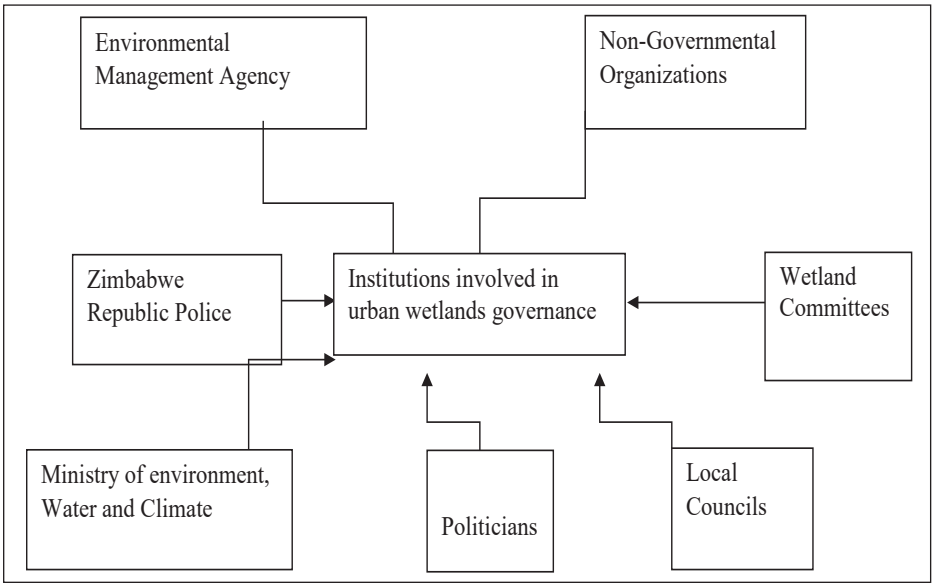


Figure 2: Institutions involved in urban wetlands governance.

responsibility also includes wetland conservation. One official from the Ministry reinforced this in a statement:

> "This Ministry is interested in the conversation and management of wetland ecosystem and tries to create policies that integrate these ecosystems so that they are effectively utilized to mitigate problems such as food shortages and stabilize climate as well as promoting tourism."

EMA is a statutory body whose mandate is to provide the sustainable management of natural resources and protection of the environment, the prevention of environmental degradation. EMA was designed to give implement the concept of "intergenerational equity," with reference to the 1987 Brundtland Commission's definition of sustainable development and petitioning current generations to consider the impact of their actions on future generation. In relation to wetland governance, the Agency is responsible for executing environmental policies, promoting wise use of wetlands, providing environmental awareness campaigns, education, and training, and undertaking any works deemed necessary or desirable for the protection or management of wetlands ecosystem where it appears to be in the best interest of the public or where in the opinion of the Agency (Moyo et al, 1991, p.31). In undertaking its mandate, EMA is obliged to maintain its core values which include stakeholder participation, transparency and professionalism.

Local authorities such as the Harare City Council (HCC) also play a part in wetland conservation and management. The HCC is responsible for governing the development

in Harare. Through local development plans, HCC determines the land uses which may be approved in the city as mandated Urban Councils Act [Chapter 29.15]. The council is mandated to conserve the environment, and this is usually achieved through preserving specific sites such as wetland areas from further development projects.

The Harare Wetlands Trust, the Conservation Society of Monavale (COSMO), Environment Africa and BirdLife International are some prominent civic environmental organizations responsible for the conservation and management of some wetlands in Harare. In 2017, the Harare Wetlands Trust and COSMO managed to stop housing development on a piece of wetland in Monavale Vlei East through protests (The Herald, February 20 2017). The Monavale Vlei East is located on the Monavale Wetland Ramsar Site which is of global importance and one of the primary water sources in Harare (The Herald, February 20 2017). Likewise, BirdLife International and COSMO advocate for the wise use of wetlands in Harare. These organizations raise awareness on the importance of wetlands in urban environments.

3.2 Policies and legislation on Wetland Management in Harare (Zimbabwe)

Zimbabwe is a signatory to a number of international policies and multilateral environmental conventions related to wetlands. These include: the Ramsar Convention on Wetlands, the Convention on Biodiversity (CBD), Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the Convention on the Conservation of Migratory Species of Wild Animals, Sustainable Development Goals (SDGs), and the Montreal Protocol. The most relevant conventions to wetlands in Harare are the Ramsar Convention, CBD and SDGs.

The Convention on Wetlands of International Importance more commonly known as the "Ramsar Convention" was adopted in Ramsar, Iran on 2 February 1971 and entered into force in 1975 (Ramsar Convention Secretariat, 2016). However, Zimbabwe only ratified the convention on 3 May 2013 and seven wetlands were designated as RAMSAR Sites – Monavale Vlei, Cleveland Dam, Lake Chivero and Manyame (all in Harare), the Chinhoyi Caves, Mana Pools National Park, Victoria Falls National Park and Driefontein Grasslands near Mvuma in the Midlands (as shown in figure 3). The Ramsar Convention since its conception promotes and seeks for commitment from member countries to ensure wetlands are sustainably utilized and that these wetlands are planned for. EMA is responsible for localizing the provisions of the Ramsar Convention in Zimbabwe, and they partner with some institutions to ensure that such wetlands are well managed.

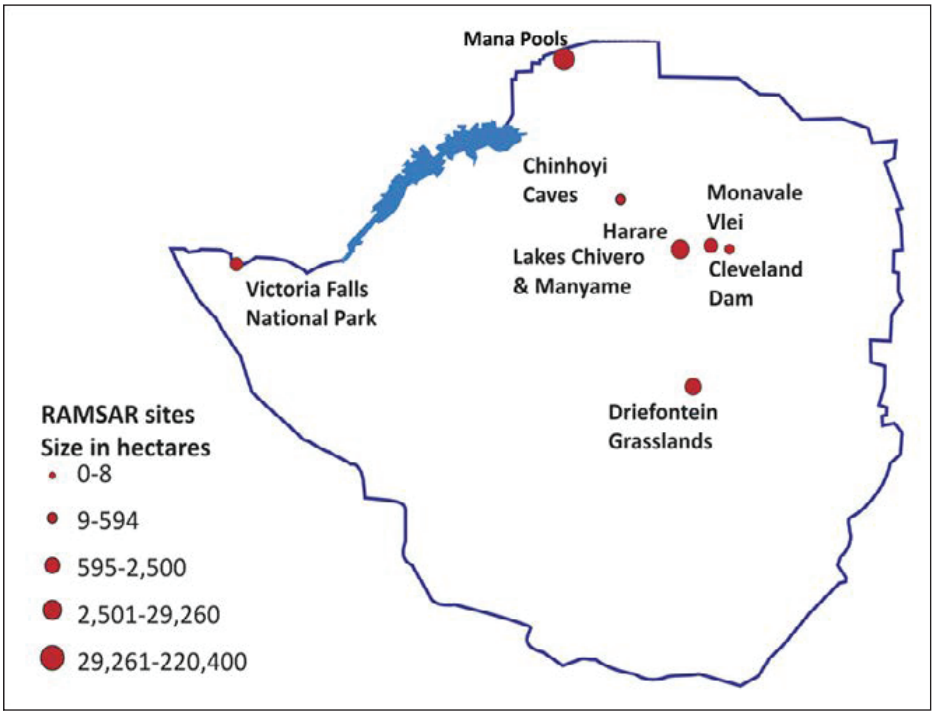


Figure 3: Zimbabwe's Ramsar sites
SOURCE: EMA

Taking into view that Zimbabwe is a signatory to the SDGs, the management of wetlands is also informed by these goals. The conservation of wetlands is considered as a great milestone in achieving the SDGs (Wetlands International, 2017). The relevant SDGs that relate with the wetlands are Goal 2, 6 and 11 which envisages ending all forms of poverty and hunger, ending water supply issues, and creating sustainable human settlements by 2030 (*Secretariat of the Convention on Biological Diversity,* 2015).

The CBD was adopted by global leaders in 1993 as a convention focusing on the conservation and sustainable use of biodiversity. The convention covers all levels of biodiversity and it includes possible domains that are directly or indirectly related to biodiversity. Taking into view that biodiversity is related with wetlands, the CBD is an essential convention in the wise use of wetlands. In 2010, the Aichi Biodiversity Targets (ABT) was set with the view to conserving biodiversity. From the 20 targets of the ABT, target 14 is especially applicable for the wise use of wetlands as it envisages that by 2020 ecosystems that provide important services, including services related to water, and contribute to health, livelihoods, and well-being are restored and protected, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable (*Secretariat of the Convention on Biological Diversity,* 2015).

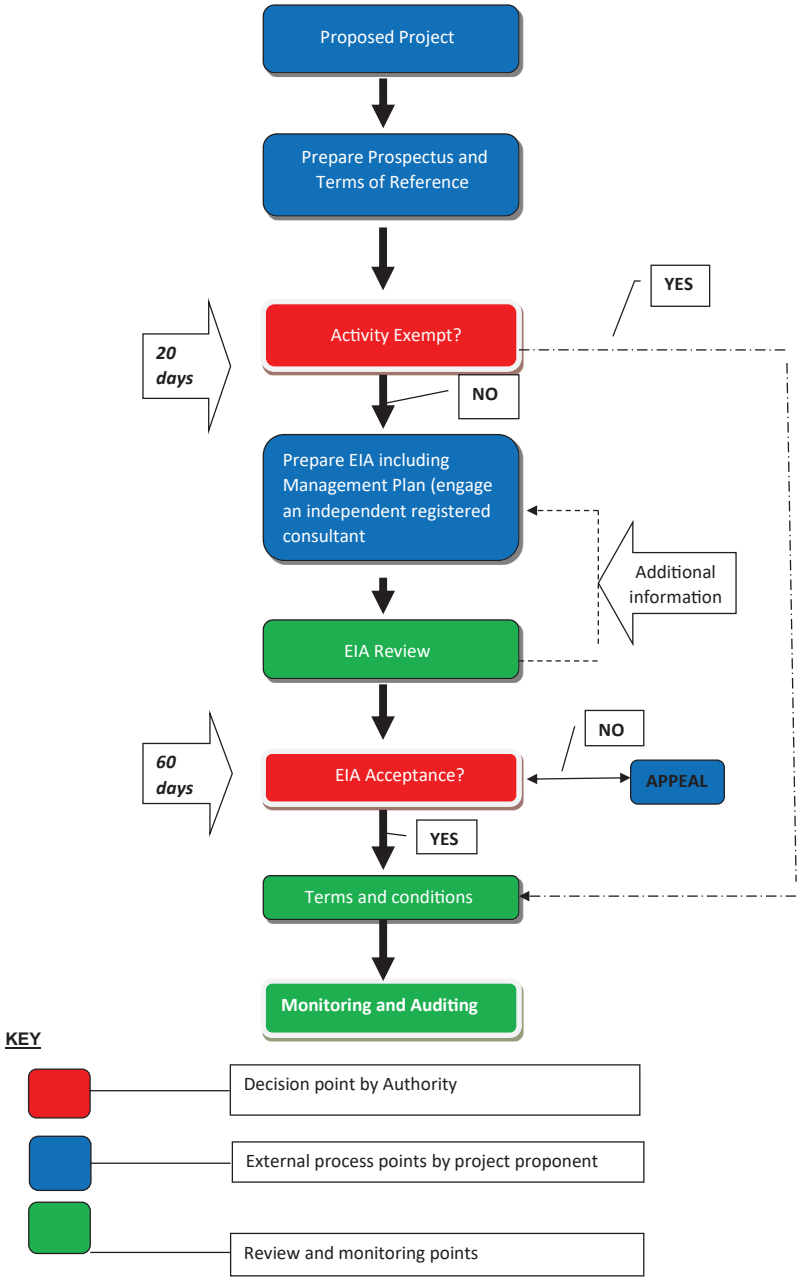
Zimbabwe in its endeavour to protect the environment and to support the Ramsar

Convention has put the provisions for the management of environment including wetlands under the Environmental Management Act (Chapter 20:27) enacted in 2002 (Act 13 of 2002) (Mutambara, 2005). The Act creates a framework for environmental management, makes provision for the formulation of environmental quality standard and develops the National Environmental Action plan.The act also encourages sustainable use of wetland resources by incorporating the public in the use and conservation and management of wetlands. Section 113(1) of the Act directly states that: "The Minister may declare any wetland to be an ecologically sensitive area and may impose limitations on development in or around such area." This section empowers the Minister of MEWC to decide on the use of certain wetlands and this shows that the decision of the Minister is usually final and legitimate. Section 113(2) of the Act shows the activities which shall not be undertaken in wetlands and these include reclaiming or draining wetlands; disturbing wetlands in a way that degrades them, and introducing alien flora and fauna into wetland ecosystems. Accordingly, section 113(3) provides for the measures to be undertaken for those who fail to conform to subsection 113(2).

The statutory instrument 7 of 2007 is one of the policies that have placed more focus on wetlands management in Zimbabwe. According to an EMA official the statutory instrument offer for the prevention of veld fires, protection of wetlands and public streams. The statutory instrument provides licenses to wetlands users with a clear wetland management plan. According to EMA, any person who disregards the statutory instrument shall be on the wrong side of the law and will be liable to fine not exceeding six months or both such fine and imprisonment.

The Statutory 7 of 2007 comprise of the Environmental Impact Assessment and the Ecosystems Protection Regulations. The Environmental Impact Assessment (EIA) is a planning tool used to identify, predict, and measure potential impacts either negative or positive that may arise from planned projects, and come up with ways with which to minimise negative impacts and enhance positive ones. The EIA is used in wetland management and conservation. The Ministry of Environment and Climate Change published guidelines that would cover; mining and quarrying, forestry, agriculture, transport, energy, water, urban infrastructure and tourism (*The Herald*, January 29 2014). For each of these sectors, the guidelines shown in figure 4 provide examples of major activities that are likely to be undertaken for projects in the sector; the type of environmental impacts; possible measures for managing such impacts; sample terms of reference and sources of information for use in an EIA study.

Figure 4: The EIA Process flow chart in Zimbabwe
Source: EMA



The Regional, Town and Country Planning Act (RTCP) [Chapter 29: 12] guides and controls any form of planning and development in the country. The RTCP's objective is to plan infrastructure and other development with the aim of conserving and improving the physical environment so as to promote health, safety, order and general welfare. The Act provides for the protection of urban and rural amenities and the preservation of buildings and trees. Thus, indirectly, it stipulates that urban wetlands are part of the urban structure and forms part of its green and brown infrastructure. The RTCP Act Section 31 states that the local planning authority has the responsibility to serve the owner of the land with a preservation order of forests, water sources, and woodlands within its area of authority.

Urban Councils Act [Chapter 29: 15] provides for the administration of municipalities and towns through vesting powers in the local authorities. As one key informant from the HCC said during an in-depth interview, this Act legitimizes the management of wetlands by the HCC although the Act does not refer to use and management of wetlands. Municipalities and city councils own land within their boundaries and can dispose the land to prospective developers and generate revenue (Chakaipa, 2010). Section 181 in the Act empowers local authorities to control public streams by giving water rights and authority within the council's area.

DISCUSSION

3.3 Analysis of the Effectiveness of Existing Policies and Institutional Frameworks on Wetland Status and Trends

Harare is a wetland city, yet its wetlands are under immense pressure and their future sustainability is highly compromised. Top among the threats to wetlands in the city is the encroachment by infrastructure development, commercial activities, urban cultivation and urban population growth. From the review of existing policies and institutional frameworks governing wetlands in Zimbabwe and analysis of their effectiveness suggest that four key interrelated factors contribute to the status quo of wetlands in Harare: institutional dynamics, political interference, corruption and nepotism, and poor knowledge of wetland law.

3.3.1 Institutional Dynamics

From the findings of the study, it was found that the major bottleneck to wetland management and conservation in Harare is the current institutional structure lack of co-ordination and the dominance of some institutions. The current institutional framework is riddled by confusion which originates from differences in institutional dimensions. Some institutions have seen other economic projects as more valuable and beneficial than protecting natural ecosystems, for example, the government and Harare City Council. Several schemes targeting residential and commercial property developments

on wetland have been and continue to be approved by the HCC and the government of Zimbabwe according to Mhlanga, Maruziva and Buka (2018). The HCC has issued many land developers land on wetlands in the face of EMA notes one resident in an interview made by the researcher. An example of such developments is the construction of a vast hotel and shopping mall on a designated wetland adjacent to the National Sports Stadium in Belvedere. The facility was established by a Chinese company in the year 2013. Tsveta notes that the environmental agency and wetland committees are said to have backed down from taking legal action against the Chinese due to political pressure.

The HCC and the Government of Zimbabwe are not doing a good job of governing and conserving the wetlands in Harare. According to the laws and policies listed on paper everything looks pretty good, but there are "flaws and inconsistencies" and policies and some statutes falter as policymakers miss the key variable which is the voice of some stakeholders at the grassroots level. Such was the case with the project of developing cluster homes on the wetland ecosystem of Monavale which was contested EMA and Harare Wetlands Trust. However, despite such contestations, the development of the cluster homes was undertaken on some of the wetland ecosystem mainly due to political intervention.

The HCC and the government of Zimbabwe has high ambitions but economic pressure wins when it comes to wetlands conservation. This was elaborated on further by an official from HCC who explained the following:

> "Our mandate is to conserve the environment when planning and designing the city. We try, by all means, to conserve wetlands by leaving them in their natural state. This is seen in the local development plans of the city where you can see that all the major wetlands were zoned as areas not to be developed. However, despite such efforts to conserve and manage the city wetlands, there are some political and economic factors that are now compromising our efforts. Furthermore, rapid urbanization in the city has forced the council to allow development in some of these wetlands."

From the foregoing quote, it can be deduced that in as much as the local authority feels the need to conserve wetlands, there are instances when they are rendered powerless owing to political and economic interference in their mandates. Furthermore, the pressure from urban growth has also increased the need for more land for urban development, and this has resulted in wetlands being sacrificed. Therefore, the institutional framework system for wetland management and conservation fails to embrace and localize the international conventions on wetlands, which then stifles the success of the localization of the initiatives.

3.3.2 Political Interference

Political interference has resulted in the belittling of wetland management and conservation as revealed by officers from government agencies. Political leaders have pursued populist policies to win the hearts of the electorate thereby allowing illegal use of the resource. Politicians have taken advantage of the poverty stricken environment and they have allocated land politically to the benefits votes. Part of this land is wet in nature. Wetlands in Harare that have been allocated as stands by politicians in order to gain votes during elections include those in Budiriro 3 and 4, Prospect, Tynwald, Glen Lorne, Eastlea, New Marlborough and that which is opposite the National Sports Stadium.

3.3.3. Corruption and nepotism

Corruption and nepotism are a stumbling block to effective implementation of the wetland legislation and policies. In practice, rules and existing sanctions around the Harare wetlands are selectively applied and corruption is rampant (Mutyavaviri, 2006). Bribes are sometimes paid to officers from government agencies by those who want to evade prosecution. This has left law-abiding citizens and the poor with no capacity to pay bribes displeased and not co-operating with environmental agencies in wetland protection. The need to preserve social relations has further weakened the ability of institutional leaders to monitor local people's adherence to law (Madebwe V and Madebwe C, 2005). The mere fact that these institutional leaders live with the people means that they have cordial social relations to maintain beyond natural resources conservation; hence they sometimes turn a blind eye to offences committed by relatives and friends. Interestingly, the authors of these wetland housing projects go unpunished, while the country bears deep scars arising from their selfishness. EMA argued that even

if they fine the politicians they simply escape the fines and the punishment because they call the shots and not environmentalists. An example which can support this was given by one of COSMO officials who alluded that when one of the politicians (cannot be named) was slapped with a US$15 000 fine by the Environmental Management Agency (EMA) for conducting himself in a manner that endangered the environment by giving out wetland to gain support, the politician simply ignored the fine and continued to allocate land in Westlea wetland areas.

3.3.4. Poor knowledge of wetland law

Lack of understanding and appreciation of wetland law by local communities continue to foster poor wetland management and conservation in Harare. The majority of the households (74%) were not aware of the permitting system (EIA) and that wetland draining for cultivation was forbidden. Instead they were surprised to be prosecuted for such practices. The effect of such ignorance about wetland laws was also pointed out by

Mutisi and Nhamo who stated that ignorance of the law was a common problem which resulted in illegal occupation of wetlands by urban dwellers. Therefore, as long as local communities are not privy to provisions of the law, defiance is likely to continue at the expense of wetland existence (Mutisi and Nhamo, 2015).

3.3.5. Effects of institutional dynamics, political interference, corruption and nepotism on wetlands

Inadequate policies and poor co-ordination of institutions have jeopardized the sustainability of ecosystem services provided by wetlands in Harare as there seem to be a lack of transparency, legitimacy, or accountability in relation to the use and management of wetlands. Overall, institutional dynamics, political interference, corruption and nepotism have had negative impacts on wetlands in Harare. These three key factors have resulted in land uses (infrastructural development, agriculture and waste dumping) that have had detrimental effects on wetlands ecosystems. The land uses have resulted in the alteration of water quality, indirect modification of the hydrological system and loss of habitat.

Wetlands in Harare have been under pressure due to infrastructural development. Examples of such developments are the construction of Sam Levy, Avondale pick n pay (supermarket) and Long Cheng Plaza. The infrastructural developments led to the clearing of the wetland vegetation on the construction sites and the subsequent was cleared thus distorting the ecosystem functions. Moreover, the flow of water in the wetland areas was disturbed as buildings were erected during construction. Commenting on the amount of water found on the Belvedere wetland, one respondent said:
In early 1970 when I started cultivating on this wetland there was a lot of water and this street was named Watermeyer because of too much water which was on this wetland. The wetland is now drying up because of these buildings (people's houses and Long Cheng Plaza mall).

Infrastructural developments have also resulted in pollution of water resources and reservoirs over time. Pollution of underground water has the potential of affecting the health of the city residents over time (Mandava, 2012). This is because the quality of water would have been altered due to introduction of foreign chemical components. For instance, one resident in Belvedere noted that during the construction of Long Cheng Plaza mall an excavator operating on the construction site spilled lubricants on the ground due to technical problems and thus this contributed in the deterioration of water quality in the wetland area. Malfunctioning sewer reticulation systems are a further source of pollution that has ended up in wetlands in urban areas. Harare has been experiencing sewer bursts due to the fact that the sewer system is old, overloaded and has not been maintained over the years (Moyo, 2005). The wetland areas therefore become sinks to the sewage that would have been directed into wetland areas. According to Mutisi and Nhamo, sewage components have eutrophication effects to wetlands that eventually accumulate nutrients which increase chemical oxygen demand in the water

quality (Mutisi and Nhamo, 2015).

Further to this, infrastructural developments have resulted in the loss of beneficial habitats, loss of biodiversity and increase of run off on open surface areas. On the other hand, the increase of run on open surface areas has the potential of flooding the suburbs in Harare. Most respondents (90%) agreed with the fact that building houses and cultivation have destroyed the habitats of animals. One respondent said: *"*Most animals like warthogs have since left this wetland after the destruction of their habitats when this Chinese mall was built."

Human health has also been negatively impacted due to housing developments in wetlands. Goredema and Sithole (2013), show that diseases have emanated from the construction of houses due to the presence of water. They indicated that wetland areas have become waste dumping areas as these are deemed open and disused areas. This waste attracts scavengers and flies and as such, disease emanate from the dumping of waste. Diseases common in waterlogged areas are dysentery, cholera and diarrhoea amongst others.

Lastly, urban agriculture has contributed to wetland degradation. In instances were land is allocated in areas that overlook streams, cultivation of maize, sugarcane and vegetables have taken place. The application of fertilizers onto the wetlands has resulted in the eutrophication and high acid content due to reactions that occur between chemicals and water present in wetlands.

The land uses have negatively impacted the wetland environment and attainment of wetland sustainability is now a "pie in the sky" meaning that the idea as noble as it is, it cannot be achieved. Overall, the ultimate goal to stifle the persisting degradation and loss of wetlands in the country is to reverse current trends of gradual and persistent reduction of wetland area in Harare and degradation of its ecosystem service functions by drastic changes to the existing wetland governance system.

Conclusion and Recommendations

This case study demonstrates how sound policies and institutional frameworks do not necessarily lead to successful management and conservation of natural resources and they can be rendered unimportant or even obsolete if they are not backed up by strong environmental institutions that can apply coercive measures uniformly across offenders, and curb power dynamics and political interference in decision making. Harare's wetlands are embroiled in a complicated matrix consisting of dysfunctional policies and institutions which all complicate the set objectives of attaining wetland sustainability. International treaties approved by the Government of Zimbabwe to protect and conserve wetland areas, carry little weight, questioning their significant and effectiveness not only in Zimbabwe, but anywhere else with somewhat similar conditions. Top-down determination of rules and exclusion of environmentalists, and those who live closest to the resource from deciding what the rules should be has created a perfect storm

for a tragedy of the commons. To reverse the current trends of gradual and persistent reduction of wetland areas in Harare and degradation of its ecosystem service functions, extreme changes to the existing governance system is required. My findings and analysis lead me to make the following recommendations for wetlands management in Harare:

- In order to eradicate problems in wetland governance and conservation which emanate from institutional dynamics, there is need to reform the current institutional set-up. This can be achieved by creating a framework to facilitate institutional meetings where common goals and work plans are drawn up so that unity of purpose in wetland conservation can be promoted between all institutions involved in wetland conservation and management. The country can achieve this by drawing lessons from Uganda whose system in wetland governance and conservation has been improving over the years. In Uganda, there is a highly structured institutional arrangement for wetland management, as this responsibility is vested in the Wetlands Inspection Division (Moses, 2008). Furthermore, given multi-institutional involvement in wetland management and conservation, for co-ordination purpose, the National Wetlands Inter-Agency Co-ordination Committee was established in Uganda and it operates at district and local levels (Moses, 2008). The establishment of wetlands inter-agency co-ordination committee in Zimbabwe would improve dissemination of wetland management and conservation information as well as monitoring of unsustainable practices in wetlands using sustainable land management tools just like in Uganda.
- Formulation of a single policy that specifically addresses wetlands and the ecosystem services they provide. The development of a national wetland policy, which recognizes indigenous practices, would encourage the adoption and adaptation of guiding principles on the utilization and management of wetlands in Harare. The country can achieve this by drawing lessons from Rwanda. The government of Rwanda in collaboration with the Ministry of Environment drew up a National Wetland Policy which pointed out the necessary procedures to be applied in the implementation of the policy into action (Twesigye and Mulisa, 2006). The government of Rwanda identified the institutions that are responsible for the management and conservation of wetlands and these institutions collaborated with each other and worked together especially in managing Gikondo wetland. Such a policy in Zimbabwe would be the go to point for all wetland related issues and would preside over any other policies that directly or indirectly address wetlands.

For these recommendations to bear fruit, however, more coordinated collaboration is needed among local stakeholders interested in conserving and managing Harare's wetlands. Moreover, better science is needed to generate the economic and environmental justifications for wetland conservation and management. Ecosystem service valuation studies will definitely reveal that Harare's wetlands are probably one of the city most valued natural assets and that the future cost to the city and her residents for obtaining clean water and avoiding flooding are monumental compared to the cost of conservation.

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The Management of Electronic Waste in Institutions of Higher Learning in Gweru, Zimbabwe

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Abstract

The usefulness of Information and Communication Technology (ICT) has led to an overwhelming elastic demand for electronics most computing devices and learning institutions are adopting ICTs at a fast pace. Widespread consumption has resulted into huge amounts of e-waste generated from non-usable or old electronics. Electronic waste (e-waste) comprises of electronics and electrical goods no longer fit for their originally intended use. Apart from the e-waste produced by use of electronics, African countries are on the receiving end of Western e-waste. Presently, Zimbabwe despite being recipients of ICTs, does not have e-waste disposal mechanisms or legislation in place. Having realized that large institutions are major consumers of electronic products, this research seeks to assess the management of e-waste in institutions of higher learning in Gweru namely; Midlands State University, Gweru Polytechnic College and Mkoba Teachers College. The research employs a survey research and comparative study with the main data collection instruments being questionnaires, interviews and observations.

Through purposive sampling, ICT heads and other stakeholders in association with e-waste management have been selected as sample respondents. This study explores the background to e-waste, accounts for the chemicals and hazardous substances in e-waste and the impacts they can have on the environment and human health, evaluates the existing institutional policy, the type and quantity of e-waste generated by institutions of higher learning in Gweru, the methods currently employed in e-waste management, challenges faced and recommends strategies that may be used to improve management of e-waste by the institutions.

Keywords - *Electronic waste management, Institutions of higher learning.*

Introduction

The exceptional growth in electronics production has led to the rapid generation of electronic waste globally. About 44.7 million tons of e-waste were produced in 2016 and this amount may rise to 52.2 million tons by the year 2021, (Balde et al, 2017). Institutions of higher learning are recognised as part of the great contributors of electronic waste in the urban environment. As advanced models of electronics enter the market over the years, older models are deemed technologically obsolete thereby contributing to the institutions electronic waste stream. Managing the electronic waste sustainably is proving to be an important task for academic institutions, not only due to its rapidly increasing volume, but more importantly because of its hazardous nature. Electronic waste contains numerous hazardous substances which may pose a threat to the environment and human health in the institutions if they are not disposed of in the correct manner. On average, about 9% of the weight of electronic waste is made of hazardous substances such as lead, cadmium, arsenic, chromium, mercury and dioxins, (Sarkar, 2008). However, the internet is now used by about half of the world population and most individuals own several Information and Communication Technology (ICT) devices yet the lifecycles of these products are becoming shorter over time, (Balde et al, 2017).

Developing countries unfortunately lack proper systems of electronic waste management nor the enforcement channels of electronic waste regulation, (Nnorom and Osibanjo, 2007). Hence, this study aims to identify the different types and quantities of electronic waste generated, assess the management of electronic waste and the challenges associated with the sustainable management of electronic waste at three institutions of higher learning in Gweru.

Literature Review

Electronic waste is posited to refer to old end-of-life electronic equipment that include phones, cameras, CD players, TVs, radios, fax machines, photocopiers, printers, toners, ink cartridges, laptops, CRT monitors, desktop computers and their accessories which are disposed of by the original users, (Balde et al, 2015). Electronic waste is currently

the fastest rising type of waste in most developing countries but there is however a challenge in managing the electronic waste as most developing countries lack the capacity to professionally recycle the electronic waste, Puckett et al, 2002). These regions are however overwhelmed with electronic waste due to receiving donations of used electronic equipment dumped on them by developed countries. Most developing countries are not supported by formal electronic waste management mechanisms such as the following up on used electronic equipment by producers and this is further aggravated by the lack of direct electronic waste management legislation, (Nnorom and Osibanjo, 2008).

Most electronic waste in Zimbabwe is not associated with local production but importation of refurbished electronic products from developed countries that have significantly raised the quantities of electronic equipment with very short lifespans thereby creating grave challenges in managing the electronic waste, (Mutsau, 2015). Moreover, Zimbabwean legislation does not clearly present how electronic waste should be managed as there is stated to be only the prohibition of discharging hazardous substances into the surrounding environment, EMA Act (20:27). There is also a great awareness lacking in Zimbabwean manufacturing and also among legislators, environmentalists as well as consumers on how to improve electronic waste management thereby creating great environmental and health challenges, (Mutsau et al, 2015). However, refurbishment for reuse is considered to be the most suitable method to handle discarded computers and other electronics, (Microsoft, 2008).

Methodology

The researcher purposively selected Gweru as the area of study basing on the on the proximity of his institution to other higher tertiary institutions in the Midlands region. The research therefore targeted institutions of higher learning such as Midlands State University, Mkoba Teachers College and Gweru Polytechnic College which all have electronic waste management activities from handling, storage, recycling to disposal. The case study approach was employed for in-depth, detailed research that explored the management of electronic waste in institutions of higher learning in Gweru. The exploratory descriptive survey research design allowed primary information to be obtained through interviews of stakeholders associated with electronic waste and observations.

Questionnaires were self-administered by the researcher to the ICT, Stores and Administration heads of departments to attain sufficient information on the quantities of the different types of electronic waste generated, waste management practices and challenges faced in the management of electronic waste in the three institutions. Closed ended questions only allowed respondents to give their response by choosing from the given options on the types of electronic waste, sources and disposal methods. Open ended questions enabled respondents to air out their own views on the challenges of electronic waste management in the three institutions from generation, storage, handling

to disposal.

Key informants included Heads of Departments, in all three institutions, Gweru City Council Cleansing Superintendent, Environmental Management Agency Environmental Quality Officer, Midlands Technologies Chief technician and Greenworks Recycling Zimbabwe Manager. Diversification of key informants was essential so as to gain varying perspectives on the challenges associated with electronic waste management in the three institutions of higher learning and possible strategies that could be effected. The semi structured interviews allowed the researcher to probe, clarify and exchange ideas with key informants on electronic waste management in institutions of higher learning.

Moreover, direct observation enabled the researcher to interact with the electronic waste as the object of investigation. Types of electronic waste, quantities, generation rates, and handling and disposal methods were observed in the field thereby increasing validity and reliability of the research. The researcher had several ground visits to Midlands State University, Mkoba Teachers College and Gweru Polytechnic College as he captured spatial temporal data and used photography to give a clear representation of the electronic waste management.

Institutional data was also taken into consideration so as to study existing documents on the management of electronic waste in institutions of higher learning and this was also effective in supporting the research with the best possible electronic waste management initiatives that could be used. Existing institutional data included records on the management of electronic equipment and electronic waste as institution assets under the Administration departments. These sources gave a detailed account of the situation in all three institutions of higher learning.

Results and Discussion

The study established that all sampled institutions of higher learning in Gweru use electronic equipment in their academic setup. Figure 1 below depicts the types of electronic waste sampled from stored or discarded waste. The most common electronic waste was desktop computers and their accessories which are being used in all departments and the high usage can be attributed to the fact that it is an age of constantly changing Information and Communication Technology. The types of electronic waste in Gweru institutions of higher learning ranged from desktops, photocopiers, printers, laptops and computer accessories such as keyboards, mouse and toner. Observations at Midlands State University confirmed that desktop computers and their accessories contributed the highest volume to the electronic waste stream. It was however observed that electronic equipment such as computers have limited lifespans of about eight years but toner as a consumable continuously accumulates due to a shorter lifespan of about two months.

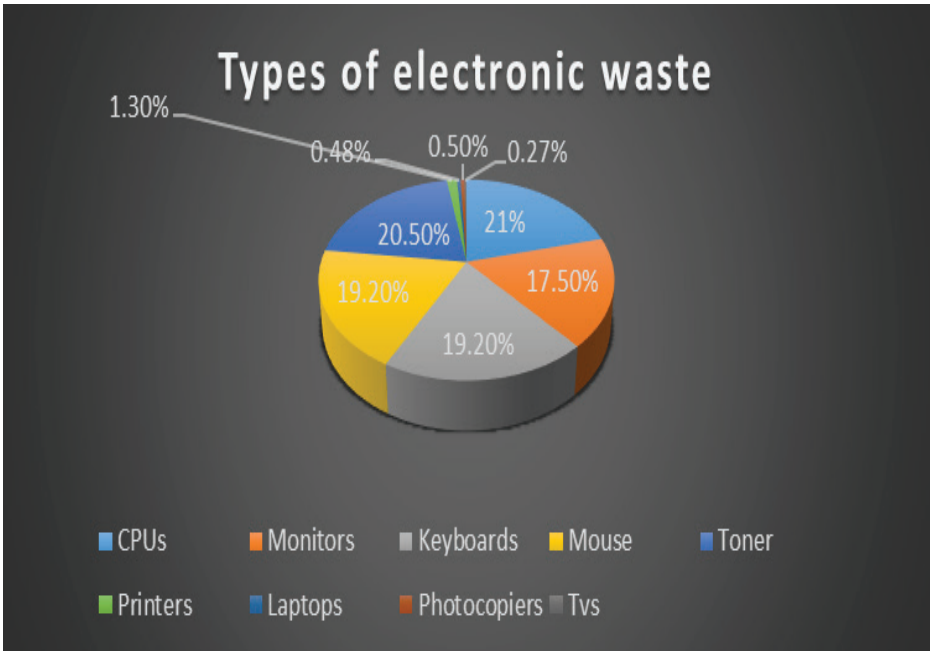

Figure 1 showing the types of electronic waste in Gweru institutions of higher learning.

Table 1 below shows the quantities of the different types of electronic waste in the institutions of higher learning in Gweru between the period of 2013 – 2018. Midlands State University was highlighted to have the largest amount of electronic waste with a total of 5202 units due to the high population of students and staff within the institution, Mkoba Teachers College with 505 units and Gweru Polytechnic College with the least amount of electronic waste at 154 units. However, from the interviews conducted at Midlands State University, the high rate in electronic waste was due to the fact that electronic waste had been stored for over 10 years and was only donated to Greenworks Recycling and Midlands Technologies in the year 2018. Findings on Gweru Polytechnic College and Mkoba Teachers College presented similar characteristics due to them sharing the same system as they are both managed under the Ministry of Higher and Tertiary Education. Information from interviews at these two institutions reflected that efforts are made to auction electronic waste almost every five years thereby minimising the amounts being stored.

Table 1: Quantities of electronic waste in Gweru institutions of Higher Learning

Electronic waste type	MSU	Gweru Polytechnic	Mkoba Teachers College
	Number of electronic equipment disposed in the last 5 years	Number of electronic equipment disposed in the last 5 years	Number of electronic equipment disposed in the last 5 years
CPUs	1200	40	47
Monitors	1000	36	43
Keyboards	1100	36	43
Mouse	1100	36	43
Toner/ cartridges	680	280	300
Printers	58	5	16
Laptops	30	0	0
Photocopiers	22	1	8
Tv/ radio	12	0	5
TOTAL	**5202**	**434**	**505**

Table 2 below shows electronic product weight estimations that were utilised by the researcher to calculate the average tonnage of electronic waste within the institutions. These average weights were acquired in the field survey through weighing with an analog scale.

Table 2: Showing electronic product weight estimations

Electronic waste	Average Product Mass (kg)
CRT Monitor	18.14
CPU	9.98
Keyboard	0.5
Mouse	0.1
Toner/ Cartridge	0.5
Printer	14
Laptop	3.5
Photocopier	45
CRT TV	30

Table 3 below shows electronic product weight estimation calculations of total tonnage that reveal Midlands State University to be contributing the highest of 33.63 tons into the electronic waste stream of Gweru. The equipment mainly comprised of CPUs,

monitors, keyboards, printers, photocopiers, cartridges and televisions. These findings support the view of (Balde et al, 2015), who states that electronic waste is in categories that include screens, monitors, televisions, laptops, notebooks, and tablets.

Computers and their accessories were presented to have the highest rates of electronic waste in the Gweru institutions of higher learning. The study highlighted the types of electronic equipment that are brought into the institutions to be both new equipment and also refurbished equipment donated from other developed countries through government donation schemes. Attaining of used equipment has however led to the increase in electronic waste due to shorter lifespans of electronic products as highlighted in an interview with Midlands State University Information Technology Services Head. The ICT departments presented to be the lead departments in producing electronic waste in all three institutions of higher learning presenting only 25% of electronic waste being produced from other departments. This is due to most electronic waste emanating from ICT products such as computers.

However, the three institutions of higher learning may not be ranked and compared at the same scale due to their differences in population. Midlands State University has a population of about 22 000 as compared to 2000 students at Gweru Polytechnic College and 1600 students at Mkoba Teachers College.

Table 3: Weight quantities electronic waste in Gweru institutions of higher learning

Electronic waste type	**MSU**	**Gweru Polytechnic**	**Mkoba Teachers College**	
	Average weight of electronic waste (kg)	**Average weight of electronic waste (kg)**	**Average weight of electronic waste (kg)**	**Total (kg)**
CPUs	11976	399.2	469.06	**12844.26**
Monitors	18140	653.04	780.02	**19573.06**
Keyboards	550	18	21.5	**589.5**
Mouse	220	7.2	8.6	**235.8**
Toner/ cartridges	476	196	210	**882**
Printers	812	70	224	**1106**
Laptops	105	0	0	**105**
Photocopiers	990	45	360	**1395**
Tv/ radio	360	0	150	**510**
TOTAL	**33.63 tons**	**1.39 tons**	**2.22 tons**	

Electronic waste management practices

All institutions of higher learning in Gweru keep records of the electronic waste they discard. The three key informants interviewed within the institutions included

Administration department Heads and they all concurred that they are responsible for management of electronic waste as assets in their institutions and had inventories available. Interviews conducted at Midlands State University highlighted that it is the duty of the Assets department through the Director of Information Technology Services, at Gweru Polytechnic College it is by the Administration department through the ICT department and at Mkoba Teachers College it is by the Administration department through the WEE ICT and Research department. It was observed that disposal of most electronic equipment such as computers was due to the end of lifespan of about eight years as well as introduction of newer technologies.

All three key informants from all three institutions concurred that they mainly partner with their institution ICT department and Stores department in identifying the types and quantities of electronic waste within their institutions. Midlands State University Assets department however stated to be a notch ahead as they also partner with their Risk Management Office which gives them advice on how best to manage their electronic waste.

Moreover, Midlands State University Assets department Head concurred with the view of Information Technology Services department that there is an ICT policy and asset disposal policy that complement each other in promoting recycling and reuse of electronic waste in the institution. However, Gweru Polytechnic College and Mkoba Teachers College Administration department Heads made it clear that their asset disposal policy does not properly support electronic waste management through initiating Integrated Solid Waste Management but merely treats the electronic waste as basic assets that have lost their value in the institution. There was a general representation of awareness of electronic waste management with only Mkoba Teachers College representing 33.3% having revealed that there was no awareness of the possible effects of electronic waste. (Mutsau et al, 2015) however states that there is generally lack of awareness amongst Zimbabwean consumers and manufacturers on sustainable electronic waste management thereby creating a great challenge in electronic waste management.

Electronic waste storage

Information from interviews presented that storerooms are utilised for electronic waste storage but small units of electronic waste such as cartridges may be stored in offices or labs thereby making it difficult to manage their proper disposal. The researcher took a tour around the three institutions of higher learning to identify the electronic waste management practices. Observations of the dominant computers as electronic waste went were noted and went hand in hand with what the Administration departments outlined in interviews. The researcher observed a lot of electronic waste mainly comprising of ink toners at Mkoba Teachers College stored randomly in offices and laboratories thereby causing an environmental eyesore.

All three institutions are involved in electronic waste separation, information from

interviews reflected that Midlands State University categorises electronic waste for easier recycling and record keeping whilst Mkoba Teachers College and Gweru Polytechnic College also separate their electronic waste for record keeping but however, a small amount of cartridges are mixed with general waste. Categories of electronic waste separation were mainly grouped into computers with their accessories, printers and photocopiers then consumables stored for disposal separately.

The researcher observed bins filled with both general waste and ink cartridges, this is against the suggestions given by Midlands Province Environmental Quality Officer in an interview as he suggested the adoption of the concept of waste hierarchy that promotes sustainable methods of electronic waste management.

Electronic waste recycling in the institutions

Only Midlands State University is involved in recycling their electronic waste amongst the institutions of higher learning in Gweru. Information from interviews revealed that they donate their obsolete computers to Midlands Technologies and they also donate their cartridges and toners to Green works recycling. Recycling has thus been proven to be a challenge in institutions and this is supported by (Puckett and Smith, 2002) who mentioned that the lack of adequate professional recyclers, refurbishers and current technology in electronic waste management is a major drawback in developing countries.

The researcher visited Midlands Technologies workshop in Gweru and observed the refurbishment of MSU electronic waste which comprised of obsolete computers being re-established to value. The electronic waste was donated to the refurbishers so as to benefit other communities without the intention of gaining profit.

The idea is supported by Microsoft (2008), as they state that the most sustainable means of managing electronic waste such as computers is through refurbishment and reuse and the refurbished computers promotes spreading of Information and Communication Technology to less fortunate communities that may not afford new computers.

MSU electronic waste management and disposal mechanisms

Figure 2 below shows that Midlands State University sends about 60% of its electronic waste to recyclers that include Greenworks and Midlands Technologies. 30% is repaired by technicians within the institution and only about 10 % is stored awaiting consideration of disposal. This procedure is in line with following the hierarchy of waste management as supported by (Raina, 2010) who posited that the concept of following the hierarchy of waste management is to promote recovery and reuse of products.

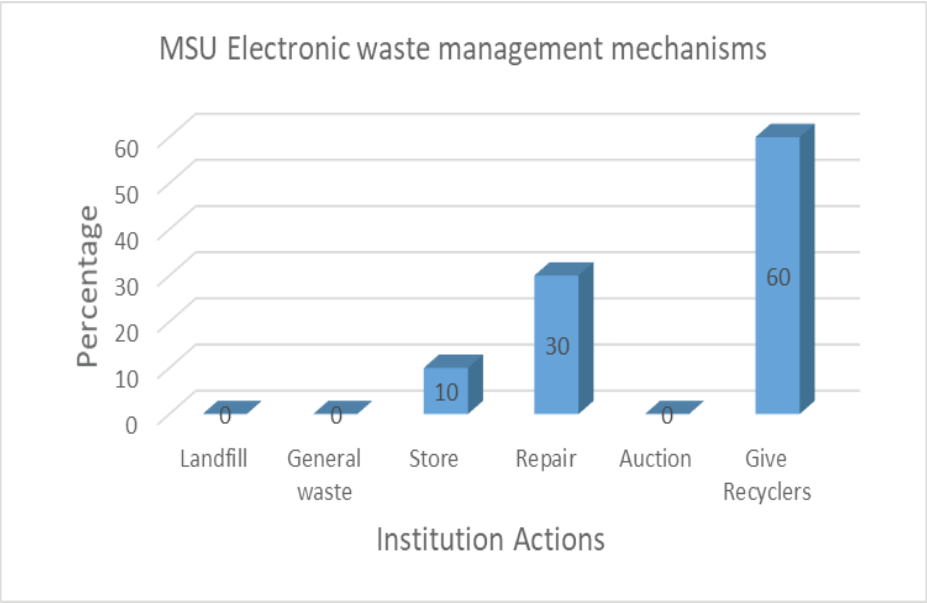

Fig 2: MSU electronic waste management and disposal mechanisms

Gweru Polytechnic College electronic waste management and disposal mechanisms

About 50% of electronic waste at Gweru Polytechnic College is auctioned as illustrated in Figure 3 below. Information from interviews revealed that public auctions are held in line the Procurement Regulatory Authority Company on assets that have been deemed obsolete by the Board of Survey. 30% of the electronic waste is being stored within the institution and information from interviews highlighted that it is due to the long procedures required before being granted permission by the Ministry of Finance to hold a public auction. 10% of electronic equipment in the institution is repaired and restored to value by technicians in the IT department. However, 10% of the electronic waste is disposed as general waste and information from interviews and observations revealed that the electronic waste comprised of used up ink toners and cartridges. However, according to (Lundgren, 2012), due to the inadequate technology and unprofessional management of electronic waste within developing countries, the environmental and human risk is far reaching.

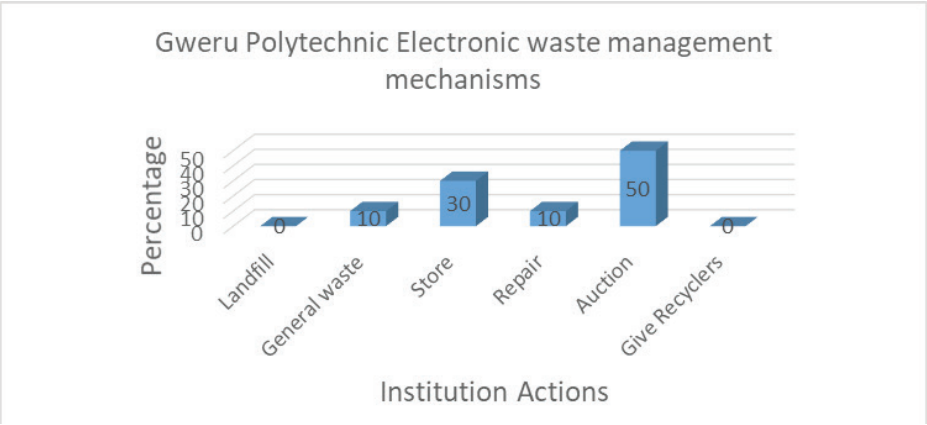

Fig 3: Gweru Polytechnic College management and disposal mechanisms

Mkoba Teachers College electronic waste management and disposal mechanisms

Figure 4 shows that about 50% of electronic waste at Mkoba Teachers College is auctioned. Information from interviews revealed that public auctions are held in coordination with the Ministry of Higher and Tertiary Education. It was observed that 35% of the electronic waste is being stored within the institution and information from interviews highlighted that it is also due to the long procedures required before being granted permission by the Ministry of Finance to hold a public auction. 10% of electronic equipment in the institution is repaired and restored to value by technicians in the IT department. However, 5% of the electronic waste is disposed as general waste and information from interviews and observations revealed that the electronic waste comprised of used up ink toners and cartridges.

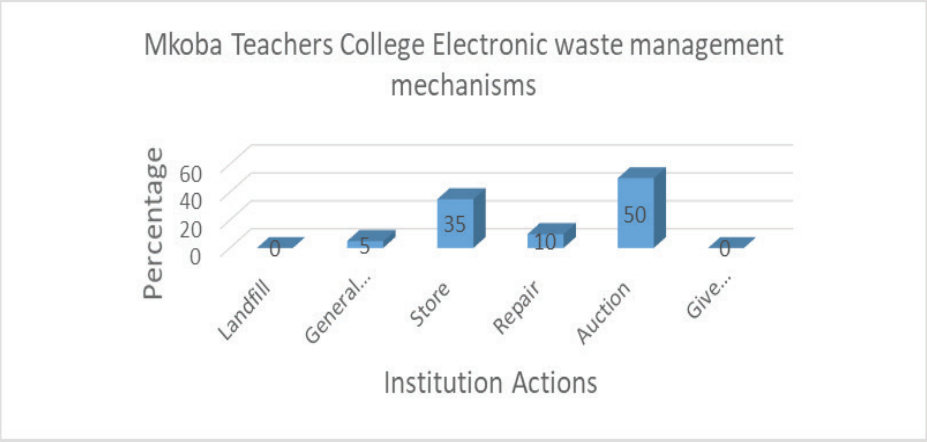

Fig 4: Mkoba Teachers College disposal mechanisms

Electronic waste management in Gweru institutions of higher learning.

All three institutions of higher learning in Gweru are not involved in landfilling electronic waste. However, a low percentage of electronic waste of 10% at Gweru Polytechnic College and 5 % at Mkoba Teachers College is mixed with general waste. Information from interviews with Mkoba Teachers College Administrator highlighted that it was a result of lack of awareness as some staff within the institution disposed old cartridges in general waste bins and this was the same case at Gweru Polytechnic College revealing about 10% of electronic waste being mixed with general waste. All three institutions evidently kept some electronic waste in storage, information from interviews with key informants revealed that the 10% stored at MSU was only awaiting collection by recyclers as confirmed by the Assets Department head whereas the 30% at Gweru Polytechnic College and 35% storage accumulation at Mkoba Teachers College was as a result of failure to auction the electronic waste such as obsolete computers as confirmed by the Administrators. Moreover, all 3 institutions add value to electronic waste through repair but MSU reflected 30% being repaired as compared to 10% in the other institutions. Information from interviews with MSU Information Technology Services department head revealed that MSU was higher in repair due to a larger workforce in the form of technicians that were ready to restore electronic equipment that would allow. Furthermore, MSU does not practice any auctioning of electronic waste but rather sends about 60% of electronic waste to recyclers. Information from interviews with Gweru Polytechnic College and Mkoba Teachers College Administrators concurred that about 50% of electronic waste is auctioned by the institutions but is however not sent to recyclers due to no standards being set by the Ministry of Higher and Tertiary Education to give away electronic waste to recycling agencies.

Challenges in lack of policy and legislation on electronic waste

All three institutions of higher learning expressed their challenge in lack of well-set Standard Operating Procedures in line with electronic waste management and they all blamed it on the absence of electronic waste legislation. This is supported by information from an interview with Gweru Municipality Cleansing Superintendent and Environmental Management Agency Environmental Quality officer who stated that there are currently no systems of electronic waste quantification in Gweru. According to the EMA Act (20:27) there is prohibition of hazardous substances discharge into environment but no direct legislation on electronic waste can be noted. However, (Sinha-Khetriwal et al., 2005) posited that the lack of reliable data poses a challenge to policy makers wishing to design an effective electronic waste management strategy. Gweru Polytechnic College and Mkoba Teachers College Administration heads however noted their own challenges in electronic waste management as they referred to too much red tape in the system. Gweru Polytechnic College and Mkoba Teachers College highlighted that there is need for policy change within their institutions due to no autonomy as all obsolete assets are auctioned on behalf of the Ministry of Higher and Tertiary Education with no returns coming back to the institutions. The process of disposing electronic waste in these 2 institutions was presented to be long and complicated as a board of survey has to be conducted, permission is sought from the Ministry of Finance as well as the Ministry of Higher and Tertiary Education and then a committee comprising of both internal and external stakeholders decides on the method of disposal thereby losing a lot of time before decisions are made. Further information from interviews at these institutions alluded that there are bottle necks in the electronic waste management process due to no frequent disposal of the electronic waste and no well-known ready market.

Only one of the three institutions has an electronic waste management policy. This is supported by information from interviews that presented that Midlands State University uses their Asset disposal policy in conjunction with their ICT policy. Gweru Polytechnic College and Mkoba Teachers College however face a challenge of lack proper procedural guidelines on how to manage their electronic waste. This is supported by (Nnorom and Osibanjo, 2008) who posited that most developing countries lack formal systems in the assuring of extended producer responsibility in electronic waste management. Midlands State University however confirmed to having an effective policy was confident with their policy as the Information Technology Department stated that all electronic waste disposal has been smooth as a result of this policy thus it is not a challenge to them.

Electronic waste awareness sensitization challenges within the institutions

Institutions of higher learning in Gweru are failing to properly train their departments on electronic waste management thereby enabling them to be aware. It is thereby a challenge mainly to Mkoba Teachers College which has not initiated electronic waste

sensitization yet. Information from interviews at Midlands State University presented that the Risk Management Office is responsible for training employees and at Gweru Polytechnic College, efforts are being made by the Administration department to train all employees on storage and reporting of electronic equipment that has lost value. Observations by the researcher have revealed that lack of awareness of health and environmental impacts has led to accumulation of electronic waste in staff offices and laboratories.

Both Mkoba Teachers College and Gweru Polytechnic College are institutions of higher learning in Gweru without awareness on what happens to their electronic waste after disposal. However, Midlands State University revealed their knowledge on how their toners and cartridges are recycled in South Africa after collection by Green works Recycling Company. Moreover, the level of awareness of surrounding electronic waste recycling companies to be at 33.3 % of all the institutions of higher learning in Gweru. Only Midlands State University has engaged Green works Recycling Company and Midlands Technologies to manage their electronic waste.

Challenges in sustainable management of electronic waste

Interviews with all institution departments revealed that there is very little collaboration between manufacturers, refurbishers and recyclers as only private partnerships are being formed with local institutions. There are very few professional recyclers in Gweru and no local electronic waste treatment plants which thereby makes it very difficult to manage the electronic waste in a sustainable manner. Information from interviews reflected that Midlands State University faces challenges in finding more professional recyclers in Gweru. Gweru Polytechnic College and Mkoba Teachers College however face challenges of obsolete electronic equipment overstaying in storerooms as illustrated in plate 1 due to disposal approval procedures that are very long. These two institutions also face a challenge of not benefitting from the auctioned electronic waste as all returns are taken by the Ministry of Higher and Tertiary Education. However, (Ogbomo et al 2012) also reflected that unsustainable management of ICT electronic waste is a common practice in institutions of higher learning in African developing countries.

Conclusion and Recommendations

This study has shown the management of electronic waste in institutions of higher learning in Gweru, Zimbabwe. The main types of electronic waste in institutions of higher learning in Gweru comprise mostly of computers and their accessories due to Information and Communication Technology being widely used by both students and staff in all departments in the institutions of higher learning. Midlands State University as a representative of universities in Zimbabwe has revealed that universities release higher volumes of electronic waste due to their high stocks of electronic equipment as

compared to other institutions such as Gweru Polytechnic College and Mkoba Teachers College. The findings of the study identified the different management practices amongst the three institutions to be a result of difference in policy and level of awareness. However, the researcher also noted various challenges affecting electronic waste management within the institutions of higher learning in Gweru and these included no direct legislation on electronic waste, policies that do not encourage sustainable management of electronic waste and lack of awareness.

Midlands State University

- Midlands State University Administration department should create innovative electronic waste policy designs and they should highlight on refurbishment, reuse, recycling, and effective electronic waste collection systems such as having particular bins for electronic waste disposal around the institutions and specific days of collection.
- Administration department should increase awareness on sustainable electronic waste management through staff training, workshops, strict procurement policies and institutional policies and awareness campaigns on reuse and the value of recycling of electronic waste.
- Technical departments such as Information and Technology within the institution should also be involved in designing electronic waste management mechanisms
- Students should develop more research on all the various types of electrical and electronic waste (WEEE) within the institution so as to design a fully guided document on electronic waste management.

- Information Technology Services department should enable all technicians to engage in serious refurbishment of electronic waste so as to benefit the institution financially and refurbished computers could be donated to Primary schools that may not afford new computers as part of Corporate responsibility.

Gweru Polytechnic College

- Gweru Polytechnic College Administration department should make efforts to Partner recyclers such as Greenworks recycling, Midlands Technologies and Enviroserve so as to promote sustainable management of electronic waste and encourage public participation.
- Administration department should adopt international standards such as only purchasing new electronic equipment and not introducing 2nd hand equipment into the institution as it has a shorter lifespan.
- Administration department should create innovative electronic waste policy designs and they should highlight on refurbishment, reuse, recycling, and effective electronic

waste collection systems such as having particular bins for electronic waste disposal around the institutions and specific days of collection.

- Administration department should increase awareness on sustainable electronic waste management through staff training, workshops, strict procurement policies and institutional policies and awareness campaigns on reuse and the value of recycling of electronic waste.
- Technical departments such as ICT and WEE, Electrical and Mechanical Engineering within the institution should also be involved in designing electronic waste treatment plants as they are not locally available.
- Students should develop more research on all the various types of electrical and electronic waste (WEEE) within the institution so as to design a fully guided document on electronic waste management.
- ICT and WEEE department should enable all technicians to engage in serious refurbishment of electronic waste so as to benefit the institution financially and refurbished computers could be donated to Primary schools that may not afford new computers as part of corporate responsibility.

Mkoba Teachers College

- Mkoba Teachers College Administration department should make efforts to Partner recyclers such as Greenworks recycling, Midlands Technologies and Enviroserve so as to promote sustainable management of electronic waste and encourage public participation.
- Mkoba Teachers College should adopt international standards such as only purchasing new electronic equipment and not introducing 2nd hand equipment into the institution as it has a shorter lifespan.
- Administration department should create innovative electronic waste policy designs and they should highlight on refurbishment, reuse, recycling, and effective electronic waste collection systems such as having particular bins for electronic waste disposal around the institutions and specific days of collection.
- Administration department should increase awareness on sustainable electronic waste management through staff training, workshops, strict procurement policies and institutional policies and awareness campaigns on reuse and the value of recycling of electronic waste.
- Technical departments ICT, Electrical and Mechanical Engineering within the institution should also be involved in designing electronic waste treatment plants as they are not locally available.
- Students should develop more research on all the various types of electrical and electronic waste (WEEE) within the institution so as to design a fully guided document on electronic waste management.
- ICT department should enable all technicians to engage in serious refurbishment of electronic waste so as to benefit the institution financially and refurbished computers could be donated to Primary schools that may not afford new computers as part of

corporate responsibility.

Ministry of Higher and Tertiary Education

Ministry of Higher and Tertiary Education should revise policies on how to handle disposed assets so as to promote sustainable management of electronic waste and also benefit the institutions. The process of electronic waste management should become localised so as to promote efficiency.

Environmental Management Agency

Environmental Management Agency should draft direct legislation on electronic waste management so as to apply strict procedures that will minimise electronic waste and promote sustainable management of electronic waste in institutions of higher learning.

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To my family and friends, I am deeply indebted to you for all the encouragement and support you offered me throughout this research. I express great appreciation to the Midlands State University Department of Geography and Environmental Studies for equipping me with the skills of knowledge to conquer the world of research. I also express great appreciation to the Environmental Management Agency for funding my research and all the stakeholders in my research for their cooperation.

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Wetlands Governance and the State of Urban Wetlands in Zimbabwe

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Abstract

The purpose of this paper is to analyse wetlands governance and implications for the management of these ecologically fragile systems, using Harare as a Case Study. The paper argues that despite the existence of environmental management legislation and the ratification of the Ramsar convention, wetlands in Harare continue to experience massive destruction mainly due to the fragmentation of institutional frameworks. For example, the Environmental Management Act (Chapter 20:27) does not define permitted or prohibited developments and uses on a wetland. This has resulted in the rampant construction of housing estates and urban agriculture activities on the City's major wetlands. There are also a number of institutional actors involved in the management of wetlands (Environmental Management Agency, Urban Local Authorities, and Community Based Organizations like Harare Wetlands Trust). This creates 'institutional pluralism'. Despite having this colossal spectrum of players in the protection and conservation of wetlands, wetlands loss and degradation is a sad reality and remains unchecked. A case study research design was employed in gathering data for this study. Laws for wetland protection and management are sometimes conflicting and there is a high degree of fragmentation which is contributing to wetlands loss.

The study noted that urban planning laws regards environmental protection, however some operative statutory plans are less attentive to wetlands protection. The study recommends legislative alignment and participatory urban planning and wetlands protection so that collaborated efforts are made to save the remaining wetlands as well as reclaiming the lost ones.

***Keywords**: Governance, Wetlands, Wetlands governance, Wetlands Protection, Wetlands Plight*

Introduction

Wetland ecosystems form a very vital part of the world's most productive ecosystems (Ramsar Convention on Wetlands, 2018). Being ecologically sensitive areas, multiple institutions, laws, policies, systems have been put in place to ensure that wetlands are protected and conserved. These institutions and systems create the wetlands governance suite which is a group of stakeholders who employ different tools and methods to protect wetlands. The sum total of ways, means and processes by which organisations, private or public, formal or informal apply policies, laws, and systems in determining how wetlands are to be used, protected and conserved is called wetland governance. Governance also entails a continuing process through which conflicting or diverse interests may be accommodated and cooperative action can be taken (UN HABITAT 2002). Ramsar Convention on Wetlands operates at the apex as a global institution on wetlands protection while the Environmental Management Agency and its allied institutions are locally based institutions operating in the confines of Zimbabwe. Although there are multiple organisations and institutions responsible for protecting wetlands in Zimbabwe, cities like Harare continue to face widespread wetland loss due to human activities. This further highlights the ineffectiveness of organisations in curbing unfavourable human activities on wetland ecosystems. The paper seeks to understand the missing link between Zimbabwe's wetlands governance systems and the protection of wetlands in Zimbabwe, using Harare as a case study. A question is raised "*Why do wetlands continue to suffer despite having institutions at all levels whose focus it to save and protect them*?"

Literature Review: An Overview of Wetlands and Wetlands Governance

The Government of Zimbabwe through the Environmental Management Act (Chapter 20:27) of 2002 defines wetlands as water body systems such as marshes, ferns, peat lands, pans, swamps, streams and lakes, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres. This definition was derived from the Ramsar Convention on Wetlands of International Importance (Article 1.1) which Zimbabwe subscribe to. Harare Wetlands Trust (2015) define wetlands as areas where water is the primary factor controlling climate, environment and associated plants and animal life in an area. Loosely defined, they are areas which are waterlogged

perennially or seasonally (Kecha et al, 2007). In Southern Africa wetlands are generally known as *vleis* (*Afrikaans*), *dambos* (*Chichewa*), *matoro / mapani/ machakwi* (*Shona*) or *amaxhapozi* (*Ndebele*), meaning inland wetland systems. These are approximately 1271 wetlands and are covering approximately 3% of the total land area (Chakanyuka, 2019). In Zimbabwe, wetlands cover approximately 4.6% of the land. The Harare Wetlands Trust (2015) suggest that wetlands in Zimbabwe include springs, pools, vleis, dambos, streams, rivers, lakes, floodplains, plans, farm ponds, reservoirs, irrigation canals, gravel, mine pits and sewage ponds. Vleis are the most dominant covering 3.6% of the areas (Sithole and Goredema, 2013). The wetlands that are designated as Ramsar Site include Victoria Falls, Drifontein Grasslands, Lake Chivero, Middle Zambezi/ Mana Pools, Chinhoyi Caves, Monavale Vlei and the Cleveland Dam (Harare Wetlands Trust, 2015). These wetlands cover an approximated space of 28582.40ha (EMA, 2019).

Wetlands Governance: A Global, Regional and Local Perspective

At a global scale, the Ramsar Convention on Wetlands of 1971 is an intergovernmental treaty whose directive is "to conserve and wisely use all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world" (Ramsar Convention Secretariat, 2010). It is from the convention that the 2nd of February was set as the World Wetlands Day. This day was first celebrated in 1997. Wetlands are also protected by the Convention of Biological Diversity. The United Nation's Millennium Development Goals (MDG's) and Sustainable Development Goals (SDG's) also contribute to wetlands protection but at a broader scale of protecting the natural environment. Millennium Development Goals has to dedicate Goal 7 to Ensuring Environmental Sustainability at a global level which was aimed at integrating the principles of sustainable development into local policies and programmes and reverse the loss of the environmental resources (United Nations, 2014). This was followed by Sustainable Development Goal 15 named Life on Land whose aim is to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forest, combat desertification; halt and reverse land degradation and biodiversity loss (UNEP, 2017). Environmental sustainability has become the centre for the SDGs considering that about half of the SDGs are directly focusing on environmental issues and address the sustainability of natural resources such as water, wetlands, human settlements, oceans and terrestrial ecosystems (UNEP, 2017). This general trend from the Millennium Development Goals to the Sustainable Development Goals position environmental sustainability at the centre of the 21st century's goals and targets.

A Global Perspective of Wetlands Governance

Management plans have been put in place for particular categories of protected areas and certain habitat types (Shine and Cyrille, 1999). In Peru, all-natural protected areas including their seven Ramsar sites must be covered by a master and operative

management plans (Solano, 1998). In Portugal, the law decree of 23 January 1993 on the National Network of Protected Areas required management plans to be developed for nature parks. Much more rarely, the law may also specify that in the event of inconsistency, such plans take precedence over other planning instruments in the region. In Spain, the Autonomous Community of Madrid has enacted legislation for the protection of wetlands and artificial water impoundments, which specifically provides for the making of binding wetland land-use plans by the Environment Agency.138 Australia's proposed legislation on biodiversity conservation, undergoing Parliamentary consideration in 1999, would make management planning a mandatory requirement for all designated sites on Commonwealth land, including Ramsar sites: the provisions of such plans would be legally binding on all Commonwealth agencies. In Netherlands, the Netherlands environmental agency has introduced the concept of well-designed buffers and transition zones that are used as spatial tools to safeguard ecological processes essential for wetlands functions and value. In Brazil, the promulgation of the Federal Constitution of Brazil in 1988 saw the localization of conservation provisions of wetlands in state constitutions. The protected habitats where categorised into two which are permanently protected areas and areas of ecological interest (Shine and Cyrille, 1999).

Regional Perspective of Wetlands Governance.

Involvement of residents has also been a major initiative in the governance and management of wetlands in the region. This kind of involvement is often initiated on an informal basis and at this level can make an important contribution to strengthening the role of human communities in wise use. Wherever possible, the rights of communities should be formalised and given legal backing under appropriate legislation. Structures for joint management may be developed on a sliding scale of formality, depending on the institutional traditions and applicable legislation of the country or locality concerned. Legal and administrative arrangements should give local communities the right to be involved in the management of all public protected areas within their geographic area. They should also specify rights to information and participation of local authorities, local businesses, scientific institutions and conservation NGOs (Synge, 1994). Some countries already have a structure of local government that provides for the formation of committees at the lowest level. This has been evidenced in Kenya were Lake Naivasha Riparian is Management by the Lake Naivasha Riparian Association in Kenya while Prespa in Greece is management locally by the Society for Protection of Prespa. In Uganda, the constitution adopted in 1995 makes specific provisions for wetlands conservation (Ntambirweki, 1998). Ugandan legislation supports the creation of local environment committees as subcommittees of local village committees. Local environment committees of this kind could be specifically created or mandated to address wetland management.

Local Perspective of Wetlands Governance

In Zimbabwe natural resources such as wetlands are communally owned, used and managed where the communal system of resource ownership entails that communities are in 'de facto' ownership of wetlands on behalf of the state, the 'de jure' owners (Marambanyika and Beckedahl, 2017). Traditional institutions are the oldest institutions that managed wetlands from time immemorial. Having laws, regulations and statutes that were not necessarily documented, indigenous institutions proved to be relatively effective in managing the environment and wetlands included. This resulted in sustainable utilization of natural resources (Dore, 2001). While this may be true, changes in population densities, land uses, land demand and external factors such as new markets now present a different challenge than when the environment was being managed by indigenous institutions. The arrival of colonial governments interfered and disrupted indigenous institutions that were into natural resource governance and management and this weakened their capacity. Post-colonial governments then inherited and adopted colonial institutions set up to manage the environment. These largely ignored indigenous knowledge and common best practices.

Post-colonial, the Ministry of Environment, Water and Climate; Ministry of Lands and Ministry of Agriculture administered management of the environment on behalf of government (Sithole and Goredema, 2013). The Environmental Management Act (Chapter 20:27) of 2002 is the primary law that governs the natural environment. It is through this act that the Environmental Management Agency (EMA) was formulated. The Environmental Management Agency is the overall body that oversees issues of the Environment in Zimbabwe. In managing wetlands specifically, subsection 113 of the Environmental management Act (Chapter 20:27) of 2002 state that wetlands utilization for cultivation or construction is only permissible upon receiving a permit. Statutory Instrument 7 (S.I.7) of 2007 speaks to the need for Environmental Impact Assessments prior to development. The Constitution of Zimbabwe also state in section 73 the need to protect the environment and wetlands are also included. Urban Councils also administer policies and regulations to protect the environment through the authority that is seeded to them through the Urban Councils Act and the Regional Town Country Planning Act (RTCP Act). Traditional authorities and rural local authorities use the Communal Lands Act and the Rural District Councils Act respectively. The challenge with these legislations of development is that they are silent about the specific land uses that can be designated for wetlands hence the uses assigned on them are very detrimental to the environment (Chirisa et al, 2016).

Area of Study: Harare

Harare is the capital City of Zimbabwe with a population of 2 123 132 million (ZIMSTATS, 2012). It falls under UTM Zone 36 South on area bounded by the following coordinates using the Arc 1950 UTM zone 365 coordinate system: Minimum

X 275021.634m and Maximum X 311501.8158m and Minimum Y 8009041.4914m and Maximum Y 804600.6733m. It falls in the catchment area of Manyame and Mukuvisi River. It is situated at an elevation of 1483m above sea level (Muronda, 2008). Generally, the topography of the city is flat. The city lies in the tropics and has a mild and cool climate with wet hot summers and dry cold winters. The locality map is shown on fig 1 below highlighting the selected wetlands.

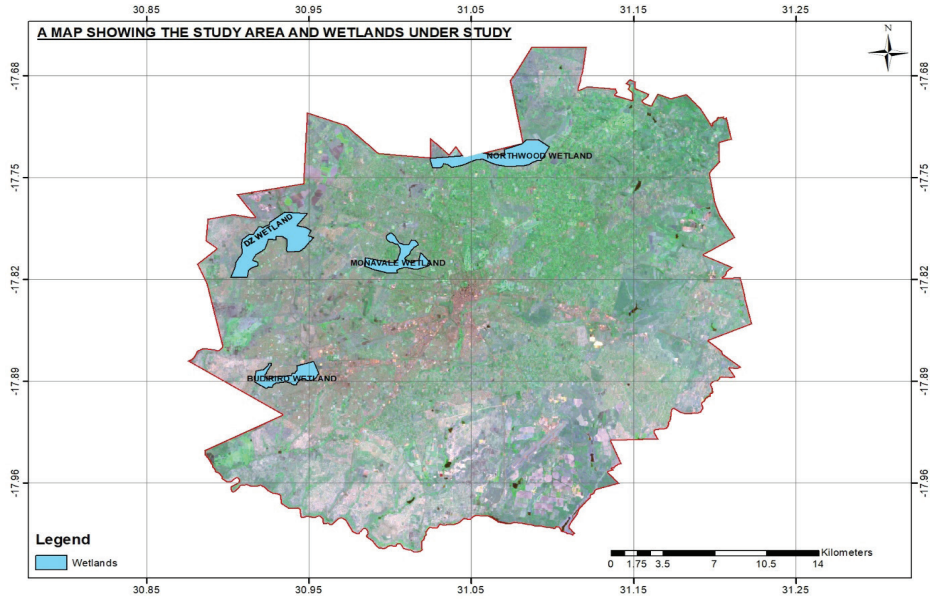

Figure 1: *Showing the 4 wetlands selected from the 29 wetlands in Harare,*
Source: *Author*

Methods and Methodology

This research employed the case study research method which is an in-depth investigation of a few selected units of study to represent an entire research population. The case study approach was selected for this study because it places more emphasis on the full in-depth analysis of a unit of study than the breadth which is not comprehensive enough. Harare was chosen specifically for this research because of its fair share of wetlands in Zimbabwe in relation to widespread developments. According to EMA's wetlands map, Harare has 29 wetlands that cover a hectarage of 23 229. According to Chakanyuka (2019), 13 of Harare's 29 wetlands have already been overtaken by construction activities which makes Harare an important research area as far as the protection of wetlands is concerned. The case study research design sought to address the "what" and "why" questions concerning wetlands plight in the face of a multifaceted wetlands governance system. The case study research design used a descriptive approach to describe the state of wetlands and the wetland governance framework. A mixed method

approach was used in this study which involved the collection and analysis of qualitative and quantitative data (Denzin, 2010). Qualitative data gathering methods used include interviews, document analysis and observations. These methods were selected because they enable the researcher to gain an understanding of underlying insights and meanings over the research problem which may not be explained by the quantitative research. The quantitate method used was a questionnaire survey. The researcher chose this method because it is more scientific, objective, fast and acceptable for the date that the research sought to gather.

A total of 182 household questionnaires were administered and analysed using the Statistical Package of Social Sciences (SPSS). Convenience sampling was used to choose respondents to questionnaires who are close to the wetlands and are most likely to have the knowledge of how the wetlands are interacting with urban development. Convenience sampling is based on the accessibility of a sampled population and the degree to which they can cooperate (Denzin, 2010). This was selected because the researcher found it feasible to administer the questionnaire to the people who were readily available on the homes in or around wetlands under study. Interviews were also done with officials from the Environmental Management Agency, Harare Wetlands Trust, Conservation Society of Monavale and City of Harare. Purposive sampling was used in this research to determine key informants based on their relevance and expert knowledge relating to this study. This technique involved the seeking out of respondents by the researcher basing on his own discretion that the respondents are knowledgeable enough in the issue under discussion (Denzin, 2010, Pande and Pandey, 2015). This method was used because it allowed the researcher to select the ideal organizations mandated to deal with issues of environment and development in the city. This meant that the depth of the data collected was sufficient for the study.

Results

This section provides the results of study as obtained through the research carried forward in the research area. Focus is mainly on the legislative framework used in governing wetlands in Zimbabwe and the current state and the plight of wetlands in the study area.

Wetlands Governance Suite and the legislative framework in Zimbabwe

Wetlands in Zimbabwe are governed through a system of local, regional and global institutional environments that are comprised of rules and organizations. These institutions are central Government Departments and Parastatals, Local Authorities, Traditional Authorities, Private Players, Non-Governmental Organizations such as Community Water Alliance and Harare Wetlands Trust, Civil Society Organizations and the local people.

At the apex, there are government ministries, departments and agencies. The Ministry of Environment, Climate Change, Tourism and Hospitality Industry is the parent ministry that deals with environmental issues. The Ministry of Local Government and Public Works through the Department of Spatial Planning and Development deals with spatial planning and hence also administer development with the environment in mind. The Environmental Management Agency which is enacted by the Environmental Management Act, Chapter 20: 27 is a government agency which regulates the use of the natural environments and manages how natural resources are used. Wetlands are administered using section 113 of the Environmental Management Act (Chapter 20:27) and Statutory Instrument 7 of 2007. In managing wetlands specifically, subsection 113 of the Environmental management Act (Chapter 20:27) of 2002 state that wetlands utilization for cultivation or construction is only permissible upon receiving a permit. This ensures that not developments are done without permission which in most cases contain development conditions especially on ecologically sensitive areas. Statutory Instrument 7 (S.I.7) of 2007 speaks to the need for Environmental Impact Assessments prior to development. The Constitution of Zimbabwe also state in section 73 the need to protect the environment and wetlands are also included. The Statutory Instrument 7 of 2007 stipulates the need for an Environmental Impact Assessment. Other allied players are Zimbabwe National Water Authority (ZINWA) and local authorities both rural and urban. These administer acts that affect wetlands such as the Urban Council's Act, the Rural District Councils Act, the Water Act and the Regional, Town and Country Planning Act, Chapter 29:12. Public institutions such as government departments, agencies and parastatals are the custodians and stewards of wetlands and spatial development, so their main role is to create a balance between the two.

Wetlands are also protected through a plethora of plans which regulate their use as well as the development that can be allowed in them. A good example of such are National Environmental Plans, Local Environmental Action Plans (LEAP), master and local plans. These plans are responsible for earmarking wetland areas that cannot be developed as well as conditions of development if any. These plans are administered at both national and local authority level. They are also influenced by international conventions to which Zimbabwe is a member. In conjunction with these plans there is the provision of the Environmental Impact Assessment in the SI 7 of 2007 where a development can only be carried out if an environmental impact assessment has been done to highlight the sensitivity of the wetland to development. These provisions resonate well with the provisions of Section 26 of the Regional, Town and Planning Act Chapter 29:12 which states that no development shall be carried out without a permit from the local planning authority. In the case that a local authority envisages that an area is a wetland, development applications should be accompanied by an EIA certificate.

Civil Society Organizations also form a part of this process. They are associations or communities that work above and beyond the state. These CBO's raise awareness of social, political and environmental issues and advocate for change, empowering local communities over their community issues or resources. In this instance, CBO's were

mainly constituted by local groups and who were mainly residents. The most prolific of these CBO's included citywide based organisation and neighbourhood-based organisation. Citywide based organization include the Harare Wetlands trust and the Harare Chapter of Community Based Organizations. Working with the Harare wetlands Trust are community-based organization such as the Conservation Society of Monavale and the Marlborough Residents Associations. The Harare Chapter of Community Based Organization consist of neighbourhood-based organizations namely, Cleveland Action Alliance, GOSDEN Conservation Trust, Dzivarasekwa Conservation Trust, Budiriro Water Foundation, Manyame Conservation Trust, Mukuvisi Conservation Trust, Blue Agenda Trust and Greenland Conservation. These community-based organizations provide an opportunity for communities and urban residents to participate in the protection of wetlands.

The study highlighted that wetlands are a critical part of our natural environment. They reduce impacts of floods, absorb pollutants and improve water quality among other benefits to animals and plants. In this regard, the majority of research respondents that is 80.8% highlighted that due to the importance wetlands community participation is crucial in the management of wetlands. The other 9.3% of the respondents neither supported nor refuted community participation, the other 9.3% disagreed that communities should be key in the management of wetlands and 0.5% strongly disagreed with community participation. A strong inclination toward community participation of residents proves that residents are concerned over the protection and management of wetlands, even though questions can be raised that in current wetland dire situation where were they? The statistics are shown on fig 2 below.

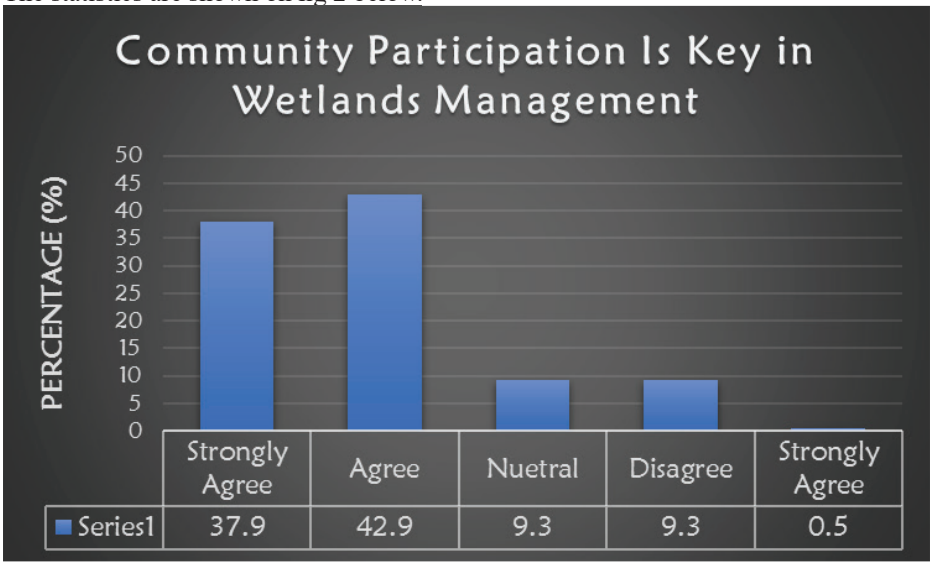

Fig 2: Scaling responses on the importance of Community Participation in Wetlands Management

The State of Wetlands in Zimbabwe: The Harare Narrative

Wetlands in Harare continue to suffer right in the face of a myriad of institutions and laws that should be protecting them. Human activities such as urban agriculture, housing developments, industrial and commercial developments and water extraction on wetlands are spreading across Harare. These are negatively impacting wetland ecosystems in terms of water availability and quality, biodiversity composition, wetlands extents, vegetation coverage and wetland/ ecosystem connectivity.

Wetlands Extents/ Coverage

Observation show that wetlands have shrunk in extents due to urban development activities. Considering that they take the character of their surroundings, development of housing and other urban development activities on wetlands has made invaded places drier thereby making them to cease to be categorised under wetlands. Although there are signs of them being wetlands, the characteristics no longer match the description of wetlands.

Findings from EMA and the City of Harare show conflicting perspectives. While EMA maps suggested a lot of developments having happened on wetlands, respondent 1 stated that only 10% of the total wetlands in Harare have been occupied by urban development and human activities. It was also mentioned that the city is still very far from reaching the maximum threshold of open spaces in terms of town planning standards. The results of interviews held with EMA indicate that 12 977.7 hectares have been built up in Harare out of a total of 23 504.9 hectares. This is more than half of the total wetlands space that Harare has. In addition to this statistic provided, the study carried out a mapping exercise of wetland using the Normalized Difference Vegetative Indexes (NDVI). The results of the mapping are presented in the following sections.

The normalised Vegetative Index Analysis of wetlands use in 2004, 2014 and 2019 is shown below. Wetlands are a dependent variable in this case and their coverage depend mainly on changes that happen in urban agriculture and construction. A general increase was recorded in construction which lead to the decrease of wetlands space. The same applies with urban agriculture except for Monavale were it decreased due to wetland restoration and protection. This is shown on the TABLE 1 below.

Table 1: Normalised Vegetative Index Analysis of Wetlands Use from 2004 to 2019

Name	Land Use	2004 ha	2014 ha	2019 ha
Northwood	Built Up or Bare	20.84	57.51	90.77
Northwood	Agriculture	144.48	270.17	301.43
Northwood	Wetland	426.24	263.88	199.36
TOTAL		**591.56**	**591.56**	**591.56**
Dzivarasekwa	Built Up	8.55	168.93	159.86
Dzivarasekwa	Agriculture	102.69	626.67	680.58
Dzivarasekwa	Wetland	874.98	190.62	145.78
TOTAL		**986.22**	**986.22**	**986.22**
Monavale	Built Up	10.8	13.55	30.56
Monavale	Agriculture	108.27	55.17	45.45
Monavale	Wetland	311.4	361.75	354.46
TOTAL		**430.47**	**430.47**	**430.47**
Budiriro	Built Up	0.27	83.16	120.76
Budiriro	Agriculture	22.14	150.48	178.23
Budiriro	Wetland	333	121.77	56.42
TOTAL		**355.41**	**355.41**	**355.41**

Source: (Remote Sensing Data, 2019)

State of Wetlands in 2004

Findings show that wetlands in 2004 were still greener and less disturbed. Although urban agriculture was evident, its impact on the natural view of wetlands is very minimal hence much part of the wetlands shows an undisturbed wetland. This is shown on the map on fig 3.

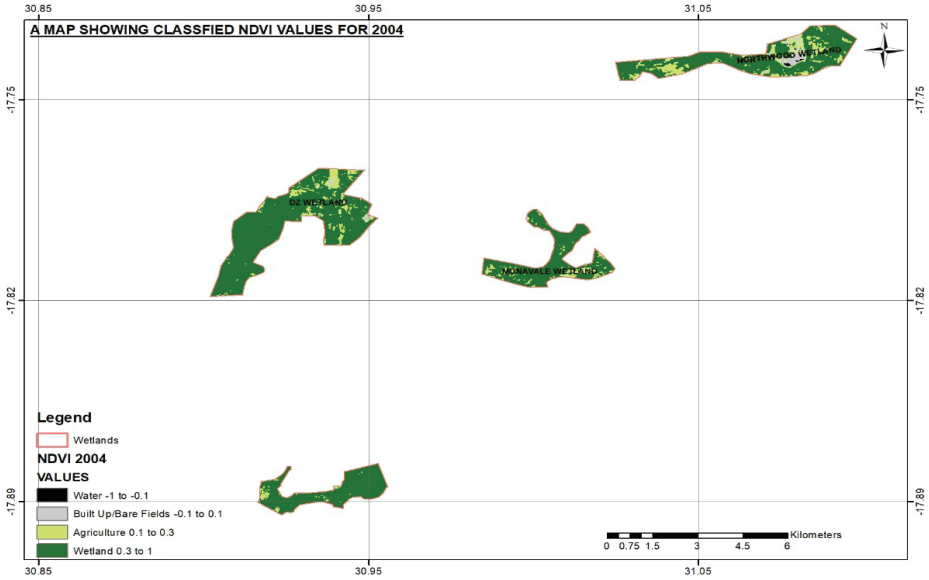

Fig 3: Showing state of wetlands in 2004 (Remote sensing Data, 2019)

State of Wetlands in 2014

Wetlands in 2014 show great disturbance as urban agriculture is now very evident. While Monavale show a greater part as a wetland in its undisturbed form, Dzivarasekwa, Budiriro and Northwood show that there is great interference in form of urban agriculture and construction which may also be bare ground. This is shown on fig. 4.

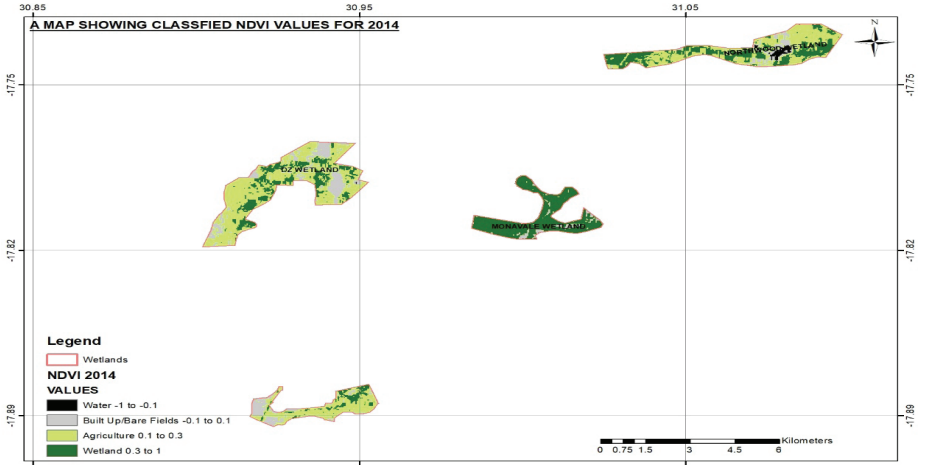

Fig 4: Showing state of wetlands in 2014 (Remote sensing Data, 2019)

State of Wetlands in 2019

Urban agriculture and construction continue to increase as shown on figure 4.10 on wetlands in 2019. Monavale Vlei is the only wetland which has much of its space covered with undisturbed wetland space of 354.46 hectares as according to the NDVI analysis. Budiriro and Dzivarasekwa wetland have been thoroughly affected by development in form of construction and wetland space has greatly shrunk. This is shown on fig. 5 below.

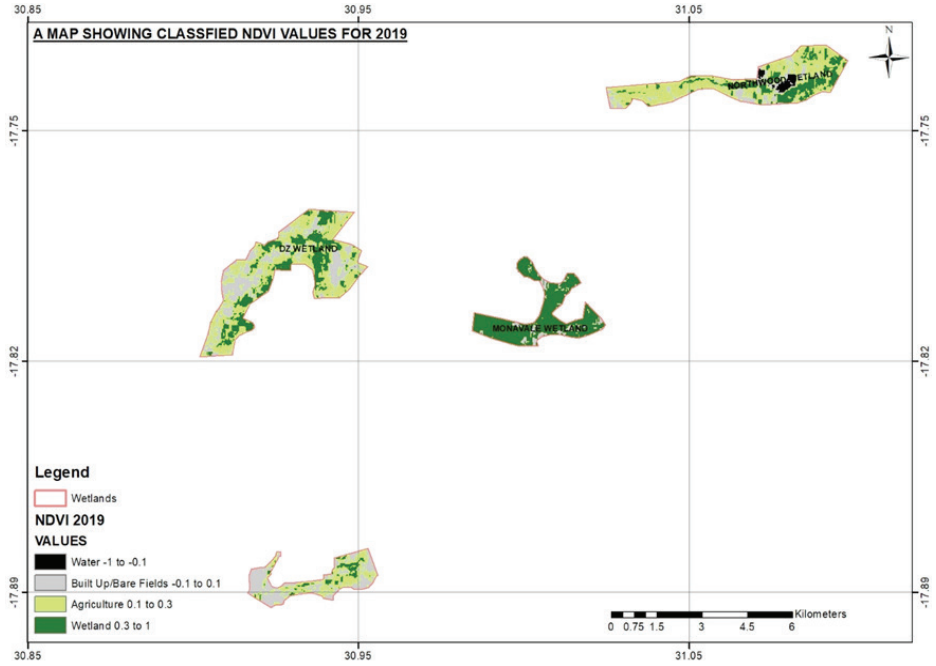

Fig 5: Showing state of wetlands in 2014 (Remote sensing Data, 2019)

Biodiversity Composition on Wetlands

The Monavale wetland is home to several animal species which includes the bush pigs, rabbits and wetlands birds such as the back headed heron and the black winged kite. These 2 bird species were observed in 3 of the 4 wetlands studied. The Wetlands have been greatly affected by urban development and subsequent human activities happening on them in terms of biodiversity composition. The major impact to biodiversity is emergence of invasive species on wetlands. Invasive plant species are those plants that are foreign to a wetland and were not naturally in existent in the subject wetland. Monavale is a treeless wetland but currently it's occupied by trees which are invasive species and foreign to the wetland. These affect the natural processes of the wetland

thereby affecting the whole ecosystem. In all the four wetlands, an observation was made that there was an intentional planting of the gum trees. These are also invasive species because they are exotic to wetlands. Plant species such as the gum trees usually drain much of the water in wetlands affecting species that depend on water for survival. This means that changes in wetlands due to invasive species lead to death or extinction of some plant or animal species in wetlands. Findings also showed that there are birds which have been recorded before which are no longer coming into wetlands because of changes in wetland composition.

Vegetation Type and Cover

Results show that Harare wetlands are treeless wetlands with short grass. However, most of these wetlands have been invaded by foreign species. One common grass species on all the 4 wetlands especially on drier edges is a long grass called the hyparrhenia. Of the 4 wetlands, the Monavale wetland is still rich in terms of biodiversity since it has been restored to its natural state. According to Conservation Society of Monavale (COSMO) (2018), there are 36 species of grass and 80 species of other plants which have been recorded in Monavale and other wetlands in Harare. Over 240 bird species, 16 reptiles and 7 amphibians have also been recorded at Monavale. Much of the space on Northwood wetlands has not been disturbed so native grass species are still very present in the wetlands. However, Budiriro and Dzivarasekwa have experienced massive urban agriculture and housing development and much of the wetland have at one point been cultivated. All native grass species have been replaced by invasive species such as the phragmites australis. A common feature on all the 4 wetlands was that they had eucalyptus plantations which on inquiry, it was learnt that they were planted to drain the excessive water that was in the wetlands. The eucalyptus, acacias and the syringa trees are invasive species that were also observed at Monavale, Budiriro and the Dzivarasekwa wetland.

Wetlands Connectivity/ Ecosystem Processes.

Wetlands connectivity has been compromised on all the four wetlands by infrastructure provision. Results show that aquatic species are the most affected by wetland fragmentation. Utilities such as roads, water and sewer pipes, have greatly affected wetlands connectivity. These facilities cut through wetlands and their installation creates trenches and hard surfaces that are difficult for wetlands insects to pass through. Roads topping the list, have been cited as the major cause of wetland fragmentation and this affect natural ecosystem processes such as water flow, animal movement and pollination in vegetation. All the four wetlands have roads passing through them. The Northwood wetland is separated from the Vainona wetland by Harare Drive as shown on fig. 6. The Dzivarasekwa wetland is separated from Kuwadzana wetland by Bulawayo Road and this is illustrated on fig. 7. Princess Road separate the Monavale wetland and the Belvedere wetland. Sherwood Road and Monavale Road cut through the Monavale wetland. Although culverts and bridges are provided, they are not enough to ensure that

natural ecosystem flows continue to happen in their natural manner and pattern.

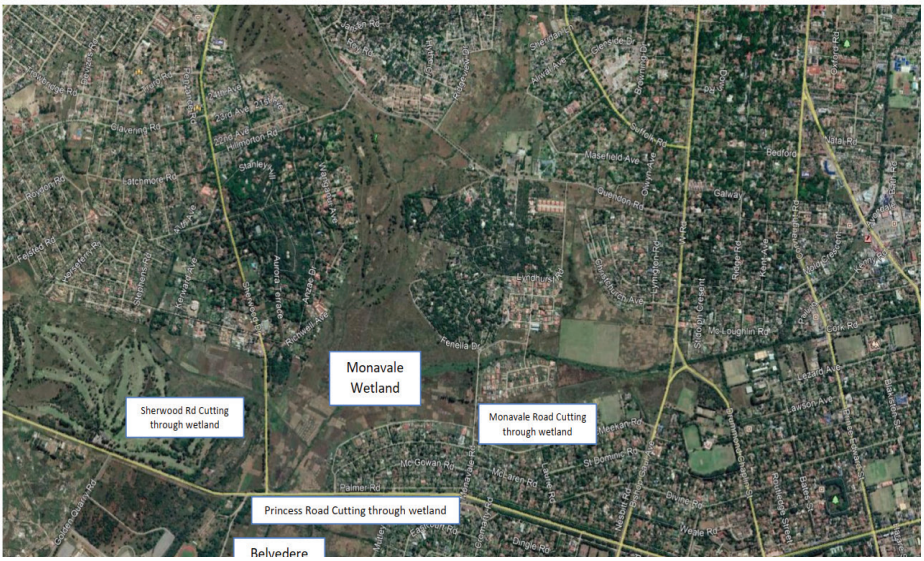

Fig 6: showing roads cutting through Monavale Wetland

Fig 7: showing roads cutting through Dzivarasekwa Wetlands

The human activities that are being practised on wetlands in Zimbabwe are detrimental to the wetlands. The way construction and urban agriculture is happening is affecting the wetlands and their associated biodiversity. The wise use of wetlands is promoted by Ramsar Convention on Wetlands (2018) which ensures that wetlands survive into perpetuity. The Centre for Watershed Protection (2005) states that humans derive positive benefits from wetlands use at the expense of the wetlands. The sustainability of wetlands in terms of water availability and quality is at stake. Harare is constructing its way out of water because the natural purifiers and reservoirs are being disturbed.

Biodiversity composition is also affected by changes in wetlands characteristics. Fresh water species that rely on wetland water are affected when the water is contaminated. When affected, biodiversity may fail to replenish or recover. This is because human activities on wetlands such as Budiriro are so intense that they do not give nature enough time to recover. For example, it was stated that some water loving bird species no longer come to wetlands in Harare because they are degraded. Habitats for animal species have been greatly affected by wetlands invasion. This means that human activities on wetlands in Harare are highly unsustainable environmentally because they do not allow the wetlands to replenish and recover. Morelli (2011) states that uses that are intense to the extent of making it impossible for nature to replenish are very unsustainable from both the environmental and economic point of view. Wetland connectivity also matter, and it has been affected by urban utilities, agriculture and housing development. The disintegration of wetland spaces through establishment of roads, sewer and water lines affect aquatic species such as fish. This is because they cannot cross from one wetland to the next hence their food supply is limited to the wetlands they are located.

Discussion

Institutions governing wetlands are significant in maintaining and restoring wetlands integrity because they put in place appropriate measures to manage, utilize, improve and protect wetlands ecosystems. It is through these institutions that rules governing wetland resource use, control and management are shaped. The success of these institutions and legal frameworks lies in the synergy that exist amongst policies, priorities and objectives that they formulate. The effectiveness of legal and institution frameworks and systems in governing wetlands lies in their ability to effectively manage these ecosystems instead of just playing a preservation role. It is also important to note that the success of institutions is also hinged on their ability to fulfil their mandate and this largely depends on power relationships, the source of mandate and political rightness or acceptability. There is also need that actions at all levels and by all players be synthesized into the overall wetlands' management mandate if the effective protection and management wetlands is to be fully realised.

As discussed above, legislative deficiency and fragmentation is one major cause that is leading to a continued loss of wetlands right in the face of stewards and custodians of wetlands. Limited recognition of ecologically sensitive areas in the design manuals used

in planning also led to all reserved land being termed open spaces. Calling undeveloped land, open spaces instead of wetlands or ecologically sensitive areas may mistakenly attract uses that are destructive to the ecological systems of the wetland. In addition to that, urban development in some parts of Harare is administered using Town Planning Schemes and Local Development Plans. These are legally binding documents and plans whose stipulations should be followed resolutely. However, most Town Planning Schemes were prepared prior to the development of the Environmental Management Act and its allied statutory instruments that's protects wetlands. This means that it was all in the hand of the then Urban Planners to protect wetlands as open spaces. This was done at their own discretion of what they would zone open spaces. This is evidenced by the fact that some of the areas that are zoned residential according to those planning schemes are actually swampy and fall into the category of what are called wetlands by the Environmental Management Act.

When development applications are made for development permits on privately owned areas marked as wetlands on the Wetlands Map of Harare but are zoned residential, commercial or industrial in the operative planning scheme, urban planners tend to incline to the dictates of the Regional, Town and Country Planning Act which is the primary act that governs planning. Also, issues of property rights come into play in reinforcing the granting of a permit to develop on controversial land. This is done at the expense of wetlands and this legislative fragmentation becomes a principal cause of the plight of wetlands. Solani (1998) argues that Peru has developed operative master plans and management plans for ecologically sensitive areas that synchronize wetlands protection and spatial development planning. This has helped to save their wetlands and ecologically sensitive areas from destruction from other activities that may be given priority of wetlands. This is the missing link in Zimbabwe that is causing continued loss of wetlands despite the presence of wetlands governance systems.

Furthermore, there is limited legislative guidance as to what uses are permissible on wetlands. The Environmental Management Act authorizes through the Minister of Environment and Climate whether or not a wetland can be used but do not specifically state the nature of uses that can be done on wetlands in their different nature. As a result, permissible uses are not even clear. What is deemed permissible in the understanding of local authority officials is different from that which EMA or Harare Wetlands Trust believes is permissible. This is legislative deficiency which leads to issuance of Licence of Use of wetlands for highly impact activity uses that detrimentally affect the wetlands. The Brazil Federal States has countered this confusion by categorizing their ecologically protected wetlands into permanently protected areas and areas of particular ecological interest. As suggested by Shine and Cyrille (1999), this categorisation has become the first step in developing specific legislations for each category which outline specific rules with regards to permitted and prohibited activities. While Brazil has managed to categorize their wetlands, which resulted in improved protection depending on their category, Zimbabwe has not invested in this and hence wetlands or crucial importance continue to suffer at alarming rates. Besides the 7 Ramsar wetland site category, all

wetlands in Zimbabwe are just classified as wetlands although they have different names and characteristics.

To add to this legislative deficiency, the Environmental Management Agency allows prospective developers of land that they deem wetlands to engage their own private consultancies to carry out Environmental Impact Assessments. This arrangement is irrational and misguiding because the consultant's hands will be tied in a manner that they won't recommend EMA to stop the development since they will be paid by the client. Conflict of interest comes into play and normally, the consultant is forced to recommend in favour of their client who is the developer.

The discussion above shows that urban development planning and environmental protection planning are not synchronized and this causes chaos in the planning for development and protection of wetlands. Harare lacks a gazetted wetland because the one that is being used presently was challenged in court and declared short falling in terms of defining a wetland in scientific terms. To further show that there was a mixture of views and fragmentation of laws, it was opined that the Environmental Management Act (Chapter 20:27) supersedes the Regional Town and Country Planning Act (Chapter 29:12). To the contrary, this opinion was dismissed denounced in another interview where it was stated that those submissions where not supported by any legal document. Urban planners believe that the Environmental Management Act does not say that there should be no development on wetlands but rather suggest that it says development can be done on the condition that one gets a permit from the Environmental Management Agency after carrying out an Environmental Impact Assessment. On the other hand, radical protectionists disregard this claim mentioning that wetlands are natural ecosystems that form part of the urban fabric and their disturbance disturbs the whole urban ecosystems hence they should be left alone and undisturbed.

Conclusion and Recommendations

This chapter has demonstrated that there is institutional multiplicity in wetlands governance in Zimbabwe. The wetlands governance suite is fragmented because there is no clear connection and collaboration of stakeholders together with the laws that they use. The introduction of new laws of environmental protection such as the Environmental Management Act Chapter 20:27 has not been supported by the subsequent alignment to existing laws such as the Regional Town and Country Planning Act Chapter 29:12 which deals with the physical planning of cities. The miscommunication between spatial planning laws and environmental planning laws has caused a situation where the stipulations of a Town Planning Scheme ignores processes which are prescribed as a prerequisite for development by the Environmental Management Act. Furthermore, stakeholders in wetlands protection from the highest inland office to the least have not invested much in developing master and local plans that are centred on ecologically sensitive areas but also incorporating other development plans. Lacking such plans

is causing great confusions and chaos as to what should or should not be done on a particular wetland. These issue among others are causing wetlands destruction despite having a congested wetlands governance suite of professionals, residents, governments, local authorities and international organisations.

Having these conclusions, this study recommends that;

1. There be a comprehensive alignment of laws, regulations, rules and statutes that governs urban development and wetlands protection.
2. Development of nationwide wetlands protection plans and wetland specific operative local plans that specifically stipulates the activities that are permitted or prohibited on each wetland.
3. A proper wetlands governance structure or framework is developed that places all stakeholders at strategic positions in the wetlands protection hierarchy to ensure a common goal of sustainable and wise wetlands management.
4. A zoning and rezoning exercise of wetlands areas be done to ensure that the remaining wetlands are protected.

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Human Health Risk Assessment And Levels of Exposure to Bisphenol A From Selected Hot Spots in The City Of Harare, Zimbabwe

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Abstract

Bisphenol A (BPA) is a persistent organic pollutant of environmental concern. It is an endocrine disrupter with several adverse effects on humans including hormone dependent cancers, obesity, infertility, aggressive behaviour, and early onset of puberty. Thus this study assessed levels of human exposure to BPA in the city of Harare. Samples were collected from hot spots in January–March of 2019. The BPA was extracted by liquid-liquid extraction using dichloromethane from bottled water, tap water, borehole water and toys. Solid phase extraction was used to extract analyte from surface water as well as soil using C-18 sorbents. The levels of BPA were determined using gas chromatography coupled to flame ionization detector using an external calibration method. Bisphenol was observed in most of the selected hot spot samples in low to high levels showing that there is potential human exposure to it. The average concentration of BPA was 0.0776 µg/L and 0.0040 µg/L for outdoor bottled water and indoor bottled

water respectively. Outdoor bottled water for all the brands showed higher levels of BPA concentrations. Tap and borehole water average levels were 0.0084 and 0.0726 µg/L. Levels in thermal paper was 0.2778 µg/kg while in baby toys and drinking bottles was < 0.01 µg/kg. The levels of direct exposure were below the no observed adverse effect level (NOAEL) at 5 mg/kg /day. The BPA levels were found to be significantly higher than the maximum permissible safety levels for Pomona dumpsite (0.3361 µg/kg) and Mukuvisi River (316.994 µg/kg). The results show potential exposure to low and indirectly medium levels of BPA. Thus efforts should be made to reduce products consisting of Bisphenol since even low levels are considered to be a potential danger to humans.

Keywords: Bisphenol, exposure routes, level of exposure, Health risk

1.0 Introduction

Bisphenol A (BPA), 4, 4'-(1-methylethylidene bisphenol, CAS no. 80-05-7 molecular formula C15H16O2 is a chemical which is produced in high doses in industries (Ou et al., 2016). It is used in consumer products meant for food, water and beverages and epoxy resins to improve physical properties like transparency, resistance, hardness and thermal stability (Le et al., 2008). It is classified worldwide by the Stockholm Convention on Persistent Organic Pollutants as a persistent organic pollutant of environmental concern (Wang et al., 2019). BPA is an endocrine disrupter with several adverse effects on humans including obesity, infertility, aggressive behaviour, early onset of puberty hormone dependent cancers such as prostate and breast cancers (Elobeid et al., 2008; Kassotis et al., 2015). It lowers testosterone levels and diminish sperm production in men due to prolonged exposure. In surface waters and leachate water BPA contributes significantly to estogenicity accounting to about 50% of the activity. In has also been linked to feminization of male fish (Belfroid et al., 2002).

BPA exposure occurs when the chemicals leach out from containers to food and water when the containers are exposed to sunlight, heat, washed or stressed by refrigeration (Geens et al., 2011). Another route of exposure (hot spots) is when it leaches out from waste dumps into surface waters and end up into domestic water because current sewage and water treatment works cannot deal adequately with BPA (Vandenberg et al., 2013; Ye et al., 2012). Hotspots are areas or places where the levels of BPA are found to be very high due to some activities that promote the accumulation of BPA in that area. Bisphenol A does not occur naturally but has become ubiquitous in the environment as a result of its high production, consumption, and subsequent environmental introduction (Tsai, 2006). Environmental sources of BPA can be classified as pre-consumer and post-consumer products. Pre-consumer sources include those attributed to the manufacture of BPA and BPA containing products, where the first source of BPA release is from effluent discharge of manufacturing plants (Staples et al., 1998, Cousins et al., 2008,

Klecka et al., 2009). Transport and processing of BPA and BPA-containing products are additional sources for its pre-consumer release (Staples et al., 1998, Flint et al., 2012). Postconsumer sources include those associated with disposal or waste including effluent discharge from municipal wastewater treatment plants (WWTP), leaching from landfills, combustion of domestic waste, and degradation of plastics in the environment Teuten et al., 2009, Fu and Kawamura, 2010, Flint et al., 2012). I Fu¨rhacker et al., (2000) reported that 90% of BPA is removed during wastewater treatment in a plant located in southern Austria. However, despite efforts to treat BPA, detection in the environment continues to be reported (Fromme et al., 2002, Mussolf et al., 2010, Xu et al., 2014). According to Environmental Working Group, (2010), and Welshons et al., (2014), thermal paper is a potential source of BPA. Landfills in Pomona as well as dumping sites around Harare where wastes are placed might pose a lot of exposure to BPA to residence of the City. Also Crowborough, Donnybrook, Zengeza and Sewage Treatment Works will provide the contaminants to the rivers supplying Harare like Manyame. Lake Chivero and Marimba. This occurs when rain water washes all the leachate containing some BPA into rivers which supply water to residence of Harare. Thus the goal of the study was to assess levels of BPA at potential exposure routes in Harare and determine the potential of human exposure and health risk by comparing with safe recommended daily intakes.

2.0 Materials and methods

Materials

BPA (GC grade >97%) was purchased from Sigma-Aldrich (Germany). Dichloromethane for GC analysis at extra pure grade was purchased from Merck, Germany. Strata C18-SPE Column obtained from Sigma Aldrich, Germany. Silica (60-120 mesh) for cleaning of samples was purchased from Sigma. A Mettler balance (AT261) was used to find the masses of soil sediments and soil samples. Anhydrous sodium sulphate for drying solvent extract prior to GC analysis was of AR grade, purchased from Sigma Aldrich Germany. Bottled water samples were purchased from supermarkets and stores around Harare Urban.

Sample preparation for bottled water

The sampling was carried out in January 2019, which was a wet season of the year. It was the rainy season of the year and there was high drainage of surface water and it was generally cool weather. A set of 3 x 500 ml different brands each of bottled water were purchased from indoor water, while the second set (3 x 500 ml, of the same brands as those in the first set) were purchased from among those sold outdoors. In each case, water in the bottles was immediately extracted and analysed. Three water bottles per brand were used in the analysis. Liquid-liquid extraction with dichloromethane (3 x 50 ml) was employed for the isolation of BPA. The extract was concentrated under a gentle stream of nitrogen.

Determination of Bisphenol A in processed bottled water

Gas chromatography/ Flame ionization detector (GC-FID) analysis of the BPA from water samples was carried out using a Thermo Scientific Gas Chromatography Trace 1300 with and Auto sampler. Nitrogen was used as the carrier gas with a constant flow rate of 0.1 ml/min. The FID interface temperature was at 150 °C. The linearity of the method was tested with an external calibration standard curve at seven different concentrations within the range of 0-2 mg/L. Using the GC-FID data, the peak areas of each standard and their respective standards was calculated for each concentration. Typical GC chromatography peaks obtained during the analysis are shown in Fig 1.

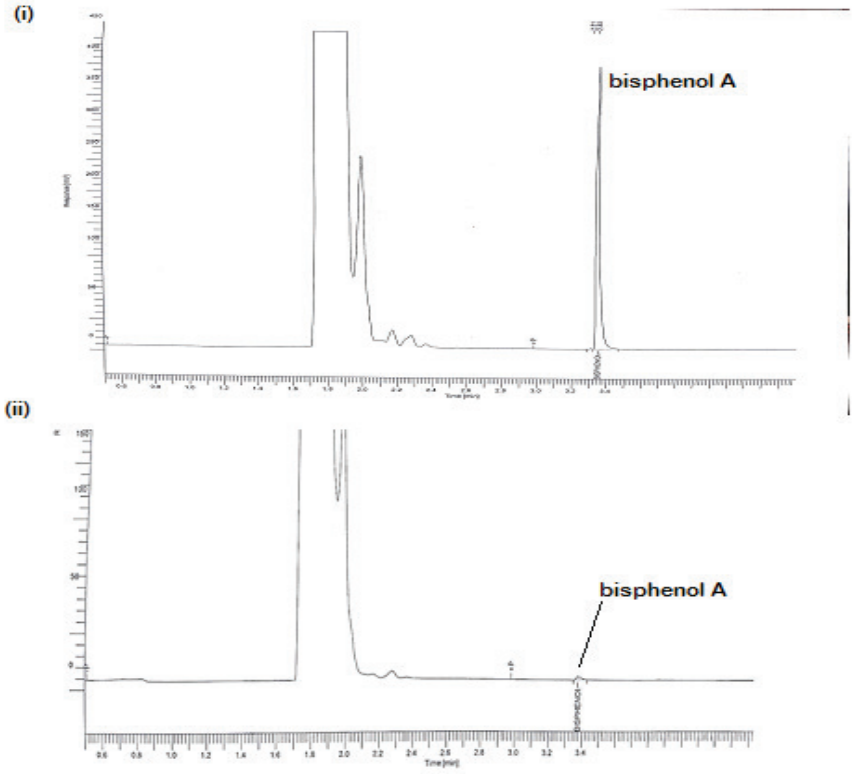

Fig 1. Typical chromatograms obtained for (i) standard water (ii) for surface water

Sample collection of surface water samples, soil samples, and sediment
Surface water was collected from Mukuvisi and Marimba Rivers see Table 1. Tap water and borehole was collected randomly from Budiriro high density suburbs. The suburbs were characterized by sewer and water pipes bursts. This was done using 2L x 3 sterilized

glass containers from five different households. Soil samples were collected randomly from five different places at Pomona dump sites in the order of 5 g x 3 from 2 m depth surface 0.5 m and 1m. Sediment sample was collected as 5 g x 3 samples from Mukuvisi and Marimba River. The samples were collected in sterile glass containers previously washed with ethanol to stop the decomposition of bisphenol A before analysis.

Table 1. Characteristics of surface water sampling sites.

SAMPLING SITE	SAMPLES	CHARACTERISTIC OF SITE
Marimba River	5	The river drains the City of Harare and discharge into Lake Chivero. Receives discharges from the Workington Industrial Area and sewage effluents from Crowborough Sewage Treatment Works
Mukuvisi River	5	River passes through Harare town and Mbare along many dumpsites.
Pomona dump site	5	It is where most of the dumping of plastic and other wastes are placed. The leachate will enter into the soils below.
Bottled water	10	Bottled water from registered and unregistered companies.
Budiriro	1	High density suburb tape water. Place characterised by, sewer and water pipe burst

Solid phase extraction of BPA from environment samples

C18-SPE column was conditioned with 2 ml dichloromethane and 2 ml sterile distilled water. Sewage and river water samples were passed through the column manually and allowed to dry at 40 0C for 4 hrs. Then the column was eluted with 2 x 2 ml dichloromethane. Eluted dichloromethane was evaporated to 1 ml and subjected to GC analysis. 100 g of soil and sediment sample was taken in 500 ml Erlenmeyer flask, mixed with 100 ml of dichloromethane and kept in a rotary shaker at 150 rpm for 24 hrs. Sample extracts were passed through 30 cm x 20 mm chromatographic glass column filled with silica and anhydrous sodium sulphate. Just prior to use, the column

containing adsorbent was washed with dichloromethane, then sample extract was eluted with additional 20 ml of dichloromethane.

Gas Chromatography analysis

The eluted sample was concentrated to 1 ml as before and subjected to GC analysis using the Thermos Scientific Gas chromatography Trace 1300 model with flame ionization detector and operating parameters were as follows: Carrier Gas- Ultra Pure Nitrogen, Flow rate of gas- Nitrogen 2.0 ml /min, Flame Source -Hydrogen and Zero air (60ml/min). Injection temperature 275°C Column temperature 240°C, Detector temperature 310°C, Sample injection volume- 1µL.

Sample preparation of BPA from toys and baby bottles

Ten children's toy samples were purchased at ten different toys shops in Harare supermarkets and toy shops or stores. Ten children`s milk bottles were purchased from ten different supermarkets and shops in Harare central business district. The extraction procedure used was intended to simulate the contact route through which children were likely to encounter BPA. The toy samples were immersed in 800 mL of distilled water, at 40 ºC for 24 hours. After this extraction process, the BPA quantity passed into distilled water was analyzed through Gas chromatography / FID as before.

Determination of Bisphenol A in thermal paper.

The study looked at ten thermal paper receipt samples collected from various workplaces randomly in Harare. Bank account receipt, bank card receipt, ATM receipt, lottery ticket, gift store receipt, gas station receipt, restaurant receipt, and four shopping mall receipts. Thermal printing paper was identified by its ability to darken upon heating. The samples were analyzed as soon as they were collected. 20 mg of thermal paper receipt samples were cut into small pieces and extracted for 60 minutes in 50 mL of dichloromethane at room temperature. After this extraction process, the BPA quantity passed into dichloromethane was analyzed through Gas chromatography / FID.

Quality assurance and control issue

Strict quality control protocols were followed. All water sampling containers were sterilized by soaking in 5% HNO3 for 24 hours. Containers were washed with a detergent and rinsed using distilled water followed by washing the glassware with dichloromethane and left in a furnace at 500 °C for 2 h. Glassware and solvents were carefully handled to avoid contamination. Reagent procedural blanks were regularly analyzed and all data presented in the study was collected for blank values to ascertain accuracy of analysis. At weighing stage analytical balance were calibrated with standard weights before readings were taken. The percent relative standard deviation (RSD %) was taken as the measure of precision of the method and preliminary results showed an RSD of below 15% which was considered to be precise. Percentage recoveries were within the accepted range of 80-120% from spiked soil and environmental water samples.

Statistical Analysis

Data was computed as mean ± standard deviation of replicate samples and analyzed using a on sample t-test using 0.05 level of significance.

3.0 Results and discussion

Levels of Bisphenol A in the selected hotspots are shown in Table 2-7 with highest levels being found in Mukuvisi River sediment, 316.9942 ± 0.0004 µg/kg and water, 5.6723 ± 0.0006 µg/L. The river passes through Harare town and Mbare along many informal waste dumps. Since Bisphenol A does not exist naturally the results shows that level of pollution is high in this area. The Bisphenol A found in the river might have migrated from polycarbonates and epoxy resin which are used in large quantities in this area. According to Huang et al., (2014) bisphenol A contamination was much higher in industrial and commercial areas compared to other regions. The results shows that Bisphenol A bind tightly to sediment and has a potential to bio-accumulate in aquatic living organisms. According to Porcel et al., (2009), sediments are good adsorbents of phenolic compounds due to their high surface area and surface activity.

Table 2 levels of Bisphenol A in processed bottled water

Manufacturer,	Concentration/ *µg/L*
Open market	
A	0.0713 ± 0.0005
B	0.0678 ± 0.0006
C	0.0943 ± 0.0002
Inside	
A	0.0008 ± 0.0000
B	0.0090 ± 0.0000
C	0.0021 ± 0.0003

Levels of Bisphenol was also found in appreciable levels in Pamona dumpsite soil. The levels at the depth of 0.5 m were higher than levels at 1 m depth. This shows that Bisphenol A remains on the top soil therefore has potential to bio-accumulate in plants thereby can be transmitted to humans through the food chain (Yamamoto et al., 2001). Their results shows that landfills leachate had a high level of bisphenol A 1.3-17200 µg/L, which they attributed to leaching out from plastic debris.

Table 3 levels of Bisphenol A in tap water and borehole water

House	Concentration/ *µg/L*
A	0.0060 ± 0.0003
B	0.0090 ± 0.0000
C	0.0081 ± 0.0000
D	0.0096 ± 0.0000
E	0.0093 ± 0.0000
Borehole water	0.0726 ± 0.0000

Table 4 levels of Bisphenol A in surface water and sediment

Sample	Concentration/ *µg/kg*
Mukuvisi river sediment	316.9942 ± 0.0004
Mukuvisi river water	5.6723 ± 0.0006
Marimba river sediment	0.0097 ± 0.0000
Marimba river water	0.0056 ± 0.0000

Table 5 levels of Bisphenol A in Pamona dump site soil

Location and depth	Concentration/ *µg/kg*
A (0.5 m)	0.3215 ± 0.0004
A (1 m)	0.0244 ± 0.0002
B (0.5 m)	0.3116 ± 0.0003
B (1 m)	0.0005 ± 0.0000
C (0.5 m)	0.3317 ± 0.0006
C (1 m)	0.0056 ± 0.0001
D (0.5 m)	0.2215 ± 0.0002
D (1 m)	0.0071 ± 0.0002
E (0.5 m)	0.3361 ± 0.0005
E (1 m)	0.0095 ± 0.0002

Bisphenol was also found in low levels in processed bottled water and tap water. This shows that Bisphenol A is migrating from the containers to the water or it is not being removed during processing of the water. The Bisphenol A was found in higher levels in bottled water stored outside than that stored in doors showing that the bisphenol might be migrating from the containers and the process is increased if bottled water is kept outside. Bisphenol was also detected in selected toys and thermal paper.

Table 6. Levels of Bisphenol A in toys and baby bottles

Toy Sample	Concentration/ ppm	Milk bottles	Concentration/ *µg/kg*
A	0.0008 ± 0.0000	A	ND
B	0.0005 ± 0.0000	B	ND
C	0.0081 ± 0.0000	C	ND
D	ND	D	ND
E	ND	E	ND
F	0.0077 ± 0.0000	F	ND
G	0.0006 ± 0.0000	G	ND
H	ND	H	ND
I	ND	I	ND
J	ND	J	ND

Table 7. Levels of Bisphenol A in thermal paper

Toy Sample	Concentration/ *µg/kg*
A	0.2778 ± 0.0000
B	0.2776 ± 0.0006
C	0.1676 ± 0.0001
D	0.2771 ± 0.0000
E	0.2778 ± 0.0002
F	0.0088 ± 0.0001
G	0.0016 ± 0.0000
H	0.2248 ± 0.0001
I	0.2117 ± 0.0002
J	0.2611 ± 0.0006

The tolerable daily intake (TDI) of BPA set by the European Food Safety Authority (EFSA) has earlier been 50 µg BPA/kg bw/day and was temporarily lowered in 2014 to 5 µg BPA/kg bw/day (European Food Safety Authority, 2014). In January 2015 EFSA lowered the TDI and it was determined to 4 µg BPA/kg bw/day (European Food Safety Authority, 2015). Results show that babies and young children are also exposed to low levels of BPA. The levels of direct exposure are below the no observed adverse effect level (NOAEL) at 5 mg/kg bw/day as well as below the ADI of 50 µg/kg/day in the diet like i.e. indoor bottled water.

4.0 Conclusion

Table 7. Levels of Bisphenol A in thermal paper

Toy Sample	Concentration/ *µg/kg*
A	0.2778 ± 0.0000
B	0.2776 ± 0.0006
C	0.1676 ± 0.0001
D	0.2771 ± 0.0000
E	0.2778 ± 0.0002
F	0.0088 ± 0.0001
G	0.0016 ± 0.0000
H	0.2248 ± 0.0001
I	0.2117 ± 0.0002
J	0.2611 ± 0.0006

Low - medium levels of Bisphenol A were found from the selected hot spots including tap water, thermal paper, and toys and drinking bottles for children as well as bottled water from different manufacturers. In indirect exposures like river water, dumping sites and thermal paper, the levels of exposures was high. Baby toys and drinking bottles showed lower exposure of

children to BPA. Pomona dumping site was found to contain appreciable levels of BPA which makes it a hotspot for BPA contamination into river waters, tap water as well as borehole water.

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Inhibition effects of heavy metal and nutrient concentrations on photosynthetic pigments production in green algae Spirogyra sp.

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Abstract

Anthropogenic activities greatly contribute pollutants such as heavy metals to the aquatic environment. Documented empirical evidence of the effect of heavy metals on aquatic systems is still scanty especially in under studied regions such as Africa. This study was done to investigate the effect of copper and zinc concentrations on the primary productivity of green algae, Spirogyra. This was achieved by spectrophotometric estimation of photosynthetic pigments (chlorophyll-a, chlorophyll-b, and carotenoids) of algae cultured at different concentrations of both copper and zinc. The first stage of the experiment was to optimize nutrient requirements in growth media of Spirogyra, by culturing algae at three different concentrations of compound D (N7: P14: K7) fertilizer. The results showed that the concentration of photosynthetic pigments significantly decreased ($p < 0.05$) with an increase in nutrient concentration. The second stage

of the experiment was to expose cultures of Spirogyra to different concentrations of zinc and copper. The results showed that the concentration of photosynthetic pigments significantly decreased ($p < 0.05$) with an increase in copper and zinc concentrations. Photosynthetic pigment concentrations cultured at concentrations > 25 mg L^{-1} of both copper and zinc were significantly lower than those of the control (Dunnett's test, $p < 0.05$). At low concentrations (< 30 mg L^{-1}), Cu had higher effects on carotenoid concentrations than Zn. The results also showed that copper was more toxic to Spirogyra compared to zinc. These results show that chlorophyll pigments inhibition by Cu and Zn can be used as a biomarker of exposure. To minimise metal pollution in the aquatic environment, there is a need for industrialists to keep effluent quality at standards recommended by local authorities such as the Environmental Management Agency (EMA).

Keywords - *carotenoids, chlorophyll-a, chlorophyll-b, compound D, heavy metals, primary production*

1.0 Introduction

Persistence of heavy metals in aquatic systems is a major threat to their sustainability (Gavrilescu, 2009). Sources of heavy metal pollution in aquatic ecosystems can be anthropogenic (e.g. industrial activities, mining, and urban runoff) or natural processes (e.g. weathering and volcanic eruptions) (Liu et al., 2019; Bere et al., 2016; Tchounwou et al., 2012). Furthermore, pollution of the aquatic environment with metals exposes aquatic species and humans to health risks (Ezemonye et al., 2019; Sankhla et al., 2016). Non-essential heavy metals such as cadmium, lead, chrome and arsenic directly affect aquatic species because they bio-accumulate in plant and animal tissues (McEneff et al., 2017). In addition, heavy metals show harmful effects on aquatic organisms at very low concentrations (Ali et al., 2019). Their effect on the aquatic environment is through the inhibition of primary productivity (Chu et al., 2019). The effects of heavy metal exposure on algae include reduced cell division, inhibited growth rate, restrained enzyme activity, and reduced photosynthesis (Ali et al., 2019). Since growth reflects the metabolism of the cell, it can be used as a key indicator of the toxicity of heavy metal ions in microorganisms.

Related studies have shown that high concentrations of heavy metals in the aquatic environment exert toxic effects on the photosynthetic pathway of algae (Chu et al., 2019). The toxicity of heavy metals to algae primarily results from metals binding to sulphydryl groups in proteins, or the disruption of protein structure (Arunakumara and Zhang, 2008). Other studies have shown that heavy metal toxicity is, at least in part, related to the oxidative stress induced in living systems (Ercal et al., 2001; Patra et al., 2011). Heavy metals can break the oxidative balance of the algae, inducing antioxidant enzymes such as superoxide dismutase, glutathione peroxidase and ascorbate peroxidase (Arunakumara and Zhang, 2008). The amount of oxidized proteins and lipids in the algal cells thus indicates the severity of metal stress.

Heavy metal ions such as Pb^{2+} can bind to thylakoid membranes, altering their structure and eventually lead to their malfunctioning (Teige et al., 1990, Heng et al., 2004). Other heavy metals have been shown to destroy chloroplasts at high concentrations (Teige et al., 1990; Aravind and Prasad, 2004). For example, Cd^{2+} disorganizes chloroplasts causing damage to photosynthetic pigments (Baszyński, 2014). Consequently, photosynthetic activity could be severely affected, causing growth inhibition or complete death of the cells. In addition, heavy metal ions interrupt routine metabolic processes by competing for protein binding sites or activating various biological reactive groups, causing poor or no growth of algae (Narula et al., 2015).

Spirogyra sp, (*Spirogyra* hereafter) are a worldwide freshwater taxa found in relatively clear eutrophic water, developing slimy filamentous green masses (Novis, 2004). The genus is one of the most ecologically important primary producers in aquatic food webs (Webster et al., 2005). It also plays a role in the regulation of methane production in the aquatic environment (Mei et al., 2020; Liang et al., 2016). Other studies suggest that some species of *Spirogyra* could be used for human nutritional, pharmaceutical and cosmetic products (Tipnee et al., 2015). *Spirogyra* can also be used for bioremediation through bio-sorption of metals (Gupta and Rastogi, 2008; Leong and Chang, 2020; Nimisha and Joseph, 2020). However, there is still a research gap on the use of *Spirogyra* as a model organism in metal exposure studies. This study investigated the effect of copper and zinc on the primary productivity of the algae *Spirogyra* by measuring the concentration of photosynthetic pigments as a proxy for algal growth. Cu and Zn are essential metals that are not only key components of electron transport chains but also of coenzyme factors that play important roles in photosynthesis and respiration (Droppa and Horváth, 1990). We hypothesized that the presence of Cu and Zn in the aquatic environment at extreme concentrations reduces the growth of *Spirogyra* through the inhibition of photosynthetic apparatus. The general aim of the study was to determine the effects of heavy metal (Cu and Zn) concentrations on the production of photosynthetic pigments by *Spirogyra.* This was achieved by first optimizing the nutrient requirements for the growth of *Spirogyra* and then exposing the algae to different concentrations of Zn and Cu to determine their effect on the production of three photosynthetic pigments (chlorophyll-a, chlorophyll-b, and carotenoids).

2.0 Materials and Methods

2.1 Optimisation of nutrients in algae growth media

The first stage of the experiment was to determine the most suitable media for the growth of *Spirogyra*. An inorganic compound D fertilizer with nutrient composition of N.P.K. (7:14:7) was used as a growth medium for the experiment. Fertilizer grains were ground using mortar and pestle and 2 g of the ground powder were dissolved in 400 ml of distilled water to make a 5000 mg L^{-1} stock solution. Three different concentrations (100, 200 and 300) mg L^{-1} of growth media were prepared by serial dilutions of the stock solutions. Similar studies have used NPK concentrations ranging from 80 – 240 mg L^{-1} (Nurmarina et al., 2018; Davies et al., 2006; Nguyen et al., 2014). After the dilutions,

250 mL of each solution were poured into glass jars and replicated three times. In each replicate, 2 g of *Spirogyra* filaments were added. The experimental jars were incubated at room temperature and exposed to variable light to simulate day and night with two fluorescents lamps (6400K 8W) for 7 days (Li et al., 2012). Photosynthetic pigments were extracted from algae and quantified for each experimental unit before the experiment and after 7 days. The most suitable concentration of media used for the experiment was the one that enabled algae to have high concentrations of photosynthetic pigments.

2.2 Experimental setup

The second stage of the experiment was to culture the algae in four heavy metal concentrations of copper (CuSO4·5H2O) and zinc (ZnSO4·7H2O) compounds. The optimum concentration of 100 mg L^{-1} from the optimization experiment was used as growth media. This was followed by preparing Cu and Zn metal solutions separately with concentrations of 25 mg L^{-1}, 50 mg L^{-1}, 75 mg L^{-1} and 100 mg L^{-1} (Takamura et al., 1989). Metal solutions were made by dissolving 1 g of each metal sulphate in 200 mL of distilled water to make a 5000 mg L^{-1} stock solution. Five replicates of each metal concentration were placed in separate 250 mL jars and mixed with 2 g of *Spirogyra* filaments. Controls with no metal sulphates were included. The cultures were then incubated at room temperature for 7 days illuminated by white fluorescent tubes on a cycle of 12 hrs light and 12 hrs dark (Li et al., 2012). The light intensity was 50-100 mol photon m^{-2} s^{-1}. After 7 days, the photosynthetic pigments were extracted and quantified.

2.3 Extraction and quantification of photosynthetic pigments

After 7 days of incubation, 0.5 g of *Spirogyra* filaments from the experimental units were weighed and ground in a chilled mortar and pestle in 5 ml of 80% acetone. The mixture was filtered with a Whatman filter paper and centrifuged for 10 min at 6500 rpm at 4 ˚C (Sumanta et al., 2014; Shoaf and Lium, 1976). A similar procedure was followed to extract the photosynthetic pigments from the optimisation experiment.

Chlorophyll analysis was done following Sumanta et al. (2014), briefly, 0.2 mL of the extracted pigment were added to 3.8 mL of 80% acetone in a test tube. The spectrophotometer was blanked with 80% acetone and concentrations of chlorophyll a, chlorophyll b and carotenoids were measured at wavelengths of 663 nm, 645 nm and 470nm respectively (Shoaf and Lium, 1976; Sumanta et al., 2014). The final concentration of each pigment was estimated as follows:

$$Chl - a = 1225A663.2 - 2.79A646.8$$

$$Chl - a = 1225A663.2 - 2.79A646.8 \text{ .....(1)}$$

$$Chl - b = 21.5A646.8 - 5.1A663.2$$

$$Chl - b = 21.5A646.8 - 5.1A663.2 \text{ .....(2)}$$

$$Carotenoids = \frac{1000\mathbf{A}470 - 1.82Chla - 85.02Chlb}{198}$$

$$Carotenoids = \frac{1000\mathbf{A}470 - 1.82Chla - 85.02Chlb}{198} \quad \text{.....(3)}$$

(Shoaf and Lium, 1976)

where *Chl-a* = chlorophyll A; *Chl-b* = chlorophyll B; **A**663.2, **A**646.8 and **A**470= absorbance at 663.2 nm, 646.8 nm and 470 nm, respectively.

2.4 Data analysis

For the optimization experiment, a paired t-test was used to determine the effect of different concentrations of compound D on the photosynthetic pigment concentration. A Two-Way Analysis of Variance (ANOVA) was used to test for the effect of metal concentration and metal type on photosynthetic pigments. Tukey multiple comparisons were done to identify differences among the pigment concentrations relative to the type of metal where ANOVA showed significant differences. Where ANOVA showed significant differences, Dunnett's tests were further performed to identify the metal concentration that differed significantly from the control. Linear regression analysis was also done to predict the concentration of the photosynthetic pigments at different heavy metal concentrations. All data were analyzed in R (version 3.5.1) (R Core Team, 2015).

3.0 Results

3.1 Optimisation of nutrients in growth media

The concentration of photosynthetic pigments in *Spirogyra* decreased with an increase in nutrient concentration of the culture media (Figure 1). The highest concentrations of Chl-a (2.97 ± 0.08) ug/mL and Chl-b (1.40 ± 0.14) ug/mL were observed in algae cultured in 100 mg L^{-1} of compound D, while the lowest concentrations of Chl-a (0.79 ± 0.18) ug/mL and Chl-b (0.42 ± 0.07 ug/mL) were observed in 300 mg L^{-1} compound D. Similarly, the highest concentration of carotenoids (1.88 ± 0.85 ug/mL) was observed in algae cultured in 100 mg L^{-1} compound D and the lowest concentration (0.66 ± 0.06 ug/mL) in 300 mg L^{-1} compound D. One way ANOVA revealed significant differences in the concentrations of photosynthetic pigments : Chl-a $F(1.7) = 49.75$, $p = 0.002$, Chl-b $F(1.7) = 33.74$; $p = 0.007$ and carotenoids $F(1.7) = 49.75$; $p = 0.001$ cultured at different concentrations of compound D. A Tukey post-hoc analysis showed that the concentration of photosynthetic pigments produced by algae cultured in 100 mg L^{-1} of compound D were significantly higher than those of algae cultured in 200 mg L^{-1} and 300 mg L^{-1}. This indicated that *Spirogyra* grows best at 100 mg L^{-1} compound D and this concentration was used for further analyses. A paired t-test also showed that there were significant differences in mean pigment concentration before and after treatment with compound D: Chl-a ($t = -14.97$, $p = 0.004$), Chl-b ($t = -14.63$, $p = 0.005$) and carotenoids ($t = -9.02$, $p = 0.012$).

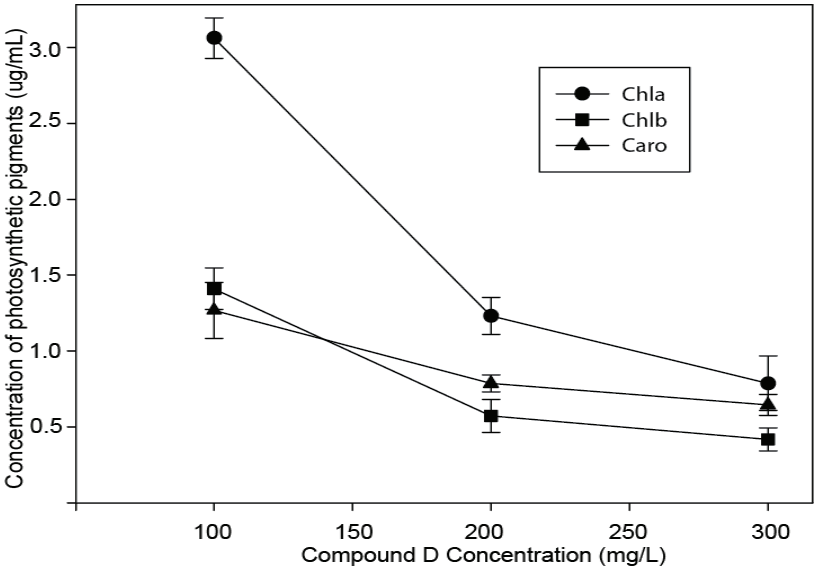

Figure 1. Effect of compound D concentration on pigment concentration in Spirogyra after 7 days of incubation. Chl-a – chlorophyll a, Chl-b – chlorophyll b and Caro – carotenoids

3.2 Effect of Cu and Zn on chlorophyll-a concentration

Linear regression revealed a significant negative linear relationship between Zn and Chl-a concentration ($\beta = -0.004$, $p < 0.001$) indicating that Chl-a concentration decreased by 0.004 ug/ml for every 1 mg L^{-1} increase in Zn concentration. Zn concentration explained about 82% of the variation in Chl-a concentration $F(1.23) = 111.2$, $p < 0.001$, adjusted $R^2 = 0.82$ (Figure 2a). The highest concentration of Chl-a (3.06 ± 0.09 ug/mL) was observed in the control where Zn was not added while the least concentration (2.58 ± 0.06 ug/mL) was observed at 100 mg L^{-1} Zn. A similar trend was observed for Cu with a significant linear relation between Cu and Chl-a concentration ($\beta = -0.006$, $p < 0.001$) indicating that Chl-a concentration decreased by 0.006 ug/ml for every 1 mg L^{-1} increase in Zn concentration. Zn concentration explained about 85% of the variation in Chl-a concentration $F(1.23) = 139.7$, $p = 2.99 \times 10^{-5}$, adjusted $R^2 = 0.85$ with an increase in Cu concentration (Figure 2a). There was a significant difference in Chl-a concentration among concentrations of Cu and Zn (two-way ANOVA, concentration $F(1.4) = 92.5$, $p = 0.001$) and between metal type (two way ANOVA: $F(1.4) = 29.72$, $p = 0.001$). The Dunnett's test showed that mean Chl-a concentrations of algae cultured at 25 mg L^{-1}, 50 mgL^{-1}, 75 mg L^{-1} and 100 mg L^{-1} of both Cu and Zn significantly differed from that of the control (0 mgL^{-1}).

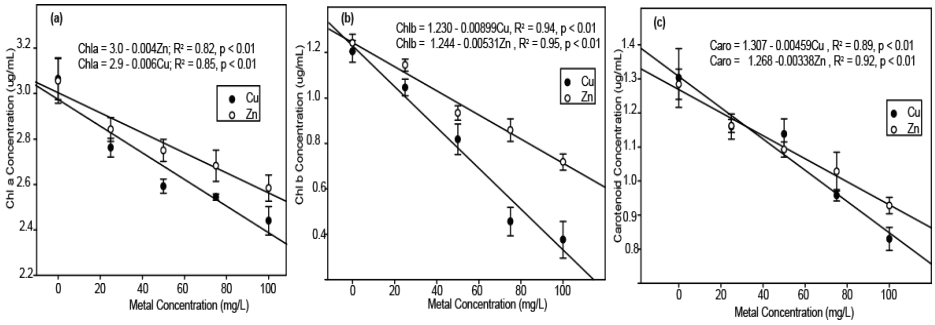

Figure 2. Effect of five different concentrations of Cu and Zn on (a) Chlorophyll-a, (b) Chorophyll-b and (c) Carotenoids concentration in Spirogyra after culturing for 7 days. Chl-a – Chlorophyll-a, Chl-b – Chlorophyll-b and Caro- Carotenoids

3.3 Effect of Cu and Zn on chlorophyll-b concentration

Linear regression analysis indicated that Zn concentration significantly predicted the concentration of Chl-b (β = -0.0053, p< 0.001), with Chl-b concentration decreasing by 0.0053 ug/ml for every 1 mg L^{-1} increase in Zn concentration. Zn concentration explained about 95% of the variation in Chl-b concentration $F(1,23) = 430.1$, $p < 0.001$, adjusted $R^2 = 0.95$ (Figure 2b). The highest concentration of Chl-b (1.24 ± 0.04 ug/mL) was observed in the control while the least concentration (0.72 ± 0.04 ug/mL) was observed at 100 mgL^{-1} Zn. Similarly, the concentration of Chl-b could be significantly predicted by Cu concentration (β = -0.009, $p < 0.001$) indicating an decrease of 0.009 ug/ml for every 1 mg L^{-1} increase in Cu concentration. Cu concentration explained about 94% of the variation in Chl-b concentration $F(1,23) = 381$, $p < 0.001$, adjusted $R^2 = 0.94$, Figure 2b. The highest 1.20 ± 0.05 ug/mL and lowest 0.38 ± 0.08 ug/mL concentrations of Chl-b were observed in the control and at 100 mg L^{-1} Cu, respectively. There was a significant difference in Chl-b concentration among different concentrations of Cu and Zn (two-way ANOVA: $F(1.4) = 100.3$, $p = 0.001$) and between metal type (two-way ANOVA: $F(1.4) = 62.5$, $p = 0.001$). The Dunnett's test showed that Chl-b concentrations of algae cultured at 25 mg L^{-1}, 50 mg L^{-1}, 75 mg L^{-1} and 100 mg L^{-1} of both Cu and Zn were significantly higher than that of the control.

3.4 Effect of Cu and Zn on carotenoids concentration

Linear regression analysis showed a significant negative linear relationship between carotenoids concentration and Zn concentration (β = -0.0034, $p < 0.001$) indicating a decrease of 0.0034 ug/ml for every 1 mg L^{-1} increase in Zn concentration. Zn concentration explained about 92% of the variation in carotenoids concentration $F(1.23) = 266.9$, $p = 2.2 \times 10^{-5}$, adjusted $R^2 = 0.92$, Figure 2c). The highest concentration of carotenoids (1.28 ± 0.04 ug/mL) was observed in the control and the least concentration (0.93 ± 0.02 ug/mL) observed at 100 mgL^{-1} Zn. A similar trend with Chl-a and Chl-b was observed in

which the concentration of carotenoids significantly decreased with an increase in Cu concentration as determined by linear regression $F(1.23) = 203.9$, $p < 0.001$, adjusted $R^2 = 0.89$. The highest concentration of carotenoids (1.30 ± 0.09 ug/mL) was observed in the control and the least concentration (0.84 ± 0.02 ug/mL) observed at 100 mg L^{-1} Cu. There was a significant difference in carotenoid concentration among different concentrations of Cu and Zn (two-way ANOVA: $F(1.4) = 120.47$, $p = 0.001$ and metal $F(1.4) = 8.92$, $p = 0.005$. A Dunnett's test showed that carotenoid concentrations in algae cultured at 25 mgL^{-1}, 50 mg L^{-1}, 75 mg L^{-1} and 100 mg L^{-1} of both Cu and Zn were significantly different from that of the control. At low concentrations (< 30 mg L^{-1}), Cu had higher effects on carotenoid concentrations than Zn.

4.0 Discussion

4.1 Optimisation of nutrients in growth medium

The results from this study showed that concentration of photosynthetic pigments (chlorophyll-a, chlorophyll-b and carotenoids) in *Spirogyra* decreased as compound D concentration increased in the order 100 > 200 >300 mg L^{-1}. The concentration of photosynthetic pigments at 100 mg L^{-1} compound D from this study were lower than those of similar studies where pigments were extracted from *Spirogyra* harvested from natural eutrophic water bodies: chlorophyll-a (6 ug/ml), chlorophyll-b (3 ug/ml) and carotenoids (1.8 ug/ml) (Tipnee et al., 2015). This suggests an inhibitory or confounding effect of compound D at 100 mg L^{-1} to the growth of *Spirogyra* due to the presence of other elements such as metals that naturally occur in fertilizers. However, chlorophytes are generally more tolerant to high ammonium nitrogen levels, but different strains have significantly different levels of tolerance (Collos and Harrison, 2014). Fertilizers containing nitrogen, phosphorus and potassium (NPK) are a cheap alternative form of culture media because they contain the basic nutrients required for algae to grow (Mahmood and Khudhair, 2017). Empirical studies have shown that increasing the concentration of nitrogen and phosphorus leads to rapid growth of algae (Fried et al., 2003, Wetzel, 2001). This study did not test the independent or interaction effect of each nutrient on algal growth, but it can be concluded that if only one nutrient is substantially increased the other nutrients lacking will limit growth of algae (Sterner et al., 2004). For example, if only nitrogen is present in high concentrations, phosphorus becomes limiting to the growth of algae. Ammonium nitrogen present in NPK is an energy-efficient nitrogen source for algal metabolism (Ruan and Giordano, 2017). However, NPK at high concentrations is less effective on algae biomass due to the effects of NH_3 and NH_4^+ (Collos and Harrison, 2014). NH_3 is the most toxic form of ammonium nitrogen due to its lack of charge and its lipid solubility, allowing it to diffuse across the cell membrane and accumulating in the cells (Markou et al., 2016; Collos and Harrison, 2014). The effects of ammonium nitrogen on photosynthesis are complex, as it not only affects photosystems I and II, but also the electron transport chain, and the oxygen-evolving complex (OEC) (Wang et al., 2018; Markou et al., 2016). NH_3 is a structural analogy of the substrate H_2O and an inhibitor of the water oxidation reaction in photosystem

II hence it can replace the water molecules in the OEC in photosystem II (Hou et al., 2011). Therefore, OEC is the main site of damage by high NH_3 concentration. High concentrations of ammonium are rarely encountered in nature but elevated ammonium concentrations from pollution and other anthropogenic activities may negatively affect primary productivity and other trophic interactions in freshwater ecosystems.

4.2 Effect of copper and zinc on primary productivity of Spirogyra

This study showed that as copper and zinc concentration increased, the concentration of photosynthetic pigments (chlorophyll-a, chlorophyll-b and carotenoids) decreased. Similar studies show that algal cells exposed to heavy metals may suffer serious morphological and biochemical alterations (Taha et al., 2012; DeNardis et al., 2019; Cheng et al., 2016). For example, studies on *Chlorella vulgaris* exposed to various heavy metal concentrations showed a decrease in the algae's chlorophyll content (Ouyang et al., 2012; Kumar et al., 2014). This indirectly influences photosynthesis hence a reduction in chlorophyll content may be used as a biomarker of exposure to heavy metals.

Copper is an essential element required for growth and reproduction in green algae. It plays a role in photosynthesis through plastocyanin production, a protein involved in the photosynthetic electron transport chain and also serves as a co-factor for several enzymes (Guanzon et al., 1994). This study showed that, at higher concentrations, copper is toxic to algae and has an inhibitory effect on the production of photosynthetic pigments. The toxicity of copper at high concentrations is due to the oxidative potential of copper (II) that causes reduction of chlorophyll (Rijstenbil et al., 1994; Buapet et al., 2019). Other studies have shown that copper toxicity results from its reaction with glutathione in the cytoplasm, which leads to oxidation of glutathione and suppression of mitosis (Stauber and Florence, 1987; Chen et al., 2012). Copper may also exert its toxicity in subcellular organelles, interfering with mitochondrial electron transport, respiration, ATP production and photosynthesis in the chloroplast (Adams et al., 2016). Therefore, the concentration of copper must be kept at minimal levels to prevent damage to the cells.

Like copper, zinc is an essential micronutrient in green algae due to its involvement in many physiological processes such as maintenance of plasma membrane stability, enzyme activation, DNA and RNA synthesis (Broadley et al., 2012). The reduction of chlorophyll pigments as zinc concentration increases could be due to its ability to bind SH groups and disruption of the structure of the enzymes responsible for chlorophyll synthesis (Kuriakose and Prasad, 2019). Other studies have shown that higher concentrations of zinc decrease algal growth, mobility, total chlorophyll content, ATPase activity and carotenoid/chlorophyll ratio in microalgae (Monteiro et al., 2011; Samei et al., 2019). Furthermore, studies have shown that the inhibition of algal growth by zinc is mainly due to extracellular than intracellular sources (Gao et al., 2016). Once

zinc is inside the cell, it may be detoxified by binding to thiol-containing proteins such as phytochelatins (Pochodylo and Aristilde, 2017). The toxicity of zinc to green algae is also related to its interference with phosphorous metabolism (Gao et al., 2016). In the presence of phosphorus in the growth media (NPK), the concentration of cellular polyphosphate declines with increasing culture age and a portion of the previously bound intracellular zinc is released into the cell (Sabater et al., 2016). When the quantity of intracellular zinc exceeds a critical threshold, phosphorous metabolism is disrupted, reducing cell division (Kuwabara et al., 1986; Geddie and Hall, 2019).

The results from this study are important in the management of aquatic systems threatened with runoff from agricultural areas. Higher concentrations of nitrates and phosphates in runoff increase algal growth leading to eutrophication of water bodies. Other studies have shown that eutrophic water bodies tend to have less aquatic biodiversity due to the dominance of a few a species (Ansari et al., 2010; Boix et al., 2007). It is therefore important to treat runoff especially from commercial agricultural areas to effluent standards recommended by local environmental management agencies such as Environmental Management Authority (EMA). Although the results from this study can be used as biomarkers of exposure to Cu and Zn, their application in the natural environment may be limited by the confounding effect of other pollutants present in the natural environment. Pollutants in nature rarely occur individually but as a cocktail of different types (Relyea, 2009).

5.0 Conclusions

Overall, results from this study show that primary productivity decreases with an in increase in nutrient concentration and high concentrations of both copper and zinc are associated with significant reductions of photosynthetic pigments in *Spirogyra*. Therefore, there is need to prevent pollution of aquatic ecosystems with heavy metals as this may disrupt trophic interactions through reduced productivity. Future studies should focus on investigating the effect of varying individual nutrient concentration on primary productivity of algae and the interaction effect of nutrients and metal pollutants on algal growth.

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Figure Captions

Fig. 1 Effect of compound D concentration on pigment concentration in *Spirogyra* after 7 days of incubation. Chl-a – chlorophyll a, Chl-b – chlorophyll b and Caro – carotenoids

Fig. 2 Effect of five different concentrations of Cu and Zn on (a) Chlorophyll-a, (b) Chorophyll-b and (c) Carotenoids concentration in *Spirogyra* after culturing for 7 days. Chl-a – Chlorophyll-a, Chl-b – Chlorophyll-b and Caro- Carotenoids

Modelling Non Revenue Water in Municipal Water Supply Systems: An Empirical study of Municipality of Chinhoyi

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Abstract

Non-revenue water (NRW) refers to the difference between the volume of water entering a treated water supply system and billed authorized consumption. International Water Association (IWA) recommends 15% of the system input volume as the maximum standard limit. The key to developing a strategy for management of NRW is to gain a better understanding of the quantities of NRW and the factors which influence its components. Chinhoyi town is experiencing critical water shortages, intermittent supply and low water pressure on customers' taps. This study sought to determine the water balance for the selected District Metered Areas (DMAs), physical losses, commercial losses, total NRW and the factors influencing it and economic losses associated with NRW. The methodology has been abstracted from IWA. NRW across all the DMAs was found to be significantly above the 15% standard ($p = 0.0001$ at $p<0.05$) with an average NRW of 42% of system input volume. The highest NRW level was recorded in Chikonohono (47%) and the lowest in the low density DMA 33%. Physical losses (30%) were found to be contributing more to NRW than commercial losses (12%). Factors influencing NRW were found to be technical and socio-economic with statistically strong and significant

correlations (at $p<0.05$) including pipe bursts and leakages ($r^2=0.946$; $p=0.005$), non-working meters ($r^2=0.995$, $p = 0.0002$) and illegal connections ($r^2=0.973$, $p = 0.002$). Age of water infrastructure had positive but weak and not significant relationship with physical losses ($r^2= 0.336$; $p=0.306$. Municipality of Chinhoyi was also found to be potentially losing 34% (US$38772.50) of its monthly projected revenue from water supply due to NRW. It was concluded that water distribution in Chinhoyi is inefficient based on international standards due to several technical and socio-economic factors and this is economically impacting on the water utility. The study recommend that the water supplier should consider investing in NRW management programs in an economically optimum manner using the baseline information generated from water balances.

Keywords: Non-revenue water, District metered area, Municipality of Chinhoyi

1.0 Introduction

Water - the most vital element of life is becoming scarce with every passing day (Taylor, 2009). Globally, water demand is rising and water resources are diminishing. Water loss from the pipe network, has long been a feature of operations management in all water utilities with a combination of poor infrastructure, poor sanitation, and intermittent supplies often posing a serious health risk (World Water Forum, 2009).

The major challenge affecting water utilities in the developing world is the non-revenue water (NRW), which is considerable difference between the amount of water put into a water distribution system and the amount of water billed to consumers (IWA, 2006). High levels of NRW reflect huge volumes of water being lost through leaks, not being invoiced to customers, or both (Asian Development Bank, 2007). NRW seriously affects the financial viability of water utilities through lost revenues and increased operational costs (Kingdom et al, 2006). This challenge could be the evidence of knowledge gap, policy failure, lack of infrastructure and mismanagement in the context of water supply systems (Mayurakshi and Zahid, 2013).

Based on a study covering 40 water utilities in South-East Asia and the IBNET database on water utility performance covering over 900 utilities in developing countries, the World Bank estimates that the actual figure for overall NRW levels in the developing world is probably in the range of 40 - 50% of the water produced (Asian Development Bank, 2007). Urban Local Authorities are mandated by governments to make adequate provision for the management and maintenance of all municipal water works and construction of new works if need arises for providing supply of suitable water for public and private purposes to meet demand (Institute of economic affairs, 2007). This requires adequate resources which are to be raised from consumers. Inadequacies in management include high proportions of non-revenue water and poor cost recovery leading to commercially non-viable urban local bodies, and inadequate service coverage.

Fueled by rising water treatment costs, recurring drought, depletion of available fresh water supplies, customer backlash from increasing rates, the increasing demand for environmentally-sustainable practices, and the increasing overall strain on municipal budgets, water accountability has become a priority like never before (William and Jernigan, 2009).

According to Farley (2003) the key to developing a strategy for management of NRW is to gain a better understanding of the reasons for NRW and the factors which influence its components. Then techniques and procedures can be developed, and tailored to the specific characteristics of the network and local influencing factors, to tackle each of the components in order of priority. Over the last few decades, there has been a paradigm shift in water management as the perception that freshwater is a free and abundant resource has changed to that of water being an economic good in scarce resource, threatened by depletion and warranting efficient use (Savenije, 2007). Although it is not feasible to eliminate all NRW in a water utility, reducing water losses to 15 per cent of the supplied quantity is widely recommended as the standard (World Bank, 2006).

Despite the fact that many utilities in the developing world have implemented NRW reduction programs with donor funding, in many cases supply is not measured and it is impossible to do water balances. A water balance is a prerequisite for designing a NRW reduction strategy. The quantification of the savings opportunity provides the evidence base for justifying the need for action and the level of resources that should be assigned to the development of a solution. Reduction in NRW could significantly improve service delivery in terms of water supply without any new investments in production facilities or drawing further on scarce water resources.

The problem of water shortage is occurring in many urban centers of the world and Chinhoyi town is not an exception. The town water supplier has often responded to the growing demand by offering the supply-side solution struggling to increase supply. The current water demand for Chinhoyi town is estimated at 30 mega litres per day against a total water supply design capacity of 24 mega litres per day. However, the actual supply currently is around 15 mega-litres per day causing intermittent supply due to capacity deficit. This paper aims to assess NRW in Chinhoyi municipal water supply system. The specific objectives were to determine the Chinhoyi water distribution system water balances for the selected high and low density suburbs, to compute the proportions of physical losses, commercial losses and total NRW, to determine factors attributing to NRW and to calculate the economic value of NRW.

2.0 Study area

2.1 Background on Chinhoyi

Chinhoyi Town is the provincial capital of Mashonaland West Province in Zimbabwe. It lies about 115km north-west of Harare along the Harare - Chirundu road at an altitude of

1145m and receives a total rainfall of about 825 mm per year with annual temperatures varying between 10^0C and 30.6^0C. The population in Chinhoyi Town has been steadily increasing with an approximated 29.5% increase from 55 968 during the 2002 census (CSO 2002) to 79 368 according to the 2012 preliminary census report (Zim Stat 2012). The municipality estimates that there are 14,000 plots (excluding Alaska and Shackleton, where there are 891 and 840 residential plots respectively) (Municipality of Chinhoyi 2012). Medium to low density housing accommodates middle to high income earners in areas that include Orange Groove, Riverside, Mzari, Golf Course, Mapako and part of Ruvimbo. Chinhoyi includes 11 high density low income residential suburbs: Brundish, Rusununguko, Rujeko, Chikonohono, Hunyani, Gadzema, Mpata, Ruvimbo 1 & 2, Katanda, Cold Stream, White City, Cherima, Old Single Quarters, Pfungwa Dzakanaka and Chitambo.

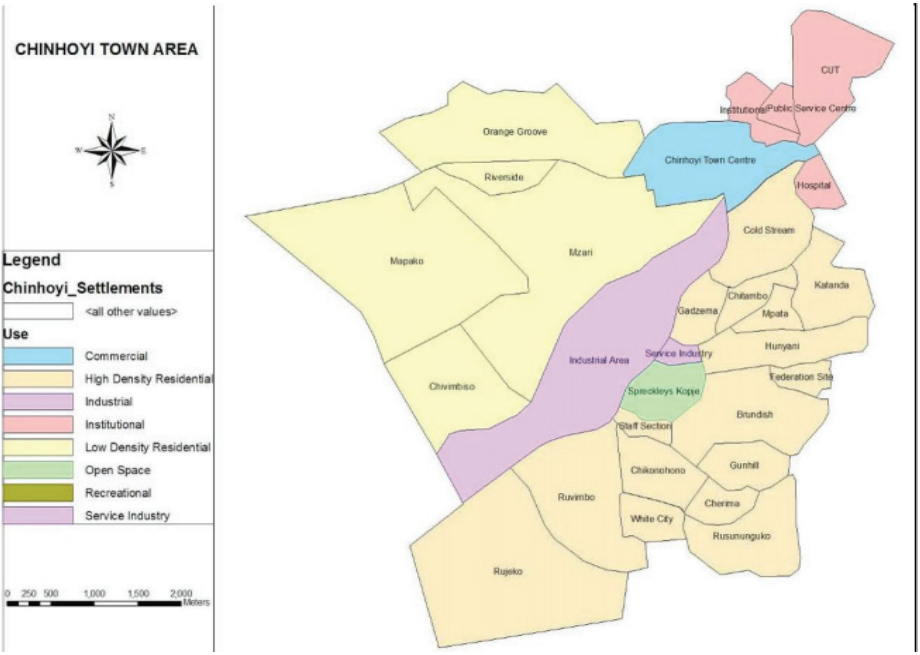


Figure 1: Chinhoyi Town settlements

2.2 Background on water supply and demand in Chinhoyi

Over the years, Chinhoyi municipality, like other urban centres in Zimbabwe, has struggled with water supply to meet the soaring demand. Even in the settlements with infrastructure, it is old and marred by incessant breakdowns both at treatment plants and along the distribution network. The town has two water treatment plants: Hunyani and Hillside water treatment plants. Even assuming the two treatment plants in Chinhoyi are

working, they can only produce 22 mega litres - eight mega litres short of the required 30 mega litres for the whole town. The shortfall is covered through water rationing and supplements from boreholes and other sources. The Chinhoyi municipality currently estimates that demand for water is 30 mega litres per day, but current capacity is often only 15 mega litres per day. Assuming both plants are at full working capacity, output would rise to 22 mega litres per day, still eight mega litres short of the municipality's estimate demand. Chinhoyi residents draw water from metered and communal facilities. It is estimated that there are 17,000 potential water customers of which 13,000 are households, the remainder being institutional, commercial and so on. Chinhoyi municipality carried out an audit in August 2011 which showed that there are 8,979 residents connected to the network.

The distribution network is made up of asbestos cement, uPVC and galvanised iron/ steel pipelines. An infrastructure assessment held by the municipality detail the level of decay and urgent need of system overhaul. The municipality estimates that almost 70 per cent of its residents have access to water, but the profile visits revealed weaknesses of measuring access since most of those who are connected can go for days without water. All the high density low income areas are without water for an average of four days each week. Chinhoyi municipality is losing a lot of water and potential revenue due to pipe bursts and because installed meters no longer work. The municipality also claims that some residents connect to the water supply illegally. A rapid appraisal by the municipality in 2017 estimated that 32 % of water meters are malfunctioning. This scenario seriously compromises the council revenue collection ability considering an extravagant average costs of water treatment approximated to be averaging US$27 000 a month for water treatment chemicals.

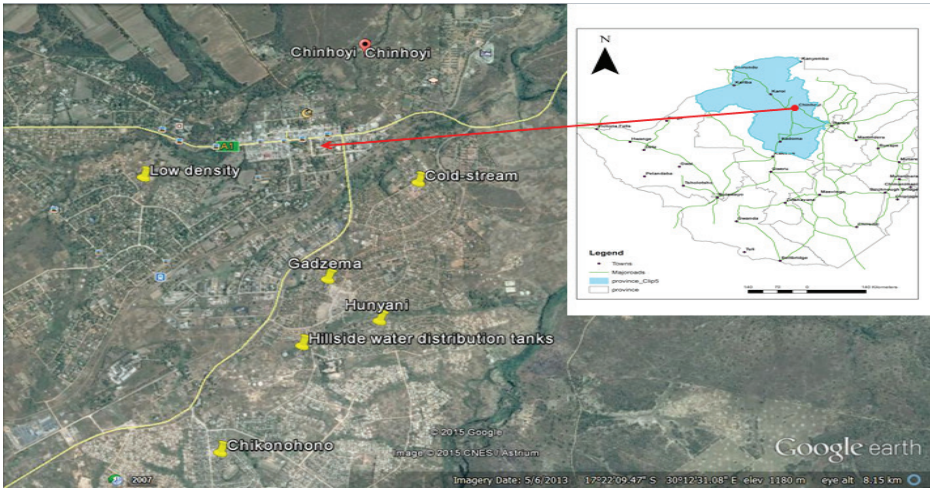


Figure 2: Study area map showing the location of Chinhoyi and sampled areas

3.0 Methodology

3.1 Research design

The research was quantitative in nature based on the treated water balance theory developed by International Water Association (IWA) as illustrated in Figure 2. The IWA water balance is an approach applied worldwide for determining and analysing water losses in water distribution systems (WDS) up to the point of customer metering. Thus, water losses occurring 'before' a customer meter are at the expenses of the water utility while water lost or wasted 'after' the meter is paid for by the customer. This applies to systems where customer metering is in place and/or consumption is charged according to the consumed volumes. However, like many WDS in the world which lack customer meters, those in Chinhoyi Town are operated intermittently and a considerable amount of water is lost.

<table>
<tr><th colspan="4">Standard IWA water balance
according to Lambert & Hirner (2000)</th><th></th><th>Seago & Mckenzie (2007)</th><th>Kanakoudis & Tsitsifli (2010)</th></tr>
<tr><td rowspan="12">System Input Volume (SIV)</td><td rowspan="4">Authorised Consumption</td><td rowspan="2">Billed Authorised Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td><td>Free Basic Water</td><td>Minimum Charge Difference</td></tr>
<tr><td></td><td>Recovered Revenue Water</td><td>Recovered Revenue Water</td></tr>
<tr><td></td><td>Billed Unmetered Consumption</td><td>Non-Recovered Revenue Water</td><td>Non-Recovered Revenue Water</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="8">Non-Revenue Water</td><td rowspan="8">Non-Revenue Water</td><td rowspan="8">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="8">Water Losses</td><td rowspan="3">Apparent Losses</td><td>Unauthorised Consumption</td></tr>
<tr><td>Meter Inaccuracies</td></tr>
<tr><td>Systematic Data Handling Error</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to point of Customer Metering</td></tr>
</table>

Figure 3: Water balance flowchart for an intermittently operated WDS without customer metering and charging flat-rate tariffs (unit: volume per balancing period.

3.2 Sampling

Stratified sampling was used to select 5 areas to determine their NRW. Thus, for high density suburbs, Cold stream, Chikonohono, Gadzema and Hunyani were selected while Mzari, Orange Groove and Riverside represented low density suburbs because they have one common bulk water flow meter. Residential areas for this study were selected based on three factors namely: population density, socio-economic status,

water distribution line and distribution network length.

3.3 Determination of the distribution system water balances

Sampling period was 6 months, from September to February. A high water demand was established during this period characterized by a constrained and inconsistent supply. Bulk water flow meter readings for water supplied to different areas were recorded daily and monthly supplies were computed. Data regarding water billed over the study period was collected from billing records. The billed consumption period for customer billing records were consistent with the System Input Volume period.

The exercise of completing a water balance was based on:

- production data;
- billing data;
- and data pertaining to authorized unbilled consumption,

The water balance also made a review of,

- apparent losses;
- meter inaccuracies;
- Data handling errors and

The level of un-authorized consumption that exist in the system.

A water audit of the system was conducted to check for the components of NRW-commercial and physical water losses. For commercial loses a survey was conducted to enumerate and record consumption of unauthorised connections, non-paid public use connections that is authorised unbilled consumption (water used in municipal properties like community halls, public toilets and parks, fire fighting and offices) and municipal staff exemptions. Unauthorized connections were recorded by the meter readers during the monthly household meter reading exercise.

Certain assumptions and estimates were made regarding: unmetered unauthorized connections and meter inaccuracies and billing data handling error water losses which constitute the apparent loss component of the water balance in accordance with the IWA water balance determination guidelines. It recommends that for developing countries water utilities utilize 5 per cent of the billed water to constitute apparent loss due to meter inaccuracies and errors. Most of the illegal connections do not have meters so consumption was estimated using the official monthly mean per household consumption of 25 m^3. Physical losses were treated as water loss along the distribution network from the point where the mainline bulk water meter is installed in the form of leakages or burst pipes up to the in-house meter. With the Apparent loss and unbilled authorized consumption components the real losses were determined. This is according to the IWA treated water balance equations below.

NRW (m^3) = System Input Volume (m^3) − Billed Authorized Consumption (m^3)

$QI = QBA + QUA\,C + QAL + QRL$

Where:

QI=System input volume [m^3]

QBA=Billed authorized concentration [m^3]

QUAC = Volume of unbilled authorized consumption [m^3]

QAL = Apparent losses [m^3]

QRL = Real losses [m^3]

3.4 Determining factors that influence NRW

The method used key informant interviews, questionnaires (using 10 % rule of the thumb), field observations and review of documentation. The primary data has been collected through household survey with the help of a structured schedule, which was canvassed in 20 households from each of the 5 suburbs. The selection of households was taken by simple random sampling method. The questionnaire was first piloted to 20 households in high and low density suburbs so as to remove all sources of weakness, error, bias and to erase ambiguities. After the pilot test, a standard questionnaire was finalized and administered to the low and high-density suburbs of the respective areas. The household questionnaire administered to consumers focused on socio-economic factors like occupation, employer from which the mean per household income and ability to pay rates was then derived. This is because in the pilot study it was realized that respondents were not willing to disclose their income which they regarded as confidential information and so an indirect way of establishing income was devised whereby they were only asked to tell their employer or sources of income. The socio-economic information gathered was compared with already existing one for surveys done by the municipality and found to be tallying.

On the supply side semi-structured questionnaires were used to interview key stakeholders such as key utility staff on the general performance of the utility. Data was also obtained from annual reports of the utility. Field observations were used to gather data to supplement the data gathered by interviews. Factors that were considered in assessing the supply side water management were cases of meter tempering, water pipe bursts and leakage cases, age of water distribution pipes and leak detection systems. Field observation were used to enumerate illegal connections and non-working water meters with the assistance of municipal water meter readers during their usual monthly meter reading exercise.

3.5 Translating NRW into economic terms

A simple financial performance indicator (PI) – monthly loss in monetary terms (*LM* [USD]*)* was calculated for each component of the three major constituents of non-revenue water. Unbilled authorized consumption and apparent losses were rated at the average sales price of water as they represent volumes of water that have been delivered to the consumer. Real losses were rated at the average production costs since they represent financial values of production as supported by Fallis et al (2004). On the other hand commercial losses were assigned selling economic value since it is water that actually reaches the customer and then not paid for.

NRW value = (L.phy +L.comm) (per unit price)

$LM = (QUAC + QAL) \times CSP + QRL \times CP$

Where:

L.comm= Commercial losses [m^3]

L.phy= Physical losses [m^3]

LM [USD] = Monthly losses

QUAC [m^3] = Volume of unbilled authorized consumption

QAL [m^3] = Apparent losses

QRL [m^3] =Real losses

CSP [USD/m^3]= Sales price

CP [USD/m^3] =Production cost

3.6 Data presentation and analysis

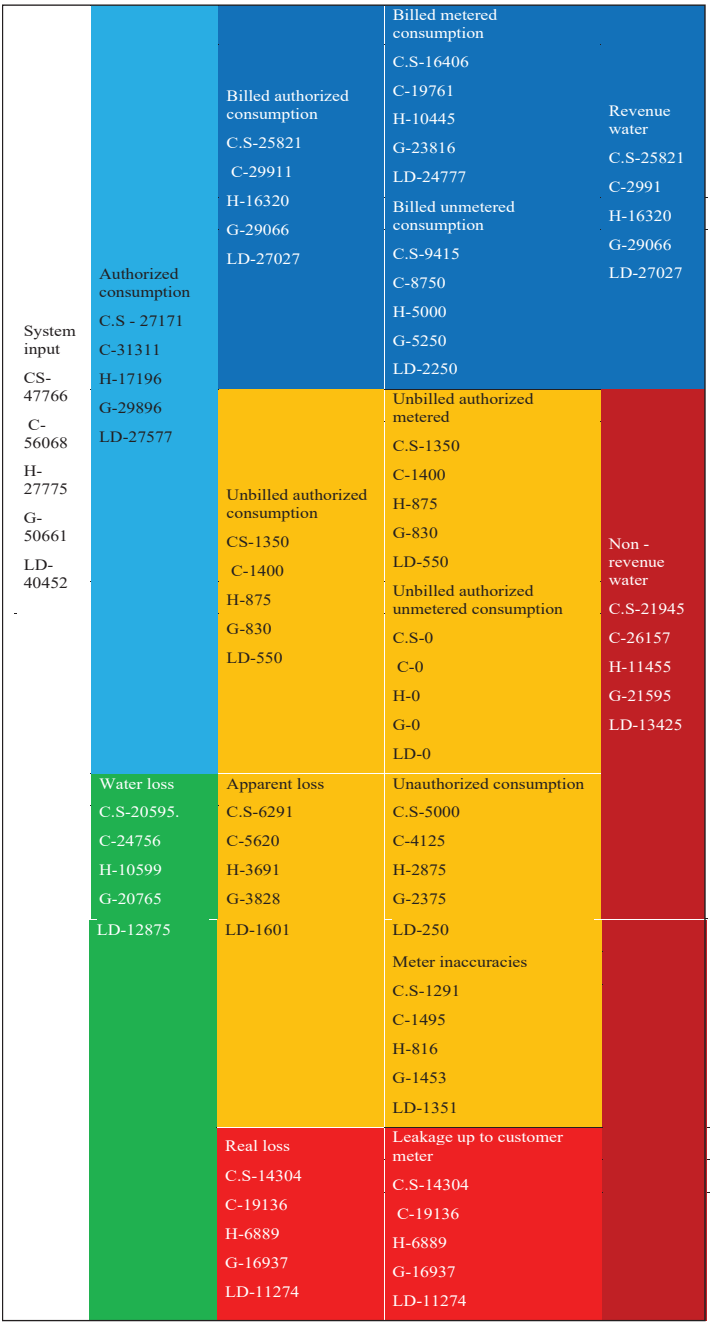
Raw data collected in the research was tabulated and presented on graphs. Student T-test was used for comparing statistically the difference between measured NRW values and the recommended standard at 5% level of significance. Correlation was used to test the strength of the relationship between factors which affect NRW and NRW value.

4.0 Results and Discussion

4.1 Water balances for the selected District Metered Areas (DMAs)

Tables 1 is showing the treated water balances for all the sampled DMAs (Key: C.S-Coldstream; C-Chikonohono; H-Hunyani; G-Gadzema; Low density) using the IWA standardised format.

Table 2: District metered areas Water balance monthly average volumes (m^3)


System input
CS-47766
C-56068
H-27775
G-50661
LD-40452
Authorized consumption
C.S - 27171
C-31311
H-17196
G-29896
LD-27577
Billed authorized consumption
C.S-25821
C-29911
H-16320
G-29066
LD-27027
Billed metered consumption
C.S-16406
C-19761
H-10445
G-23816
LD-24777
Billed unmetered consumption
C.S-9415
C-8750
H-5000
G-5250
LD-2250
Revenue water
C.S-25821
C-2991
H-16320
G-29066
LD-27027
Unbilled authorized consumption
CS-1350
C-1400
H-875
G-830
LD-550
Unbilled authorized metered
C.S-1350
C-1400
H-875
G-830
LD-550
Unbilled authorized unmetered consumption
C.S-0
C-0
H-0
G-0
LD-0
Non - revenue water
C.S-21945
C-26157
H-11455
G-21595
LD-13425
Water loss
C.S-20595.
C-24756
H-10599
G-20765
LD-12875
Apparent loss
C.S-6291
C-5620
H-3691
G-3828
LD-1601
Unauthorized consumption
C.S-5000
C-4125
H-2875
G-2375
LD-250
Meter inaccuracies
C.S-1291
C-1495
H-816
G-1453
LD-1351
Real loss
C.S-14304
C-19136
H-6889
G-16937
LD-11274
Leakage up to customer meter
C.S-14304
C-19136
H-6889
G-16937
LD-11274

Key

Colour code	*Water loss components*
Orange	*Commercial*
Red	*Real Loss*
Green	*Water loss*
Blue	*Revenue water*
Dark Red	*Total NRW*

The components show where and how much water is lost, information which can be used in developing a NRW reduction strategy and deciding on key priorities. There is zero unbilled authorized unmetered consumption in all the DMAs water balances because all the exempted and municipal property connections which make up this component are metered. Unauthorized consumption averaged 2925m^3, with Coldstream recording the highest unauthorized consumption followed by Chikonohono, Hunyani and Gadzema respectively. Unauthorized consumption is a function of illegal connections which means that illegal consumption of water is most rampant in Coldstream. Low density area had the lowest illegal consumption component on its water balance averaging 250 m^3. The differences can be attributed to socio-economic factors particularly income which is lower for high density suburbs than low density resulting in low ability to pay. These findings are in agreement with those of Gagnon (2002) who also established a significant proportion of illegal connections in low income areas as compared to high income areas. Hitherto, unauthorized water losses due to illegal connections and pipe bursts in high density suburbs is a key contributor to NRW loss thus should be of key focus in development and implementation of interventions.

4. 2 Physical and commercial loss contributions to total NRW

Figure 4 shows the physical losses, commercial losses and total NRW for the sampled DMAs with the horizontal line indicating the 15% reccomended standard NRW level.

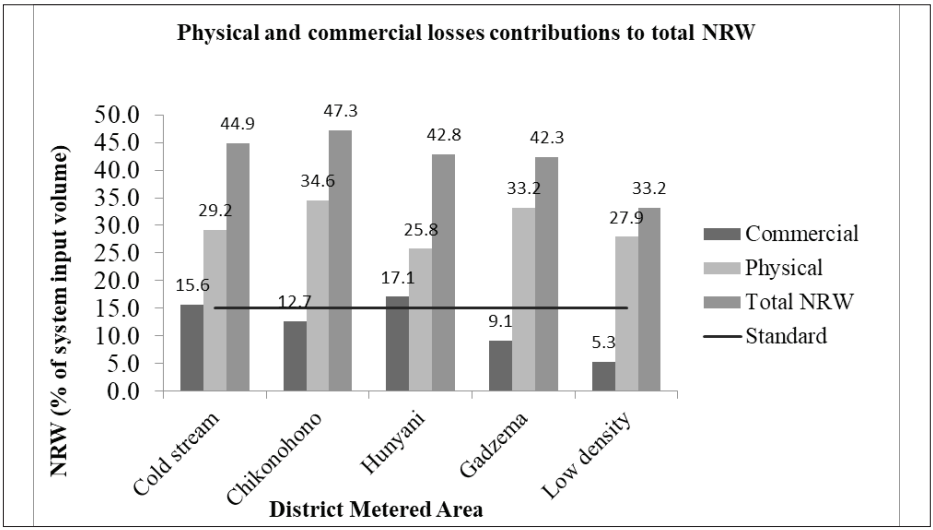


Figure 4: Physical and commercial loss contributions to total NRW

The monthly average NRW levels show that Chikonohono has highest NRW which is 47.3 of the system input volume (26157m^3) which can be attributed to frequent pipe bursts in the area. The low density has the least NRW of 33.3 % of the system input volume (13425 m^3). The established NRW estimates in sampled high density suburbs were also found to be within the same range, 40-50%, as those of other municipalities in low to medium income economies as is read with IBNET database (Kingdom et al, 2006). However, established NRW estimates fall short of the World Bank NRW recommendation which states that a well performing utility should have about 15% NRW of system input. The difference between the 15% limit and measured NRW in all the five DMAs is significant at $p < 0.05$ ($p = 0.0001$). There is also significant difference across all the DMAs ($p = 0.00002$). NRW above 15 percent of system input volume for municipal systems indicate the need for immediate actions (World Bank, 2010). The NRW water is moreover almost similar to that of greater Harare, estimated to be ranging from 57 to 60% (City of Harare, 2011). Similarly, Ndunguru and Hoko (2016) opined that that major contributing factors include high physical losses and a significant portion of the customers not being in the database in serviced areas by Zimbabwe's municipalities. Results of NRW were also in congruence of those found by Kimey et al (2007) in Tanzania where in Korogwe town NRW was 42% while in Muheza town it was found to be 47% for the year 2006/2007. Similar findings were also found for Tshwane Municipality in Gauteng South Africa which indicated that the amount of 9 026 999 m^3 of water purchased as the system input volume for six months from July 2009 to December 2009 after distribution, provided 4 047 076 m^3 NRW. This indicated that 44.83% of the water purchased ended as NRW (Mhlongo, 2009). Such similarities as established in both South Africa and Tanzania, are a recurrent characteristic of a

redundant water distribution network marred by and not limited to illegal connections and incessant leaks in sampled areas. Physical losses are higher than commercial losses in all the areas reflecting high leakages of water from the distribution network thereby increasing water supply capacity deficit. The same was observed by Marunga et al (2009) in Mutare. Chikonohono has the highest physical loss contribution 19136 m^3 which is 34.6 % of the system input volume whilst the lowest is in Hunyani with only 6889.3 m^3 translating to 25.8 % of input volume. Area of particular interest is low density which has 27 out of its 33% NRW as physical losses. This shows relative high physical losses in the sampled area. Hitherto, it can be stablished that NRW is a characteristic of most, if not all, municipalities in low to medium income economies which invariably explains constrained revenue coffers which impede improvement and maintenance of the water distribution systems which are under constant pressure from the soaring water demand due to the unprecedented increase in population and requisite serviced zones or residential areas.

4.3 Factors influencing NRW

4.3.1 Bursts and leaks

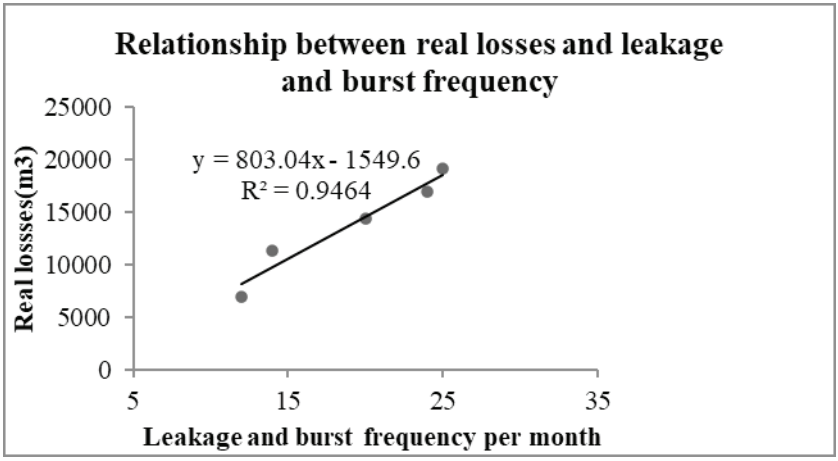


Figure 5: Relationship between real losses and leakage and bursts frequency

Figure 5 illustrates the correlation and causation between real losses and leakage and burst frequency across the sampled DMAs. The graph shows that there is a strong positive relationship between the two variables with 94.64% of the variation in leakage and pipe burst frequency per month explaining real losses. Thus, an increase in bursts and leakage frequency results in an increase in real losses. The relationship was also found to be significant with a p-value of p (0.00536) < 0.05, at 5% level of significance. This p-value confirms that leakages and burst of pipe frequency causes physical losses. The water utility does not have an automated leak detection system and it relies on

reports from customers a practice that is inefficient in leakage management. Reporting burst pipes, faulty valves, leaks, or other problems that limited utility crews may not detect is vital in reduction of real losses. Farley et al (2008) found a large amount of unreported leaks as the major factor influencing real losses in Peru municipal water supply systems. It was also gathered that the utility also sometimes delays attending to water bursts taking up to a week owing to resource constraints, both technical and financial, which is continuously exacerbated by an unstable and moribund Zimbabwean economy. Pressure management is also a vital aspect of pressure leakage management but currently the supply system does not have pressure gauges and water distribution pressure cannot be measured. Increasing pressure will result in a higher flow rate from existing leaks and an augmented occurrence of new pipe bursts and leaks. Kingdom et al (2006) concluded that network pressure has a direct, approximately linear, relationship with physical losses for example, 10 percent more pressure translates into about 10 percent more leakage in volume thereby making it a crucial factor in controlling pipe bursts and leakages

4.3.2 Age of pipes

Factors influencing leakage are age-dependent. Consequently, the age of a pipe section can appear to be a vital root cause for leakage.

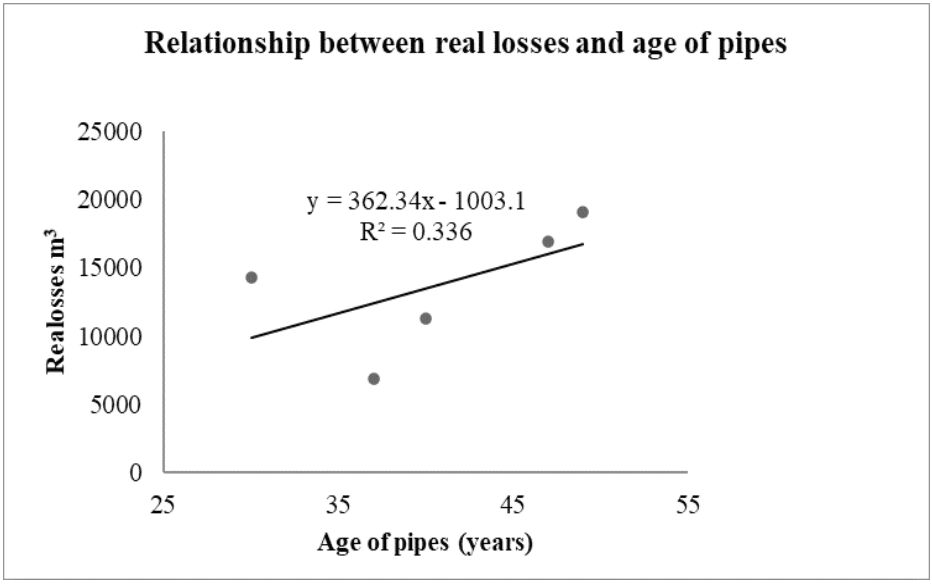


Figure 6: The relationship between real losses and age of pipes.

Fig 6 illustrates a weak positive relationship between real losses and age of pipes. The relationship indicates a tendency of increase in real losses with increase in the age

of water distribution infrastructure. Extended life of distribution pipes explains why Chikonohono with a 47 year old water supply network has the highest volume of real losses averaging 34.6 %. The distribution infrastructure has aged such that the latest pipes were laid in 1985 and have not been replaced since. According to Malcon et al (2003) an acceptable life span for a water supply system ranges from 20 to 25 years depending on the type of pipe materials. However, the relationship is insignificant with a p-value of 0.30563 at 5% level of significance. Thus, only 33.6 % of the variation in the age of pipes explains variation in real losses. This means that the impact of age of pipes on pipe bursts and leakages and subsequently on real losses is relatively insignificant probably confirming the influence of other factors including but not limited to, network pressure (Section 4.3.3), leakages and bursts. This observation is in agreement with Farley et al (2008) who suggest that age of pipes is not necessarily the most significant factor, if the pipe has been carefully designed and installed, maintenance is carried out at regular intervals and external conditions are favourable. As a result of a water supply audit done in 2013, the Chinhoyi City Fathers resolved to address the challenge of leakages in two ways. The first approach was to replace the whole water pipes network as the city has continuous pipe bursts because the pipes in the network are now old. The second way in addressing the leakage margin was through the installation of pressure reducing valves. However, such interventions haven't been implemented since due to unavailability of financial resources.

4.3.3 Distribution network length

Figure 7 below shows the relationship between real losses and water distribution network length. The results show positive and moderate relationship between the two variables. This means an increase in network length results in an increase in real loses to a lesser extent. This is due to an increase in water distribution network length resulting in a probable increase in points susceptible to leaks. However, the relationship is insignificant ($p>0.05$) at 5% level of significance with only 36.2% of the alteration in distribution network length explaining variation in real losses.

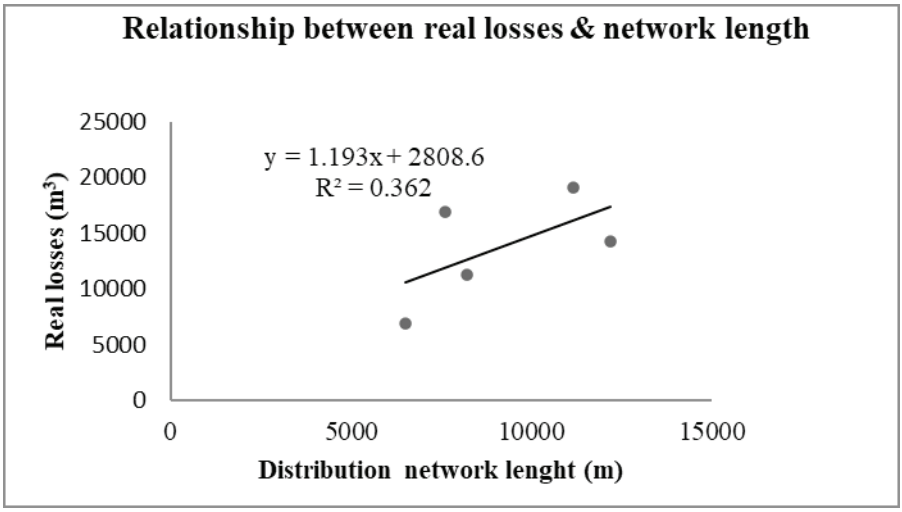


Figure 7: Relationship between real losses and network length

Physical leakages of water from the distribution network generally increase with network length (Wyatt, 2010). Wyatt (2010) observed a strong positive correlation between network length and physical losses in most developing countries. However, according Marunga et al (2006) network characteristics such as age may outweigh the influence of network length and this may account for the insignificant p-value obtained.

4.3.4 Elevation

Figure 8 shows a weak and negative relationship between real losses and DMA elevation. This means that high elevation DMAs have lower real losses than low elevation DMAs. There is a tendency for real loses to decrease with increase in elevation. This relationship is somewhat expected since the water distribution network system in the study area uses gravity which means low lying areas experience water supply at very high pressure which subsequently yield incessant pipe bursts which explains higher real losses when compared to high lying DMAs. However, the relationship was found to be insignificant with only 3.1% of the change in elevation explaining the variation in real losses.

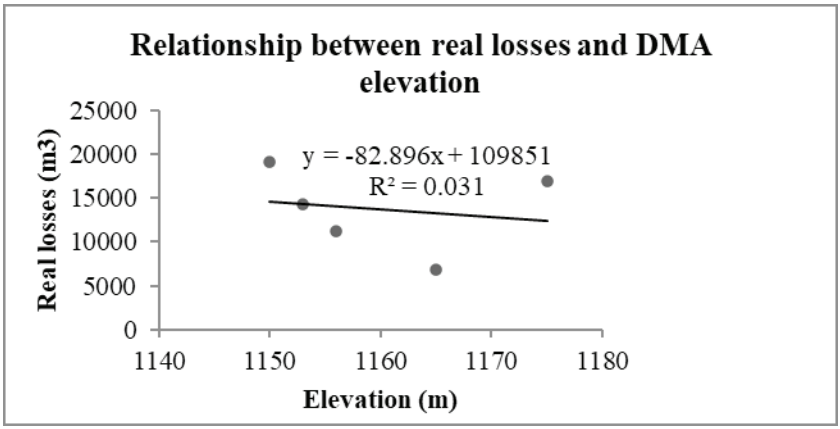


Figure 8: Relationship between real losses and DMA elevation

DMA elevation relative to water reservoir directly influences network pressure and indirectly influences the level of physical leakages (Kilic, 2011). Kilic (2011) observed that for gravity dependent water distribution systems areas of high altitude have lower network pressure than lower altitude zones.

3.3.5 Non-working meters

Figure 9 illustrates a positive and strong correlation between commercial losses and non-working meters. This means that there is a strong tendency for commercial losses to increase if non-working meters increase and vice versa. The relationship is also statistically significant with a p-value (0.00015) <0.05 at 95% CI. Thus, 65.9 % of change in the number of non-working meters explains variation in commercial losses.

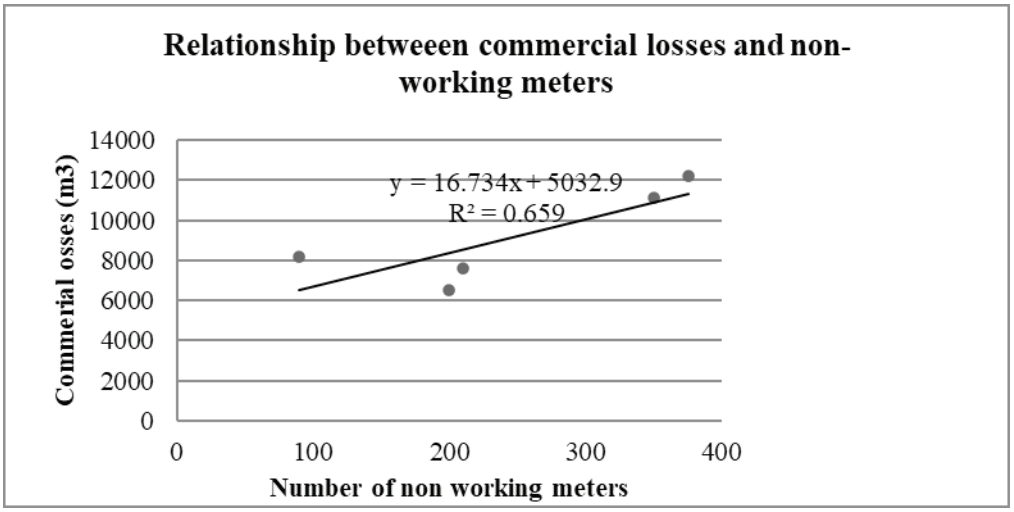


Figure 9: Relationship between commercial losses and non-working meters

The meters are the cash registers, the monitors, and the most visible physical part of any utility system and when they are not working it results in underestimation and/or overestimation of consumption when billing. Marunga et al. (2006) found that faulty meters were contributing up to 25% of NRW in Mutare City. Similar observation was made by Chikasema (2005) who established that there was a positive near linear relationship between the number of estimated bills and NRW. Gumbo (2004) supports the relationship by concluding that cities performing well in terms of NRW management have also higher metering coverage. The American Water Works Association (2005) recommends that every water utility meter all water taken into its system and all water distributed from its system at its customer's point of service.

4.3.6 Customer disconnections

Figure 10 illustrates a positive and strong relationship between commercial losses and customer disconnections. This means that customer disconnections result in an increase in commercial losses with 57.8% of the variation in customer disconnections explaining commercial losses in the study area.

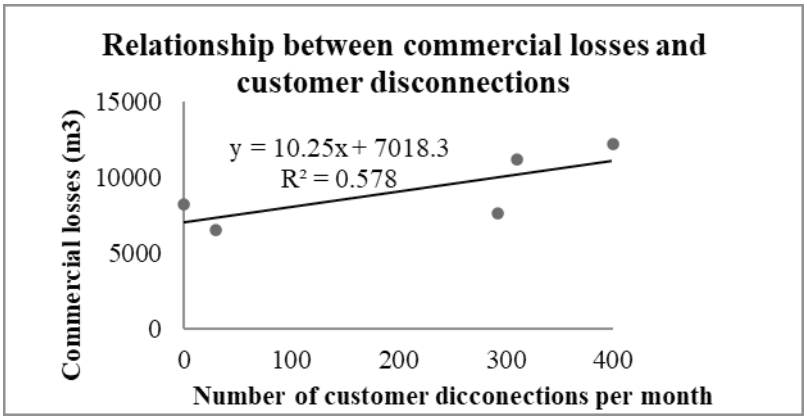


Figure 10: Relationship between commercial losses and customer disconnections

When a customer's supply is cut off after non-payment and the customer cannot afford, or does not want to pay to be reconnected they resort to unauthorized access so this could have caused the commercial losses. In addition, when an account is closed by turning the valve off rather than removing the meter, a customer may turn the valve on again. The customer then receives free water that will not be billed. Through interviews with the municipal water distribution staff it was established that disconnection of customers trigger illegal consumption of water. A study findings of Adenta town in Ghana indicated that NRW (50% in 2009) was as a result of theft and poor billing (Taylor, 2009).

4.3.7 Ability to pay for water services

Figure 11 shows a negatively moderate and significant correlation between commercial losses and customers disposable income. The relationship reflects a tendency for decrease in commercial losses with increase in disposable income with 51.5% of the variation in monthly disposable income explaining variation in commercial losses.

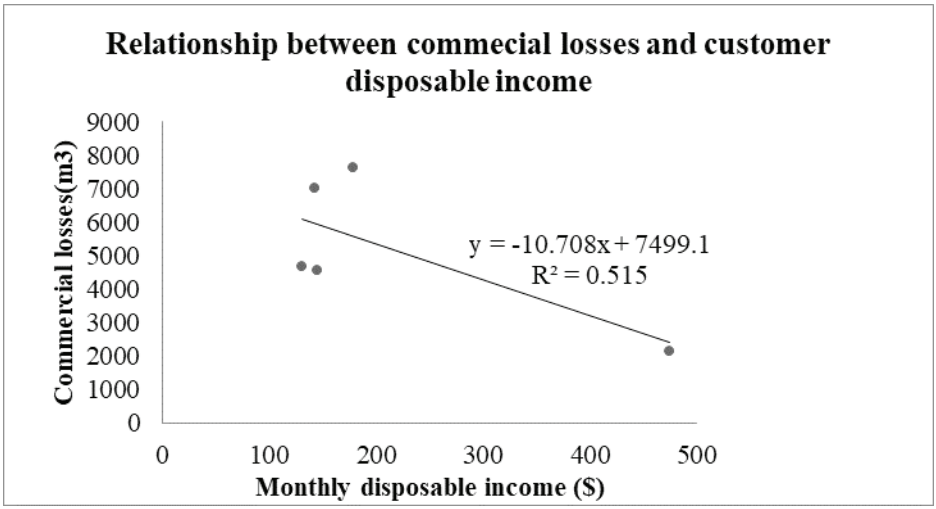


Figure 11: Relationship between commercial losses and customer disposable income

Average income in the high density areas ranged between $150 to $200 and low density had an average of $500 .The average bills for high density is between $20 and $22 whereas that for low density is $25. According to the World Bank recommendation, households should not spend more than a maximum of 5% of monthly income on water supply and sanitation services. The household incomes obtained show that rate payers in high density suburbs are spending between 10 and 14.7% of their monthly incomes, this is far above the recommended limit. Low density households pay 5% of their monthly income for water and sanitation and this is considered affordable. The utility technical staff cited low affordability as one of the major reasons for the unauthorized connection and meter tampering which contributes to non-revenue water.

4.3.8 Illegal consumption

The findings on illegal connections presented in Figure 12 show a positive strong relationship between commercial losses and illegal connections. There is therefore a strong tendency for commercial losses to increase when the number of illegal connections increases. The relationship is also statistically significant ($p<0.05$) with 97.3% of the variation in illegal connections explaining the change in commercial losses.

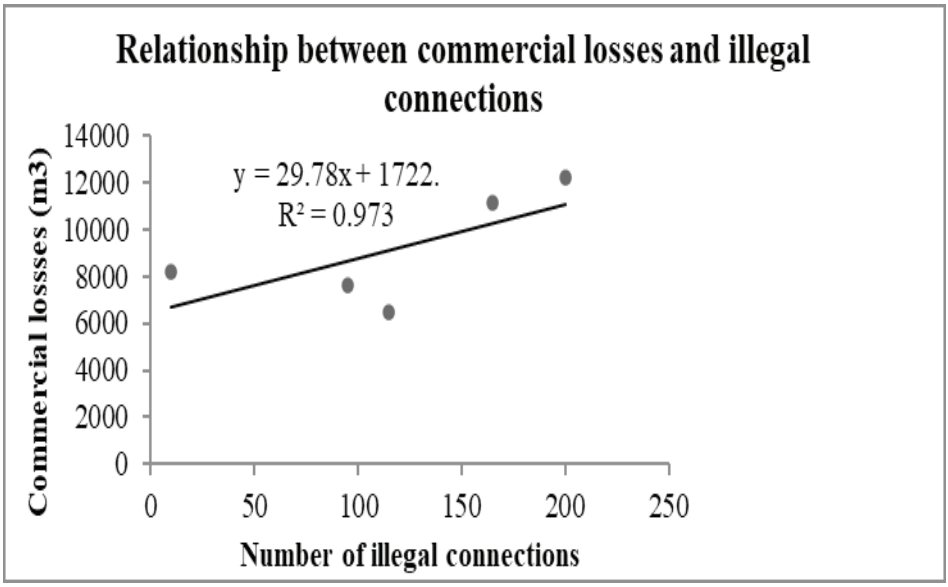


Figure 12: Relationship between commercial losses and illegal connections

The study found that illegal consumption is rampant in high density suburbs as compared to low density suburbs, a characteristic which can be explained by disparities in income between the two zones. Thus, the low income population tend to not afford the seemingly extravagant water rates and are highly likely to rely on illegal connections to access water. Similarly, Gagnon (2002) posited that illegal taps are more likely in low income areas and enforcement and imposition of fines by a city or increased vigilance and legal action by a utility will probably be required to curtail this problem. Similarly, in a water audit conducted in 2013, the City of Harare attributed commercial losses to illegal syphoning or non-payment for use. To address the challenge of commercial losses the City of Harare referred some cases of water theft to law enforcement agents so that the perpetrators can be brought to book. However, according to the key informant findings in Chinhoyi, no legal action is taken against illegal consumers despite having by-laws authorizing prosecution of such offenders which could see escalation of illegal connection rates and more so NRW.

4.4 Economic value of NRW

Table 2 results show that financial losses increase with increase in NRW which is a statistically significant relationship (p (0.0025) <0.05) at 5% level of significance. Total average economic loss due to NRW is $38 772.50 which translates to 34.8% of the projected monthly total revenue water sales $111 361.40.

Table 3: Monthly water losses in econometric terms

DMA	SIV (m^3)	SIV value (US$)	Total NRW (m3)	Total NRW value (US$)
Cold stream	47767	23883.25	21946	9093.62
Chikonohono	56068	28034.00	26157	10692.67
Hunyani	27775	13887.65	11455	4787.19
Gadzema	50661	25330.50	21595	8748.13
Low density	40452	20226.00	13425	5450.89
Grand total	222723	111361.4	94578	38772.50

Farley (2003) suggests that economically, the target should be derived from a financial/ economic analysis that determines the optimal level of leakage in any situation that is, when the marginal cost of saving a cubic meter of water equals the marginal cost of supplying it. Thus, setting targets for developing country water utility like Chinhoyi based on the performance of the best utilities in the developed world could easily be counter-productive. Therefore, with established significant NRW values in dollar terms, revenue generated is compromised which therefore, constrains the utility's self-sustenance.

4.5 Conclusions

It can be concluded that the NRW for Chinhoyi water supply District Metered Areas (DMAs) is high (42% average) and significantly different from the recommended 15% limit ($p=0.0001$) rendering the water distribution system inefficient based on international standards. Physical leakages constitute higher non-revenue water than commercial losses. Commercial losses are being influenced by technical (metering) and socio-economic factors (disposable income, customer disconnections and illegal connections). It can also be concluded that Municipality of Chinhoyi is potentially loosing huge sums of money (34% of projected revenue generation) upon which investments for non-revenue water reduction can be based.

4.6 Recommendations

Basing on baseline information generated by this study it is recommended that Municipality of Chinhoyi takes a diagnostic approach, followed by the implementation of solutions that are practicable and achievable for reducing non-revenue water through the following strategies:

Active leakage control: monitoring network flows on a regular basis to identify the occurrence of new leaks earlier so that they can be detected and repaired as soon as possible with the use of a comprehensive leak detection system.

Pipeline and asset management: managing network rehabilitation in an economical manner to reduce the need for corrective maintenance

Speed and quality of repairs: repairing leaks in a timely and efficient manner (often requiring a thorough shakeup of working practices, organization, and stock keeping of repair materials)

Pressure management: installing pressure gauges and regulating network pressure through the judicious use of pressure-adjustment valves

Ensuring that customer meters are in proper working condition and duly replaced at the end of their useful lives reduces under-metering and recourse to estimated billing.

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An Assessment of Solid Waste Generation and Management in Small Towns: The Case of Mvurwi

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Abstract

This research sought to establish solid waste generation rates, waste profiles and investigate the causes of municipal solid waste problems in Mvurwi as evidenced by illegal dumps. The study employed a mixed method approach encompassing both quantitative and qualitative data collected through fieldwork, observations, questionnaires, interviews and document reviews. With an average of 8.8 tonnes of municipal solid waste generated per day and 0.77kgs waste generation per capita rate, the study established poor waste management in Mvurwi characterized by intermittent waste collection, littering, open dumping and burning of waste. Such challenges were mainly attributed to lack of knowledge and understanding on the merits and demerits of both proper and improper waste management among residents with budgetary constraints also a key factor. As such, these problems should be solved by improving stakeholder participation, environmental education, solid waste management facilities and adopting sustainable principles of efficient solid waste management. Sustainable waste management requires the system to be environmentally effective, economically affordable, and socially viable.

Keywords: Municipal solid waste, Mvurwi town, sustainable waste management, waste generation

1.0 Introduction

Solid waste is defined as any garbage, refuse, sludge or any other unwanted solid material that is deemed useless from industries, commercial areas, mining and agricultural operations and the community (Moeller, 2005). Municipal solid waste (MSW) waste constitute residential, commercial, industrial and in some instances institutional waste (Medina, 2010). In urban areas, large quantities of municipal solid waste are generated during a number of activities such as cooking, industrial or manufacturing processes and vending among other things (Gawaikar, 2012). There is a growing problem of solid waste management with the development of industry and the expansion of cities of many countries in the world (Zuilen, 2006). These wastes are to be stored, collected, transported, processed and disposed of in an environmentally friendly manner, so as to keep the city tidy and hygienic (Medina, 2010). According to Chandra and Devi, (2009) solid waste management has become a worldwide challenge for human beings. The 1992 Agenda 21 action programme of the United Nations Conference on the Environment and Sustainable development emphasized that environmentally sound practices for the management of waste are critical for maintaining the Earth's environment and achieving sustainable development (Zuilen, 2006). The World Summit on Sustainable Development, held in Johannesburg in 2002, encouraged consideration of development options that are socially, economically and environmentally sound. The summit elevated the issue of waste management into a global concern. In 2006, the total amount of municipal solid waste (MSW) generated globally reached 2.02 billion tonnes (most of which was plastic and organic waste) thus signifying a 7% yearly increase compared to 2003 (Global Waste Management Market Report, 2007). World generation of municipal solid waste rose by 38%, which can be interpreted as an 8% increase per annum between 2007 and 2011 (Environment Africa, 2013).

Municipal solid waste (MSW) management constitute as one of the most punitive challenges facing African towns and cities (Saungweme, 2012). Medina (2010) stipulates that many cities in Africa and Asia collect less than half of the waste generated and worse still, dump it in open dumps. Leonard and Morerell (2007) and Buenrostro and Bocco (2003) attribute non waste collection in city centres and illegal dumping to insufficient logistics of municipalities such as financial, technical and human infrastructure resources. Municipal services in developing countries are handicapped by narrow finances and ever escalating demand on urban services (Chirisa, 2012).

It is apparent that municipalities are facing major problems with managing domestic, commercial and industrial solid waste. A report by Environmental Management Agency (EMA, 2013) indicated that in Zimbabwe, about 15 000 tonnes of waste are generated every day. This amount is far greater than the country's collection systems to dispose the waste. A good case in point is the decline in the 2008 waste collection rates in Harare. This can be attributed to rapid urban population growth, high generation rates,

poor waste handling practices coupled with hyperinflation and recurrent poor budgets for local authorities. As such, in Zimbabwe, about 60% of the waste generated in urban environments is disposed at official dumpsites with the remaining waste being dumped illegally in undesignated areas namely storm water drains, open spaces, alleys and road verges. The report further state that residents have resorted to burning, burying or throwing the uncollected waste on undesignated areas. Consequently, waste generation and management is one of the major problems the government of Zimbabwe is facing (Practical Action Southern Africa, 2006; Mubaiwa, 2013). If bigger cities such as Harare, with a much broader base for revenue generation, skilled personnel and equipment are facing logistical constraints of such magnitude, the smaller towns such as Mvurwi with a much slim revenue collection base, few skilled personnel and less equipment are more likely to be hit by the same problems. In light of the above, this study seeks to determine the solid waste generation rates, handling practices and the challenges faced by small towns in Zimbabwe in managing solid waste using Mvurwi Town Council as the case with the aim of proposing policy recommendations that could help in resolving solid waste problems in small towns.

3.0 Methodology

3.1 Study area

Mvurwi town is situated on the North Eastern part of Zimbabwe in the Mazowe District of Mashonaland Central Province. It lies between latitude, $17^0\,01'29.42"$S and longitude, $30^0\,52'05.39"$ E at an elevation of 1479m. It has a population of 10 490 with a 2% annual growth rate (Central Statistics Office, 2012). There are approximately a total of 2 560 households in Mvurwi town (Mvurwi Town Council, 2019). A number of small scale businesses exist; a lot of people earn a living through vending and peri-urban farming. These businesses contribute to the waste stream of the town.

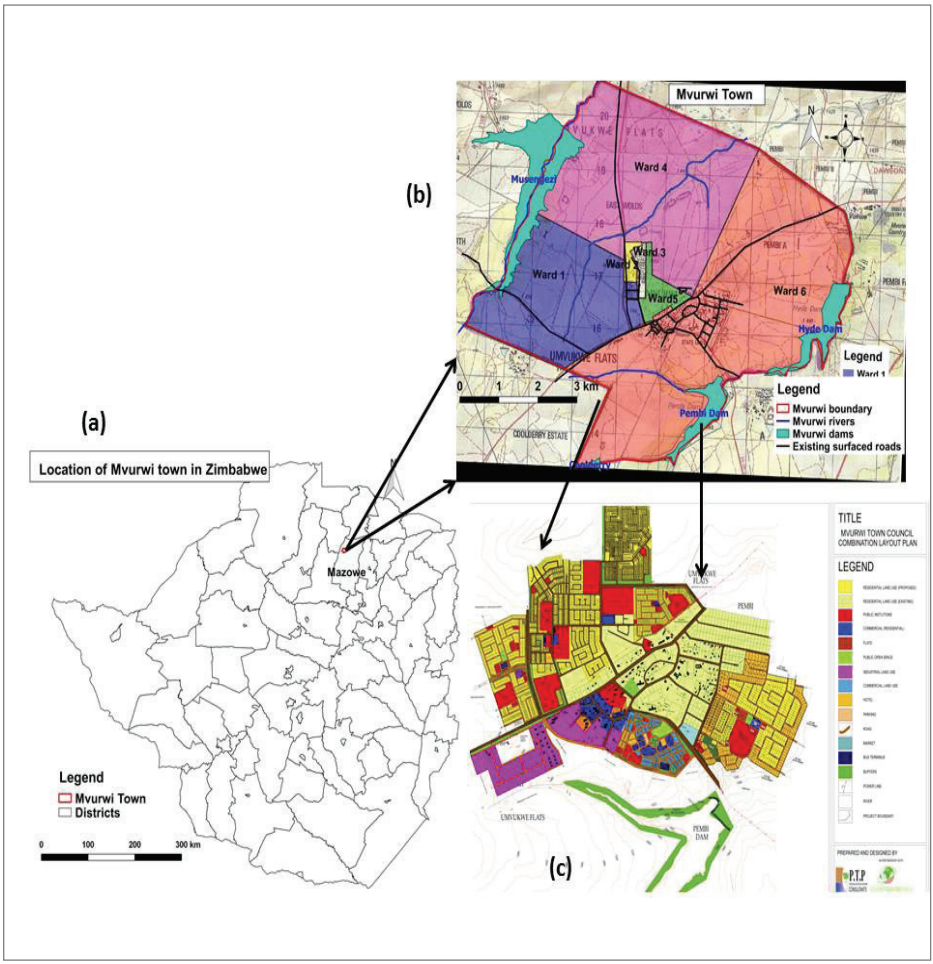

Figure 13: Mvurwi Town

3.2 Research design

A cross-sectional study embracing both qualitative and quantitative approaches was used in this enquiry. The study was carried out for a period of 5 months, from November 2018 to March 2019. Population in this research referred to employees from Mvurwi Town Council (MTC) and the residents of Mvurwi Town.

3.3 Sampling

The samples were first stratified into three different strata namely residential, commercial and industrial areas. This was done to obtain a representative sample from each sector

regardless of size. In the residential sector, the researcher used the stratified random sampling technique to put the locations into low, medium and high density suburbs and then used a sample size that was calculated using the 10% rule of thumb as supported by Alreck and Settle (1985) from each location based on population size. Systematic random sampling was used to select respondents from the commercial sector. At the dumpsite sampling was done once a week throughout the study period. This was done to replicate so that bias and errors could be reduced.

3.4 Waste characterization and quantification

Sorting and quantification of municipal solid waste streams was conducted on a weekly basis through-out the study period. Tools and equipment used in carrying out waste characterization and quantification included a weigh bridge from a local Grain Marketing Board depot, a waste bin, hanging scale, a shovel, hard broom, disposable litter receptacle bags and protective clothing (overalls, heavy duty gloves, and facemasks). The research made use of a weigh bridge to record the amount of waste meant for the disposal facility. Subsequently, a sample of waste of 150 kg was then grabbed randomly for sorting at the waste disposal facility. The waste was separated physically into its individual constituents in the categories metals, glass, vegetables and petrucibles, paper, plastic and others (rubber and cloth). The waste that had been separated was brought to scale and weighed using a hanging scale. The above described procedures were done for the waste coming into the dumpsite from residential, commercial and industrial areas. Waste coming from each sector was independently characterized and quantified.

3.4.1 Waste generation rates

The following expression was used to obtain the rate in kilograms/capita/day: -

$$\frac{weight\ of\ sample\ per\ week}{(number\ of\ people\ per\ household)(7days\ per\ week)}$$

3.5 Waste handling practices

Self-administered questionnaires consisting of both open ended and closed questions were used to gather information from residents and other waste generators. These were used to gather information on solid waste handling in Mvurwi Town and also on gathering opinions on how to improve the council's current solid waste management practices.

The questionnaire had questions on the following:

i. Methods of solid waste disposal

ii. Components of waste.

iii. Cost of waste collection services.

iv. Waste separation.

v. Community involvement in solid waste management activities

3.6 Determining the challenges faced by Mvurwi Town Council in managing its solid waste

Key informant interviews were used to obtain required information from waste managers that is Town Council officials. Ten council employees in the department of Community Services and Environmental Management were interviewed. They were interviewed on:

- Availability of technical expertise
- Political influence on waste management
- Attitude and perceptions of Mvurwi residents on waste management
- Community education, mobilization and participation, and outcomes
- Opinions and priorities for improving interaction on solid waste management

3.7 Field Observations

An observation checklist guide was used to triangulate information collected using other data collection techniques in particular examining the entire waste management system from waste collection to final disposal. The research team physically observed the actual collection of waste, the type of vehicles used in waste collection, the waste receptacles and how residents handled waste. These variables would then reflect on the challenges being faced by the town council and in general the waste handling practices. Observations were also done to identify illegal dumpsites.

3.8 Secondary Data

This is data collected for purposes of supplementing primary data. Information on municipal waste collection schedules, bye-laws and municipal administrative organogram was provided by Mvurwi Town council from their official documents.

3.9 Data Presentation and Analysis Procedures

Collected data was analysed using the Statistical Program for Social Sciences (SPSS) computer software. Graphs, tables and pie charts as well as thick, rich and deep descriptions were utilized to present information.

4.0 Results and discussion

4.1 Solid waste compositions and generation rates

4.1.1 Solid waste composition

Figure 2 shows solid waste composition by percentage weight. Study results across all sectors (residential, commercial and industrial areas) showed that waste characteristics varied with sectors.

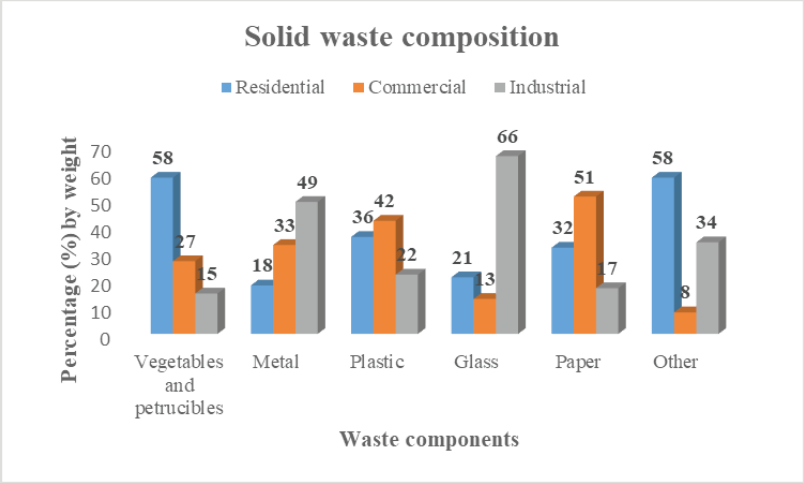

Figure 14: Solid waste composition

Variation of waste composition on a sector basis was found to be significant (p (0.045) <0.05) at 5% level of significance. It was found that the residential sector generated most organics (58%). The commercial sector generated most paper and plastics (51 % and 42 % respectively) as compared to other sectors. This could be due to waste generated from packaged goods which is found to be dominant in commercial sectors. Waste composition varied due to various activities done in each sector. This was also stated by Muniafa (2007) that in most African urban centres waste characteristics across residential, commercial, industrial and institutions differ due to differences in activities that lead to solid waste generation. The study also established plastic and paper as the dominant waste streams in Mvurwi Town. This is in sharp contrast with other studies carried out in Zimbabwean towns. A study carried out in Chinhoyi by Musademba et al (2011) shows that plastic and paper had 24% and 13% respectively. These differences can be attributed to the ever changing consumption patterns where people are now resorting to more packaged products thus causing a rise in the amount of paper and plastic in waste streams.

4.1.2 Solid waste generation per sector

Table 4: Waste generation per sector in Mvurwi

Area	Average waste generation rate per day in kilograms
Residential	8077
Commercial	525
Industrial	157.5
Total	8759.5

Source: Field results

The results reveal that Mvurwi generates an approximated average of 8760kgs of municipal solid waste per day. The results also show that the residential sector generated more solid waste per day as compared to other sectors. This can attributed to the nature of activities that are carried out in each sector. Activities such as backyard gardening (produces green waste), the use of packaged products by residents among other things lead to the existence of high volumes of waste in residential areas. Since this sector was found to be the major waste producer, it was necessary to calculate per capita and household waste generation rates as shown in table 2. This information would then be used by the local authority for planning purposes.

4.1.3 Household and per capita solid waste generation

Table 5: Household and per capita generation rates

Average household waste generation rate per day in kilograms	Average per capita waste generation rate per day in kilograms
3.16 kgs/household/day	0.77kgs/capita/day

Source: Field results

Waste generation per capita was above the national average of 0.7 at 0.77kg/capita/day. This rise in generation rate can be attributed to the fact that in the area under study there is lack or limited application of the 3R's (re-use, recycle and recovery) resulted in more waste entering the waste stream as was established from the interviews. Muniafa in his study of 23 African local authorities in 2007 concluded that the lack of adoption of re-use, recycle and recovery principles lead to the production of high per capita volumes of waste. The per capita generation rate fares well with that of Mutare which was at 0.78kg/capita/day which was reported by Manyanhaire (2009).

With an average household size of 3.9 in Mvurwi (ZimStat, 2012), the results also point out that each household generates approximately 3.16 kgs of solid waste per day, which translates to 1153kgs per year per household. Noteworthy the 3.16kg sharply contrasts with the Chinhoyi town's 2.7kgs per household per day reported by Musademba et al, 2011. Probably this contrast can be attributed to the differences in the average number people per household and also the level of economic development.

4.2 Solid waste handling practices

Figure 3 shows the alternative waste handling practices in Mvurwi Town for residential, commercial and industrial sectors. These include but are not limited to waiting until collection, burning, dumping and composting of organics.

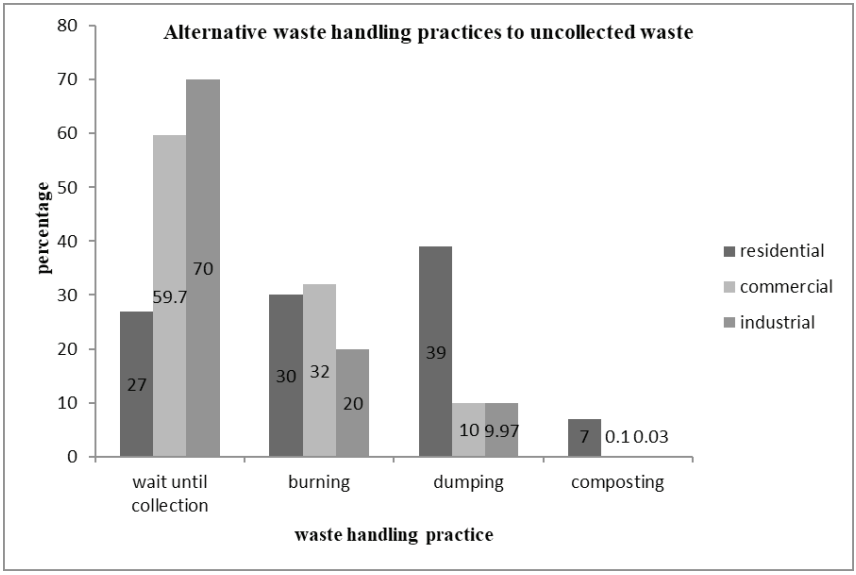

Figure 15: Alternative ways of handling uncollected waste in Mvurwi

Irregular and sporadic refuse collection schedule lead the residents to adopt various methods of waste disposal such as dumping, composting and burning which may trigger contamination of the environment and pose health risks. Waste dumping is common within the residential sector and this mainly due to high volumes of waste produced in these areas against the dwindling solid waste collection services. All areas practiced burning waste chief amongst them being the commercial areas. Waiting until collection is common in the industrial and commercial sectors mainly due to these abiding to national laws and by-laws. Composting is less popular in Mvurwi, but is being practiced in residential areas mostly in low density areas where residents would want to use the compost products in their gardens.

4.3 Types of waste receptacles in Mvurwi Town

Figure 4 illustrates the varied distribution of waste receptacles in Mvurwi Town.

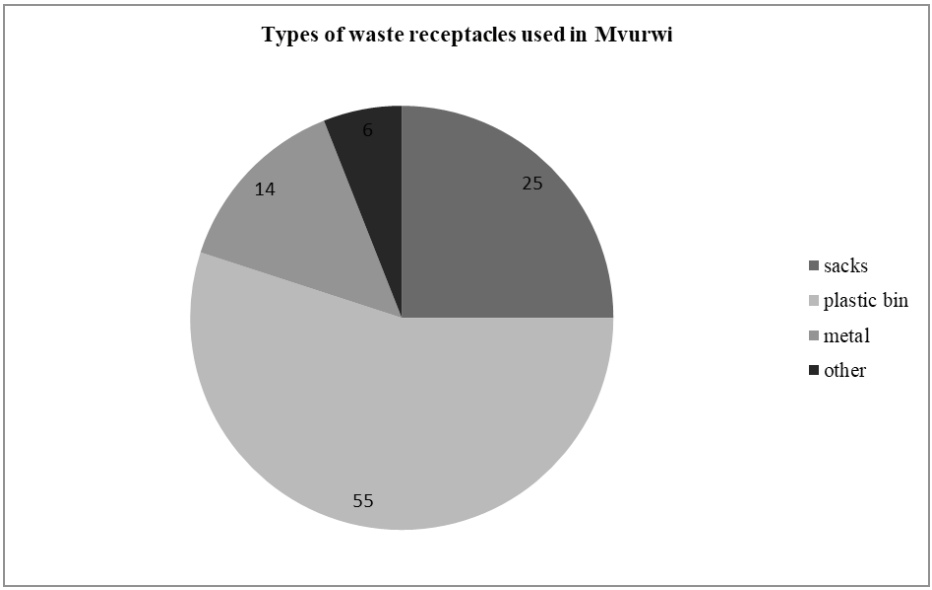

Figure 16: Types of waste receptacles used in Mvurwi

Majority of the respondents in all three sectors (residential, commercial and industrial) indicated that they use plastic bins as waste receptacles (55%). The plastic litter bins are given at the Town Council every month on payment of service charges. The use of these plastic bins was more common in residential areas (80% of the 55%) with the remainder shared equally between commercial and industrial areas. These plastic bins are small and if council takes long to come for collection they quickly overfill hence littering is more prominent in the town and this may lead to the subsequent burning or burying of the waste. Metal bins (14%) were mainly used in industrial, commercial and public convenient places due to their huge carrying capacity and durability. Sacks were also found to be used across all sectors but mainly in the residential areas.

4.4 Residents' views on waste recycling and recovery

Figure 5 shows the views of residents' pertaining to waste recycling and recovery in Mvurwi Town.

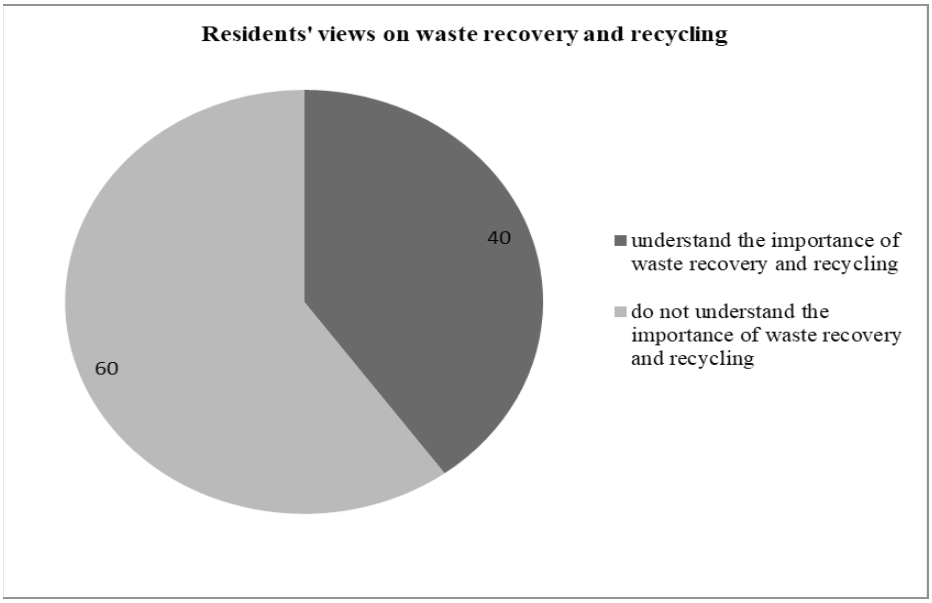

Figure 17: Residents' views on waste recycling and recovery

An approximate 40% of the people in Mvurwi understand the need to recycle and reuse waste as they attest to knowing the environmental implications of not disposing of waste properly. , whilst the remaining 60% disagree, citing contribution to waste reduction through reusing instead. Thus, they viewed recycling and recovery as being expensive and could only be viably possible at a municipal level. These ones believe that it is the obligation of the local authority alone to manage waste. This lack of understanding of the importance of recycling, re-use and recovery may lead people to indulge into unsustainable waste handling practices especially littering and burning (Mangizvo, 2010). This may be the cause of littering and burning in Mvurwi. However, understanding the importance of solid waste recovery and recycling will ultimately improve the environment by reducing the volumes of waste being disposed and also by decreasing the exploitation of virgin resources (Ncube, 2012).

4.5 Challenges being faced by Mvurwi town council in managing solid waste

Study participants cited resource constraints and political interference as the major impediments to proper management of waste in Mvurwi Town.

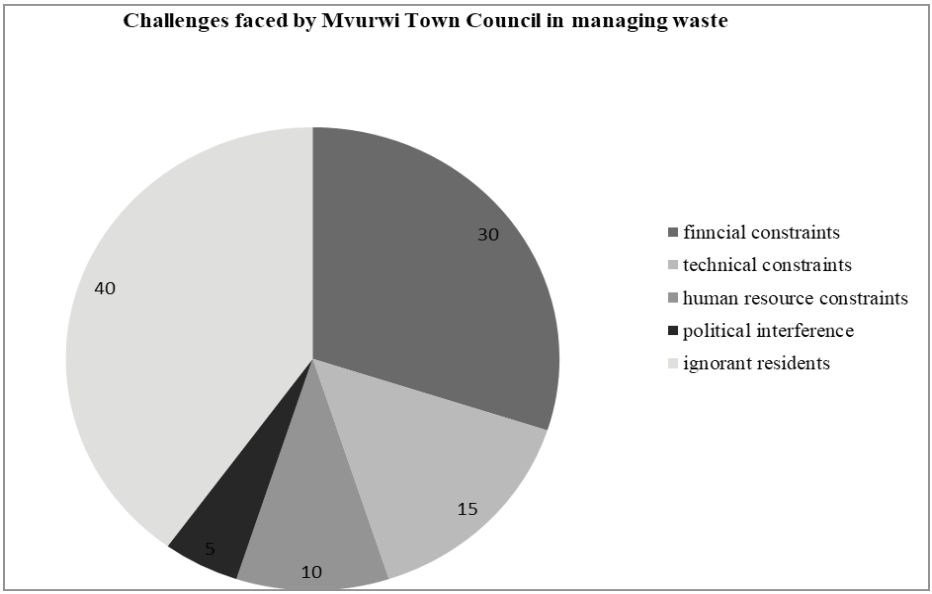

Figure 18: Challenges faced in managing waste in Mvurwi Town

It was found that, in Mvurwi Town, the greater percentage (40%) of the challenges facing the council in managing its waste is mainly a result of lack of knowledge and understanding on the importance of proper waste management among residents. Thus, residents mainly view waste management and more so, environmental protection and preservation as the sole responsibility of the local authority. Agunwamba *et al* (2003) also found that 43% of the waste management challenges in Anambra State of Nigeria were mainly a result of lack of knowledge on merits and demerits of proper and improper waste management practices among residents.

Another major challenge facing Mvurwi Town Council is that of constrained budgets. Shortage of funds derails solid waste management practices in a number of ways. Failure by the local authority to pay waste collectors results in reduced morale amongst the waste collectors and thus hinder effective and timely solid waste collection services. Fuel to power the tractors used for waste collection needs to be bought and if it is not well budgeted for, the result is ineffective waste collection services.

Technical constraints (15%) have also troubled Mvurwi Town Council in managing the solid waste produced in areas under its jurisdiction. Tractors are used for solid waste collection in Mvurwi. However, at the time of the study, it was found that of the 3 available tractors, only 1 was functional for refuse collection. Frequent breakdowns were reported to be a consequence of overuse. Moreover, the collection trailers are in a state of disrepair in most cases. This results in inadequate service coverage in most parts

of the town. As a result, the residents end up dumping waste at any vacant place, public space, or burn it in their backyard, thereby polluting the air.

Another problem that has stalled solid waste management activities in Mvurwi is the lack of expertise and manpower to run solid waste management programs. The department that oversee solid waste management is professionally understaffed and adequately staffed with poorly trained workers. Majority of council workers have little or no functional background or training in waste management, so their operations result in ineffective and inefficient solid waste management. There is no reliable measurement of generated waste. This has seen prioritization of less important issues in waste management such as concentrating on waste collection and disposal only rather than the adoption of an integrated solid waste management strategy.

Lastly, Mvurwi town council is also troubled by political interference in managing solid waste. There are times when council operations are directed by some political heavyweights for their political mileage. Council may be provided with fuel to service one particular area at the expense of other areas.

5.0 Conclusion and Recommendations

5.1 Conclusion

In the final analysis, it can be concluded that there is poor municipal solid waste management in Mvurwi. The dominance of illegal dumps, overflowing of bins and the burning of waste is due to non-collection, high generation rates and poor urban planning by the Town Council as well as ignorant and negligent residents. An array of factors, such as lack of financial, human, and technical resources have contributed to the existence of poor municipal solid waste management in Mvurwi. Members of the public exacerbated the situation by having very little concern for the environment and currently the role they play is passive and reduces them to mere ratepayers and the Town Council becomes the belligerent service provider. This is a draw back towards concerted, integrated and sustainable municipal solid waste management. Also the local authority has made insignificant strides in terms of coming up with solid waste management by-laws and educating the public.

Mvurwi Town's waste generation rates varies across the three sectors with the residential sector generating more waste followed by the commercial and lastly the industrial sector. Per capita waste generation rate was found to be significant and slightly above the national average. The municipal waste constitutes remarkable proportions of valuable renewable recyclables like paper and plastics and these were either blown up in smoke or crudely abandoned in the illegal dumps.

5.2 Recommendations

The findings and conclusions showed that the state of Mvurwi Town's waste management systems threatens the health of the people and the environment, while at the same time reducing the aesthetic value of the town. The study therefore, recommends the following primarily to Mvurwi Town Council, since it has the legal mandate as per the Public Health Act, the Environmental Management Act and the Urban Councils Act, to deliver sound solid waste management services.

i. There should be an integrated approach in solid waste management. Shop owners, the Town Council, the Environmental Management Authority, law enforcement agents, and members of the public should work in unison to alleviate haphazard disposal of solid waste in all areas. The business community has a social and environmental responsibility to provide waste receptacles where members of the public could deposit their waste after consumption of their relevant products. Advertising on those bins can also be done to gain some mileage on their business activities. These bins should be protected from vandalism, theft and should have lids to prevent scattering by scavengers.

ii. Mvurwi Town Council should rearrange their waste collection schedule from being once a week for each sector to at least twice a week or rather as according to waste generation for all the sectors. Adopting such a strategy may help to continuously map waste management problems being faced by the residents together as well as by the council. It is therefore a way for continuous assessment and evaluation.

iii. There is need for public awareness and education. This should be done through educational campaigns, the use of the mass media and also educational workshops within various communities. This does offer a platform for residents and the authorities to share their grievances and agree on relevant measures for continual functioning of the solid waste management systems in the town. Sensitizing social conscience is more effective than regulatory penalties.

iv. A well planned recycling and composting program can help to both create job opportunities and conserve material resources, hence the council should aggressively seek partnerships with the country's major waste recycling companies such as National Waste Collection in order to institutionalize waste recovery and recycling practices in the town. There is in to establish a Waste Sorting Site in the town.

v. Also the town council may consider seeking partnerships with NGO's such as ***GIZ***, local commercial institutions and the local Industry among others so that it may get financial, technical and expertise in solid waste management.

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The Scars of Gold Mining: Impacts Of Illegal Gold Mining in Chimanimani District, Zimbabwe.

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Abstract

Illegal mining violates legal instruments governing the extraction of minerals. This opinion article explores the impacts of illegal gold mining in Chimanimani District of Zimbabwe. Illegal gold mining is an evolving challenge whose impacts are both immediate and long term, but varies spatially and temporally. The main objective of the study was to examine the impacts of illegal mining in the district of Chimanimani Zimbabwe. The research uses expert knowledge and judgement based on secondary literature and personal observations by the author. In the district, alluvial gold is mined along rivers whilst reef gold is extracted from crushed rocks and purified using mercury. The gold is bought by middlemen for the market locally and for export. The economic meltdown in the country increases vulnerability of many people who in turn engage on illegal gold mining even in unstable environments. Gold mining in the district has both positive and negative impacts. Positively some people are employed, income is earned, better homes and small businesses are built. Negatively, the research concludes that illegal gold miners ignore legislation leading to destruction of forests both indigenous and exotic and river pollution. Additionally, wildlife is endangered, geoheritage in

the tourist attractions are threatened and agro-based livelihoods are threatened. The pristine water in the district is polluted as seen by changed water colour. Deteriorating economic fortunes continues to attract illegal miners into gold mining. There is lack of evidence of reclamation in the mined areas which is not surprising since the miners do not obey any regulation to protect the environment.

Keywords: Illegal, gold, mining, Chimanimani, Zimbabwe.

Introduction

Illegal mining violates legal instruments governing mineral extraction and environmental protection in many countries the world over. Mawowa (2013) notes that small scale mining has intensified due to increasing poverty levels and perennial drought occurrence. By the year 2015 there were over 400 000 unregistered illegal miners in Zimbabwe (Ncube, 2015 cited in Chandiwana, 2016). Mineral extraction is the most destructive industry to the environment (Chenje, 2000). Uncontrolled mining has the potential to cause ecological disaster (Ncube-Phiri, 2015). This background has led to the desire to explore the impacts of illegal gold mining in Chimanimani whose terrain is rugged and steep.

The article seeks to reconsider the implications of ongoing illegal gold mining in the district focusing on both positive and negative environmental and socio-economic effects in the affected areas. Illegal miners have been cited as major culprits of environmental degradation since they do not have measures to protect themselves and the environment (Chisango, 2015). The continued discovery of new gold mining areas in the district such as Blocky, Roscommon and Nyabamba in addition to the old mining areas dotted in Chimanimani National Park, Tarka Estate and Kurwaisimba areas imply that degradation of the environment is spread in those various parts of the district.

Despite several attempts by government to end illegal mining through operations like Operation Hakudzokwi in 2008 and Operation Chikorokoza Chapera in 2006, illegal gold mining goes on unabated (Spiegel, 2015). Even the lock down due to Covid 19 virus which started in March 2020 in Zimbabwe has failed to lock down the illegal gold mining industry. This then led to this review opinion paper with comments on the nature of the industry and its impacts.

Chimanimani district offers a number of economic opportunities to the country of Zimbabwe ranging from diamond mining, gold mining, timber plantations, tea estates, banana and tourism opportunities. The preservation of Chimanimani Eland sanctuary, Haroni Forest and Nyakwaa Forest is evident of the unique environment of international significance. Chimanimani Trans-frontier National Park is internationally renowned for its high biodiversity and for its endemic species of fauna and flora (Ndunguru, Dondeyue and Mulaboa, 2006). This study explores how illegal gold mining has affected the

environment, society and the local economy on the Zimbabwean side.

Preservation of Chimanimani's ecosystem is undoubtedly negatively impacted by continued discovery of gold in different parts of the district. This opinion paper is guided by previous research papers and personal observations of the impacts of gold mining activities by illegal miners and news articles on environmental issue.

This opinion article thus explores the impacts of illegal gold mining in Chimanimani District as a unique geographical area in Zimbabwe. The article uses expert judgement based on observations and secondary literature study of scientific studies on illegal gold mining conducted after the beginning of the gold rush in Chimanimani District in the first decade of the 21st century. The World Health Organisation (2016) notes that gold mining comes at a price. The price referred to by the global health body pertains to health and safety and environmental destruction (ibid).

Study area

Chimanimani District is situated in the southern part of Zimbabwe's Eastern Highlands. It consists of 23 wards covering an area of 354,805 ha and comprises all 5 agro-ecological zones of Zimbabwe (Chimanimani Rural District Council, 2017). The map on figure 1 shows the wards in which illegal gold mining is done.

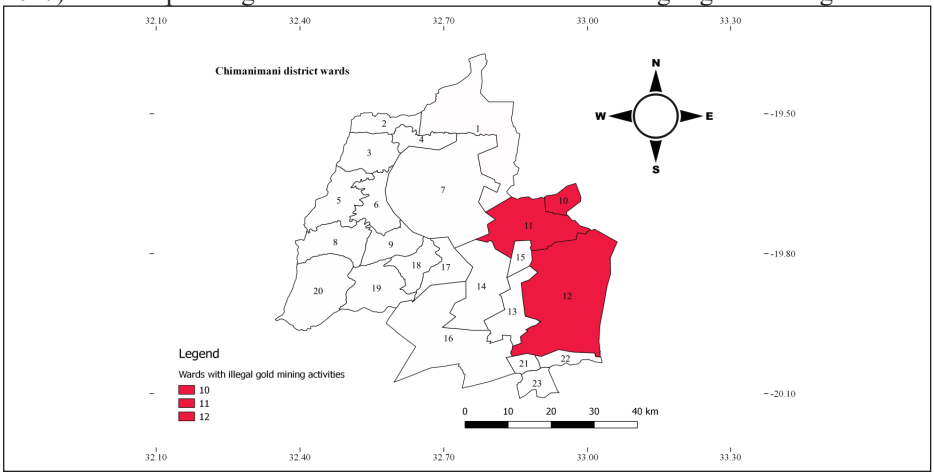

Figure 1: Map showing the wards in which illegal gold is mined in the district. Source: Research mapping

The researcher had the opportunity to visit some areas in the wards indicated during vacation and observed activities and impacts of illegal mining. The study focuses on wards 10, 11 and 12 of the district as they are the wards where illegal gold mining has been done between the year 2002 and 2020. High rainfall of up to 1400 mm per year is received in the eastern mountainous parts while the low veldt areas in the west,

declining to altitudes of 350 m only receive between 300 and 800 mm in 'normal' rainy seasons (Chimanimani Rural District Council, 2017) .

Geological formations also varies with the eastern parts being composed of fold mountains with quartzite-schist rocks The western parts are composed of the valley along the Save valley.

Due to high rainfall in the east there is dense population in Rusitu valley's Ngorima A and Ngorima B. In these communities agricultural activities are dominated by banana, maize, yams, sweet potatoes and other water loving plants.

The western parts have irrigation schemes sustaining crop production at Nyanyadzi, Chakohwa and Tonhorai irrigation schemes. However, this study focuses on the eastern part's wards 10, 11 and 12 where illegal gold mining is done.

Exotic forestry plantations dominate the economic base of the eastern parts with Border Timbers, Wattle Company and Allied Timbers being the major players. The timber industry is promoted by high rainfall received and rugged terrain which hinders mechanised commercial crop production. Indigenous forested and dense woodland areas are protected in the Haroni and Rusitu Botanic Reserves adjacent to the Makurupini Forest (Timberlake et al 2016).
Chimanimani district's eastern part is richly endowed with gold. The sandstone and quartzite formations, which constitute the summits of the mountains, are rich in gold (Ndunguru, Dondeyue and Mulaboa, 2006). Illegal miners are extracting gold in areas such as Nyashoko near Rusitu Mission, Roscommon, Nyabamba, Chimanimani National Park in the Mountain range, Charleswood Estate, Blocky, Tarka and Kurwaisimba. Gandiwa and Gandiwa (2012) in their study on biodiversity conservation versus artisanal gold mining in Chimanimani National Park noted that gold deposits are found in many parts of the park where they threaten the survival of vital flora and fauna.

These gold mining areas produce pure gold nuggets as well as gold ore from gold containing ore. The gold deposits are found where other viable economic activities in the district such as forest plantations, tourism, banana plantations and tea plantations are done. Besides gold there is also official mining of diamonds near Charleswood estate by the government owned company.

Legislation against illegal mining in Zimbabwe

A number of laws are in place against illegal mining in Zimbabwe. These laws include the Water Act of 1998 (20:25, The Environmental Management Act of 2002 (20:27), the Mines and Minerals Act of 1961 (21:05) with their amendments (Chandiwana, 2016) . All these laws among other laws aim at protecting the environment against degradation.

The methods of illegal gold mining in Chimanimani District

In Chimanimani, gold is mined by small syndicates of illegal miners ranging from 2 to 10 members. The gold is usually panned near streams and rivers for easy separation of the gold from the ore since most of the gold is found as pure gold nuggets or referred in the mining areas as *points.*

Gold is mined using simple methods of picks, shovels and dishes. Shafts as deep as 15 metres are common where illegal gold miners mine even along river banks (Zhakata, 2019). At Nyashoko near Rusitu Mission for example deep shafts were observed which were a danger to the miners, who however showed no sign of fear.

Some miners have brought in rock grinding machines where the gold is extracted from the gold bearing rocks. Observations indicated that mercury is used by those who crush rock ore for processing of gold. There is less doubt that mercury is smuggled into the district from outside the district by gold dealers who sell it to the illegal gold miners.

The smugglers and unaccounted gold loss

Mawowa (2013) notes that while official gold production has reportedly been declining, artisanal small miners and smuggling activities have been increasing. This observation is supported by Gono (2007) who notes that over 15 thousand kilogrammes of gold valued at over US$400 million, diamonds worth over US$800 million and other minerals worth over US$200 million were being smuggled out of the country annually.

The mined gold is mainly smuggled across the porous borders of Zimbabwe into Mozambique and South Africa where it is sold at a higher price than in Zimbabwe. Some of the gold is smuggled through the common exit points but likely by well connected corrupt individuals who do not care about national development, but fattening their own pockets. The smuggling is mainly done by gold dealers who buy it from the miners whose lifestyle is mainly mining for subsistence. The gold smuggling industry is beyond any doubt linked to the politically strong muscles who can easily by-pass all the attempts to reduce gold loss through illegal export and smuggling. Observations made indicated that gold was sold to those buyers known to the illegal miners. New comers were treated with suspicion to the illegal miners since there was fear of the law enforcement agents.

The Alternative Information and Development Centre (2016) notes that in the first week of March 2008 during Operation Hakudzokwi about 38 soldiers and 19 cops were arrested at Chiadzwa for operating mining syndicates. This is a clear example of well connected and elusive mafia type of illegal activities with little regard for negative impacts of illegal mining. Corruption has rendered the illegal gold mining industry thrive due to economic hardship. Thus, smuggling of gold and other precious minerals

is likely to stay as long as corruption stays with us. This judgement came from the observations done during the visit to some mining areas.

Socio-economic impacts of illegal gold mining in Chimanimani

Mutero (2016) notes that despite the negative effects of illegal mining there is need to consider it as a livelihood strategy. Hamilton et al (2006) notes that it is possible to transform mineral wealth to other forms of wealth such as buildings, machines and human capital.

It was observed along Nyabamba River mining area that people are employed in the gold mining industry though informally. Moreover, some people have established businesses from the mining benefits. General dealer shops, transport operators and some houses have been pointed to the researcher as being direct benefits of gold mining.

Gold is a valuable mineral that is usually a symbol of wealth. Gold is purified to produce some of the most expensive necklaces, rings and other jewellery. Gold is also a store of value and wealth. It is used to stabilise currencies in the form of reserve banks bullions. It is rarely kept by the poor but the affluent like to be associated with it. Thus, the riches from the ground are smuggled with little to show as a sign that the district has valuable minerals. Despite this, individuals have benefited a lot from gold mining in the district.

Conflicts over control of mining tunnels are common. This was the case at Blocky mining area. Moreover, at Nyashoma near Rusitu Mission conflicts over tunnels was also observed. In the National Park and timber plantations which are private property, evidence of conflicts was observed. Miners were not at liberty to entertain a visitor who was new in the area for fear of arrest as one miner said.

Also flea markets have been established to sell clothing materials. Food stuff in the area is very expensive for example a broiler chicken was selling at US$9-10 each. This is an indication of how expensive goods are in the mining areas as compared to other areas in the district where no mining is done. This observation indicates a hive of economic activities in the mining areas.

Environmental scars of illegal mining in Chimanimani

In Chimanimani the environmental scars left by illegal gold miners and their rich associates in the smuggling industry are visible. These scars heal slowly. The old scars heal whilst new ones are opened due to continued discovery of gold deposits. Gandiwa and Gandiwa (2012) cited a lot of research findings on the impacts of gold mining in the district and proffered remedies specifically to safeguard the ecosystem in the National Park and surrounding areas. Some effects of greater significance are riverbank instability, loss of vegetation, land degradation, reduced water quality, ground water

contamination and abandoned pit scars (ibid).

River banks of the following rivers: Muchira, Nyabamba, Haroni and smaller streams in the study area are destroyed. The water is clearly brown-redish where the miners wash their gold ore.

Commenting on gold mining on the Mozambican side Timberlake et al (2016) notes that gold mining activities are having very deleterious effects on aquatic ecosystems, particularly on flow regimes and probably on populations of aquatic invertebrates and vertebrates. This also applies to the Zimbabwean side of the mountains. Thus, illegal gold mining leaves a lot of damage and possible permanent disturbance of ecosystems in the mountains area.

These effects have effectively been spread to all the areas in the district where gold is being mined and discovered. Since the gold rush in the district started in the year 2002 the extraction is still ongoing, being driven by the economic meltdown of the country that is driving the majority of people to the gold mining industry.

Effectiveness of society and environmentalists is being tested daily against the impacts of illegal gold mining in Chimanimani as in any district in Zimbabwe. Samaita (2020) notes that machete wielding gangs hold Zimbabwe gold miners hostage leading to permanent social scars due to murder of some innocent miners by the gangs. This is also the case in the district where some people have lost lives due to illegal miners' menace.

Many solutions have been proposed against the panners but the war is still ongoing to the extent that the famous *machete* gangs have even developed the guts to challenge law enforcers in their own bases.

One of the impacts of gold mining in Chimanimani District is river pollution. Bande (2020) notes that cattle in Penhalonga died after drinking water contaminated with gold refining cyanide. This is also common where the illegal miners are involved in Chimanimani District. Several rivers in the district have shown signs of degradation through pollution. Heavy red soils, cyanide and mercury have all been dumped and deposited into the rivers. Fears of underground water contamination are high in the mining areas as indicated by Gandiwa and Gandiwa (2012). Rusitu, Haroni, Nyabamba, Mwatsara, Nyahode Rivers and other smaller streams have been changed from once beautiful clear water rivers into red and hazardous waters.

Fertile soils have been disturbed through open cast gold panning along river valleys. It was observed at Blocky which was part of Agricultural Rural Development Authority farm that holes and trenches have been left open. The farming area on the south facing ridge has been degraded with deep holes being clearly visible without rehabilitation being done. Gandiwa and Gandiwa (2012) have also indicated that disturbance of soil structure and soil profile are common in the mining areas in the district. Land degradation

is evident in the district in places like Nyabamba, Kurwaisimba, Charleswood, National Park and Tarka mining areas.

Indigenous trees have been destroyed. Exotic timber plantations have also been destroyed in search for the yellow mineral. Pine trees and gum plantations belonging to Allied Timbers and Border Timbers have been felled. Tarka Forest, Chisengu and Tilbury have been disturbed with trees being destroyed beyond economic recovery. Thus, Bande (2020) concurs and pointed out that illegal gold mining activities in the district ravages timber plantations belonging to Allied Timbers. In this process even endangered species are threatened.

Animal species have been dispersed since their habitats have been destroyed. Eland sanctuary is offered in Chimanimani National Park but the presence of gold panners has threatened the survival of Eland sanctuary and other wildlife in the park. Chimanimani National Park measuring 8186 hectares was gazetted in 1949 to conserve the mountain ecosystem and promote tourism (Timberlake et al 2016). Illegal gold mining in the National Park disturbs geoheritage of the country and hence affects geotourism and ecotourism. The minerals, mountain range, caves in the mountain, water, waterfalls, springs and rocks are part of the geoheritage that has been threatened by gold mining in the National Park areas.

The rugged terrain of Chimanimani makes it the source of many countless water sources. The mountainous terrain makes the watersheds separating different river of stream sources vulnerable. Illegal miners follow the gold belts which are found in these watersheds which then become vulnerable. Thus, headwater wetlands and water sources are threatened.

Conclusion

This conclusion gives expert judgement from observations made in some sites where illegal gold mining is done and studying scientific literature. It has to be noted that there is evidence of environmental disturbance in the mining areas though some socio-economic gains can be identified.

The economic meltdown in Zimbabwe makes environmental management difficult. There is need to balance sustainable livelihoods and environmental protection. The majority of panners are likely to argue that they have little or no option but to try their luck in the gold mining for survival. This has also been raised by Zhakata (2019) along Sakubva River where illegal miners were claimed to even mine in the heavily polluted river.

Economic challenges also contribute to high levels of corruption which makes it difficult for the law enforcers to follow ethical values or procedures against illegal gold mining. It can be said when the stomach is hungry the mind knows no morals. However, there

must be order to ensure that the exhaustible resources of Zimbabwe, once discovered, can only be depleted after contributing to tangible wealth creation for future generations in the form of human capital development, infrastructural development and social improvement of the inhabitants (Hamilton, 2006). Thus, mineral wealth from gold can lead to sustainable development in the district.

Socially, gold mining in the district is seen as a source of employment by the unemployed who are involved directly and indirectly in the mining activities. Income is raised to fund building of houses and shops by some of the local people.

Thus, Zimbabwe and Chimanimani district in particular must ensure that there is evidence left behind for future generations to witness that gold was mined in the area. Rehabilitation of mined areas can also ensure vegetation growth is promoted. Since the areas receive plenty of rain water vegetation growth and recovery can be expected within a short space of time.

One of the recommendations made is that more studies have to be done perhaps using remote sensing and geographic information sciences to quantify the level of damage resulting from illegal mining activities in the district. Moreover, impacts of illegal mining of gold on other livelihood strategies may need to be examined through study in the district where specialised and diversified farming thrive.

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Design And Development Of A Constructed Wetland For The Remediation Of Water Pollutants Along Perennial Rivers.

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Abstract

Access to clean water in Harare has been hindered by the anthropogenic activities occurring along the perennial river channel wetlands. These activities destroy the unique plant and microbial ecosystems harbored by wetlands that would normally remove the pollutants present in wastewater. This study aimed to design, develop, and construct an artificial wetland prototype as a cost-effective wastewater treatment strategy. The wetland was developed using Typha latifolia and Cyperus alternfolious, as well as acidophilic microbes isolated from the root surfaces of both aquatic plant species. Total Nitrogen, Total Phosphorous, pH, BOD, COD, lead, cadmium, zinc, and copper concentration levels in the water at different points of Mukuvisi River were measured and analyzed using the students' t-test. The p-values of Total Nitrogen, pH, and zinc were 0.08071, 0.8330, and 0.9077 respectively, which meet the World Health Organization (WHO) effluent discharge threshold values. However, the total Phosphorous, COD, BOD, lead, cadmium, and copper concentration mean values

were significantly greater than WHO discharge threshold values with p-values 0.02112, 0.01689, 0.01196, 0.01337, 0.01825, 0.0293, respectively. The bioremediation processes in the constructed wetland were evaluated at 14 intervals, with both Typha latifolia and Cyperus alternfolious plant species shown to reduce the quantity of water pollutants. In addition to the water filtering properties, the constructed wetland design proposed in this study may be harnessed along perennial rivers with aesthetics as well as air pollution monitoring features.

Keywords

Bioremediation, Constructed wetlands.

1. Introduction

Domestic water quality is a critical challenge in Harare since it has affected the quantities of water released from Morton Jeffery water treatment plant to residential areas for domestic use (Mufandaedza and Kamusoro, 2012). Perennial rivers in Harare which include Mukuvisi and Marimba act as reservoirs of both water and pollutants since the water they catch through industrial effluent discharges and water inflows from residential areas (Nyamangara *et al*., 2012). Prevalent water shortages in Harare, which are due to a limited supply of imported chemicals to treat wastewater, drive residents living near the perennial river to use the polluted and raw sewage water for domestic use and agriculture purposes (Masara, 2012). These shortages pose threats to waterborne diseases such as typhoid (Magadza *et al*., 2008). The re-occurrences of waterborne diseases such as the cholera outbreaks in 2009 and 2010, has claimed many lives in Zimbabwe (Mangizvo, 2009; Lee, 2013). Exorbitant water charges and acute water rationing prevail in Harare are partly due to shortages of imported chemicals required to treat water at Morton Jeffery water treatment plant (Nhapi, 2007). Lake Chivero, which is the sink of Marimba and Mukuvisi River has been attacked by aquatic weeds such *as Eichhornia crassipes*. The growth of the *Eichhornia crassipes* (water hyacinth) has affected aquatic life, causing the death of fish and affecting recreational activities. The growth of *Eichhornia crassipes* is continuously enhanced through the enrichment of nitrogen and phosphorous from sewage overflow from residential areas, which is carried by perennial rivers in Harare into Lake Chivero (Masara, 2012).

Constructed wetlands have been widely used to filter several pollutants from different polluted water sources (Aremu and Ojoawo, 2012) such as sewage systems and industrial effluents (Schlesinger, 2008). Wetlands also break the cycle of virulent pathogens of new and emerging micro contaminants such as the endocrine-disrupting compounds in polluted water (Davies-Colley *et al*., 1999). However, in Zimbabwe, the idea of constructing wetlands using naturalized semi-aquatic plants such as *Typha latifolia* and *Cyperus alternfolious* species to filter water pollutants has not been adopted. Other aquatic plants that have high ecological risks such as the *Eichhornia crassipes* have been widely studied and have shown a great remediation potential.

The factors that influence phytoremediation, which is a natural process of pollutant removal in wastewater involving plants, involves accumulation of the pollutants in the cells of roots and translocation of the pollutants to different parts of the plants (Piyush *et al*., 2012). The substrates such as gravels, sand, limestone, and river rocks used in the constructed wetlands influence the remediation processes in wetlands by directly precipitating and filtering suspended solids, absorption of heavy metals, and organic matter (Murray-Gulde *et al*., 2003). The constructed wetland substrates also indirectly influence the remediation processes by adhering microbes to the aquatic plant roots to form biofilms and supporting the growth of plants through root anchorage.

The metabolic mechanisms of the microorganisms in wetlands have enhanced their survival through the reduction of water pollutants. Aquatic environments contaminated with recalcitrant organic compounds can further be remediated by the interaction of plants and microbes in the rhizosphere (Collins *et al*., 2013). Biochemical changes are integral to phytoremediation technology on account of their increased efficiency. Biotechnological applications such as genetic engineering, omics (proteomics, genomics, and metabolomics), and bioinformatics have made remarkable advances in boosting the efficiency of phytoremediation technology (Macek *et al*., 2000).
This study is of great importance since the development of environment bioreactors will serve as a natural water filter, to improve river water quality. The aquaculture industry will be boosted since hyperaccumulator plants will deal with nitrogen and phosphorous enrichments, gradually suppressing eutrophication by problematic plants such as *Eichhornia crassipes*.

2. Methodology

2.1 Preparation of the simulated wetland

The ponds in the simulated wetland were plastered with mortar containing cement, clean river sand, and impermo powder. The ponds were filled with river sand.

2.2 Identification and selection of aquatic plants of low ecological risk

The common aquatic plants in both the wetlands and the major rivers in Harare (Manyame, Marimba, and Mukuvisi Rivers) were collected for identification and characterization. The plants that were collected were identified and characterized by Professor S. Kativu. The researcher visited the National archives at the Botanical Gardens to confirm the record of the selected plants in aquatic environments in Zimbabwe.

2.3 Water collection for analysis

Water samples were collected along the Mukuvisi River to analyze physical and chemical parameters regardless of the site. A site along Mukuvisi River with coordinates S17° 51'11.16"E31° 2' 42"used to collect water for the remediation process in the simulated

wetland pond.

2.4 Planting of the selected plants

The selected plants (*Typha latifolia* and *Cyperus alternfolious* species) were collected in some natural wetlands with coordinates, S17°48'11.9412 " E31°2'17.1852 " and S17°47'30.472 " E31°2'25.6236 " respectively. The sampling technique used was random quadrant sampling. The young shoots of *Typha latifolia* plants and young plants of *Cyperus alternifolious* species were used for the experiment. The shoots of the *Typha latifolia* plants were cut 24 cm from the rhizomes and young plants of *Cyperus alternifolious* species were transplanted into the ponds for the bioremediation process after the ponds had been filled with the Mukuvisi River water sample. The different treatment ponds were makeshifts ponds which were the control*, Typha latifolia* plants, *Cyperus alternifolious* plants only, and both *Typha latifolia* and *Cyperus alternifolious* plants which were run in duplicate to remove bias.

2.5 Isolation of acidophilic microbes in a selected natural wetland

Two wetland sites in Waterfalls residential are with coordinates, S17°54'30.55752 " E31°1'52.56087 " and S17°54'20.68415 "E31°1'41.51516 " were sampled using the transect sampling. The demarcated area was dug to a depth of 10 cm at 2m intervals diagonally; three replications of the soil sediments were taken at each site using a sterilized hand metal scooper. The soil sediments were collected in sterile 250 ml glass bottles. The pH of soil sediments that were collected at the two different wetland sites is were measured. The protocol for the isolation of acidophilic microbes from wetlands was adapted from (Noriaki and Mimasaka, 1986). Bacteria were isolated on Glucose-Yeast extract agar (g/1 of distilled water: $(NH_4)_2 S0_4$, 2.0; KC1, 0.1; K_2HP0_4, 0.1; $MgS0_4$ $7H_20$, 0.5; glucose, 1.0; yeast extract, 0.1, agar 30. The pH of the medium was adjusted to 4.0 with H_2S0_4.

2.6 Water quality testing

The physical and chemical parameters were tested following the Standard Methods for the examination of water by the American Public Health Association guidelines (APHA methods of 1985).

2.7 Statistical analysis of the water samples

One sample t-Test was used to analyze the values obtained from the physical and chemical parameters from the water samples along the Mukuvisi River regardless of site.

2.8 Design of the constructed wetland

The constructed wetland was designed in such a way that it was easier to manage, it had additional features that restored aesthetics and promoted the bioremediation processes. The plan of the artificial wetland was designed using the Achicard software.

3. Results and Discussion

3.1 Identification and selection of semi-aquatic plants of low ecological risk

The common aquatic plants that were identified in the aquatic ecosystems were *Nymphaea lotus* (Water lily*)*, *Panicum repens* (Torpedo grass), *Imperata cylindrical* (Cotton wool grass), *and Typha latifolia* (Cattail), and *Cyperus alternifolious* (Sedges). The Botanist recommended the semi-aquatic plants, *Typha latifolia* and *Cyperus alternifolius* species to be used for bioremediation processes. The *Cyperus* plants have intrinsic characteristics which include high reproductive output, rapid growth, extended seed dormancy that promotes population expansion after disturbance (Dowler *et al*., 1974), which makes these plant species highly competitive over other wetland plants (Kativu, pens. com). Cultural methods of hand removal, hoeing have been used effectively to control the growth of sedges (Elmore, 1984). Mechanical tillage, flame cultivation, and application of chemical treatments are also effective methods to control the growth of sedges. *Cyperus alternifolious* can be grown using seeds, stolons, runners, tubers, and corms (Bailey, 1962).

Typha is semi-aquatic evasive plant species that grow on different substrate types which include gravel, sand, peat, clay, and loamy soils (Morton, 1975). *Typha* species are evasive they can be controlled chemically and physically. *Typha* plants can be treated using chemicals such as the roundup herbicide. Herbicide treatment at the flowering stage of cattails plants can be effective than other growth stages since it is a critical stage where energy investment by the plant has been channeled into flowering. Physical methods of controlling cattail growth by hand removal or mechanical removal followed by submergence of all cattail stems are effective to stop cattail regrowth (Nelson and Dietz, 1966)

3.1 Isolation of acidophilic microbes in a selected natural wetland

The acidophilic microbes were isolated in the root surfaces of the *Typha latifolia* and *Nymphaea lotus* plants soil sediments. The morphology of isolated microbes is presented in Table 1 and Table 2. The isolated microbes in Fig 1 from the soil sediments of the natural wetland grew at pH 4. The pH 4 for the medium composition, was selected since studies on the isolation of acidophilic heterotrophic bacteria by (Noriaki and Mimasaka, 1986) acidophilic heterotrophic bacteria from acidic mineral environments soil sediments ranged between pH 2.4-5. During (Noriaki and Mimasaka, 1986) study there were no reports about the isolation of acidophilic heterotrophic bacteria from weakly acidic environments. In this study fungi and bacteria were isolated in a mean pH of 7.4 and 7.6 of the soil sediments sampled from the root surfaces of wetland plants, suggesting that the microbes that were isolated could have survived in alkaline

conditions for 16 hours after soil sediment sampling in the wetland.

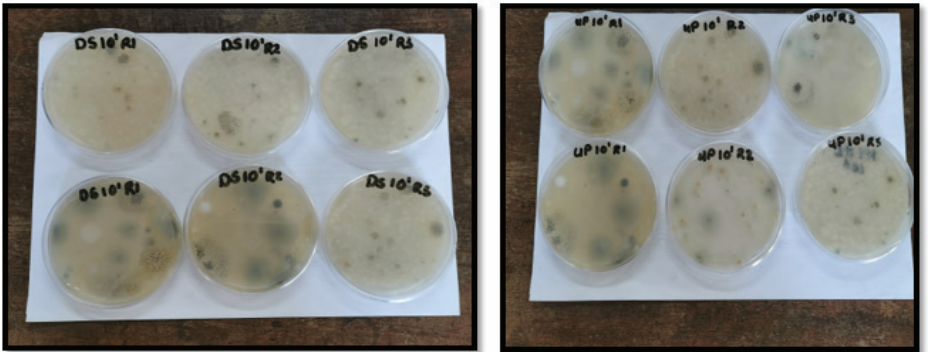


Figure 1: Selected Petri dishes with fungi and bacteria colonies.

Table 1: The morphologies of bacteria colonies isolated from Waterfalls wetland.

Pigmentation	Form	Surface	Density	Edges
red	circular	smooth	opaque	entire
white	circular	smooth	opaque	entire
cream	circular	smooth	opaque	entire

The bacterial colonies had the same morphologies except for pigmentation which differentiated them. The fungal colonies in GYE agar from the soil sediments of the root surfaces displayed different morphologies as described in Table 2.

Table 2: The morphologies of fungal colonies isolated from Waterfalls wetland.

Pigmentation	Form	Surface	Density	Nature of spores
dark green	rhizoid	rough	opaque	not present
white	rhizoid	glistening	opaque	not present
Grey	circular	filamentous	translucent	budding

Some acidophilic microbes are not cultivatable hence the molecular techniques such as 16S rRNA sequence-based approaches and environmental metagenomics are used to identify microbes in wetlands (Ferrari *et al.,* 2008). Culture methods of isolating acidophilic microorganisms are challenging to the microbiologists since they have to identify required nutrients, to provide them in the growth medium in the appropriate concentrations to sustain the microbial growth, and avoid the co-precipitation of the introduced chemicals. The fraction of the "not-yet-cultured" groups of prokaryotes can be grown by the refinement of classical approaches (Bollmann *et al.,* 2007). Two types of "*in situ* colonization devices" have been developed: the diffusion chambers

and the carriers to remove low-molecular-weight inhibitory end-products, as well as the exchange of chemicals between the chamber and the environment, thereby making high-density cultivation possible (Kaeberlein *et al.,* 2002).

3.2 Assessment of the water quality along Mukuvisi River

The grab sampling technique was used to collect water samples along Mukuvisi. Two water samples were collected along with different points with coordinates S17° 51' 50" E 31°1 ' 47", S17° 51'11.16"E31° 2' 42", S17° 54' 30"E30° 58 ' 22, S17° 58' 17"E30° 50' 45" and S17° 58' 47' E31° 56' 53" respectively. The mean values of the assessed parameters were entered into a statistical program R, to analyze data. The outcomes of the One-Sample t-Test for assessing the water quality of the Mukuvisi River regardless of the site showed that the Total Nitrogen, pH, and zinc met the WHO threshold values for effluent discharge into water bodies. The p-values of Total Nitrogen, pH, and Zinc were 0.08071, 0.8330 and 0.9077 respectively, these p-values were greater than 5 %. The mean values for Total Nitrogen, pH, and zinc are not significantly different from the WHO threshold values.

However, Total Phosphorous, COD, BOD, lead, cadmium, and copper mean values were significantly greater than WHO threshold values with p-values 0.02112, 0.01689, 0.01196, 0.01337, 0.01825, 0.0293 respectively were less than 5 %. The WHO threshold values on Total Phosphorous, COD, BOD, lead, cadmium, and copper were not met regardless of site. The high concentration of Total Phosphorous in the Mukuvisi River could have been contributed by surface runoff from agricultural practices through fertilizer application since the water samples were collected after since the sample was collected beginning of the rainy season. Sewage overflows and dump sites along Mukuvisi River tributaries might have contributed to the high concentration of the Total Phosphorous. The high concentration of metals which include lead, copper, and cadmium in the Mukuvisi River may be evidence that the effluent discharged by manufacturing industries is not being treated before discharge in surface waters.

3.3 Assessment of *Typha latifolia* and *Cyperus alternifolious* plants in bioremediation

The six water samples collected using the grab sampling method along Cripps Road with coordinates S17° 51'11.16 " E31° 2' 42 ", were analyzed for the physical and chemical water quality parameters and their mean values were calculated and presented in Table 3. The mean values of the assessed parameters were used to investigate how the *Typha latifolia* and *Cyperus alternifolious* plants in different treatment ponds, were remediating the collected Mukuvisi River water sample.

Table 3: The mean values of the Mukuvisi River water sample used for the bioremediation

process.

Water quality parameter	Mean value
Total Nitrogen	31mg/l
Total Phosphorous	4.7mg/l
pH	4.3
COD	356mg/l
BOD	186mg/l
Cadmium	6.10mg/l
Copper	3.25mg/l
Lead	5.75mg/l
Zinc	2.30 mg/l

3.4 Analysis of Water quality parameters during the bioremediation

The ponds were divided into two quadrants for each treatment. The water was collected in sterile 500 ml glass bottles. The treatments for the ponds were the control pond which has the Mukuvisi River water sample only, *Typha latifolia* plants pond, *Cyperus alternifolious* plant pond, and two ponds that had both the *Cyperus alternifolious* and *Typha latifolia* plant species. The two ponds which had both the *Cyperus alternifolious* and *Typha latifolia* plants had almost the same capacity as ponds which had one of the plant species only. During water sampling at 14-day intervals, the growth stages of the plants were observed and recorded as presented in Table 4. However, on campaign 5, had an excess of 9 days.

Table 4: Report of aquatic plant biomass in the simulated wetland during the bioremediation process.

Campaign	General description of the plant biomass in ponds with different treatments
0	The initial planting of Cyperus *alternifolious* and *Typha latifolia* plants
1	*Typha latifolia* and *Cyperus alternifolious* plants had developed new rhizomes and the roots in *Cyperus alternifolious* plants had attached to the river sand which was the substrate.
2	*Typha latifolia* plants showed many rhizomes and numerous shoots developing in *Cyperus alternifolious* species.
3	Shoot development is seen in *Typha latifolia* species and an increase in foliage development in *Cyperus alternifolious* species.
4	An average of 4 shoots per plant in *Typha latifolia* plants and an increase in *Cyperus alternifolious* plant foliage per plant. Litter in ponds from *Cyperus alternifolious* species.
5	The ponds had been colonized with both the *Cyperus alternifolious* and *Typha latifolia* plants

3.4.1 Total Nitrogen concentration in ponds with different treatments at 14-day intervals

There was a Total Nitrogen concentration decrease in water in the ponds which had *Typha latifolia* plant species only and in the water in duplicated ponds with both the *Typha latifolia* as shown in Fig 2. *Cyperus alternifolious* plants and the control pond water Total Nitrogen concentration was showed a slow decrease. Studies have revealed that major nitrogen removal mechanisms in constructed wetlands in wastewater are microbial interactions with nitrogen, sedimentation, chemical adsorption, and plant uptake (Khatiwada and Polpraset, 1999). The influence of nitrogen removal in wetlands includes nitrification, denitrification, and accumulation of organic nitrogen in peats because of the redox potential of hydric sediment (Shah, 2014). The removal of nitrogen through nitrification is performed by nitrifying microorganisms which include *Nitrosomonas*, *Nitropira*, *Nitrosococcus*, and *Nitrobacter* (Maille *et al*., 2009). Microorganisms that remove nitrogen through denitrification in wetlands are heterotrophic and they include *Pseudomonas*, *Micrococcus*, *Achromobactor*, and *Bacillus s*pecies under anaerobic or anoxic conditions (Shah, 2014). The biofilm formed on the root surfaces of wetland plants may increase denitrification rates because periphytic algae provide a desirable carbon source for denitrifiers (Armstrong *et al*., 2005).

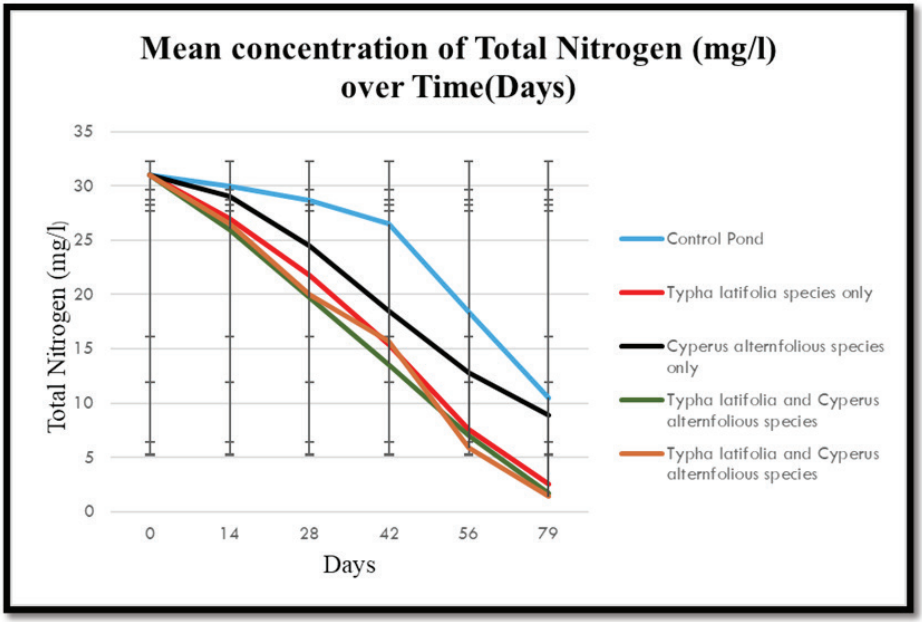


Figure 2: The graph of mean Total Nitrogen concentration of the Mukuvisi River water sample at 14-day intervals in ponds with different treatments.

3.5.2 Total Phosphorous concentration in ponds with different treatments at 14-day intervals

The water in ponds with the *Typha latifolia* plants only and the duplicated ponds with both the *Typha latifolia* and the *Cyperus alternifolious* plants showed a rapid decrease in Total Phosphorous concentration. The water in the control pond and the pond with the *Cyperus alternifolious* plants only showed a slow decrease as shown in Fig 3. The mean of Total Phosphorus concentration in water, with ponds, duplicated ponds with both the *Typha latifolia* and the *Cyperus alternifolious* plants including *Cyperus alternifolious* plant species only, had a slight increase of the Total Phosphorus mean concentration around day 56.

Some other studies in constructed wetlands treating wastewater with *Cyperus alternifolious* plants revealed that litter from *Cyperus alternifolious* plants can release phosphorus (Nichols, 1983). The physical mechanisms in phosphorus removal in wetlands include adsorption, filtration, and sedimentation (Vinita *et al.*, 2008). Total Phosphorus reduction in wastewater in constructed wetlands can be achieved through phosphorous storage in sediments, biota, (plants, biofilm, and fauna), detritus in constructed wetlands (Polomski *et al*., 2009).

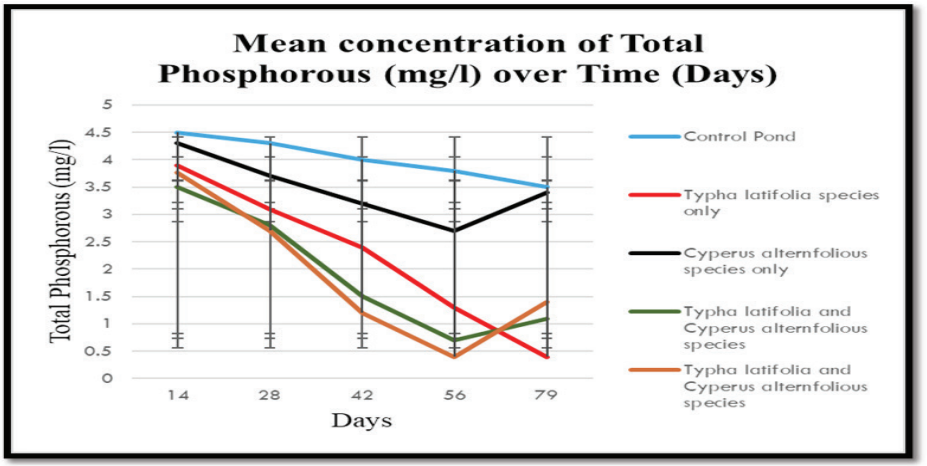


Figure 3: The graph of mean Total Phosphorous concentration of Mukuvisi River water sample at 14-day intervals in ponds with different treatments.

3.5.3 Analysis of pH in ponds with different treatments at 14-day intervals

The water in the ponds of the simulated wetland showed a pH increase during the bioremediation period from acidity to alkalinity as shown in Fig 4. Environmental factors such as rainfall could have influenced pH alkaline conditions in the control pond of the simulated wetland through dilution of the Mukuvisi River water sample.

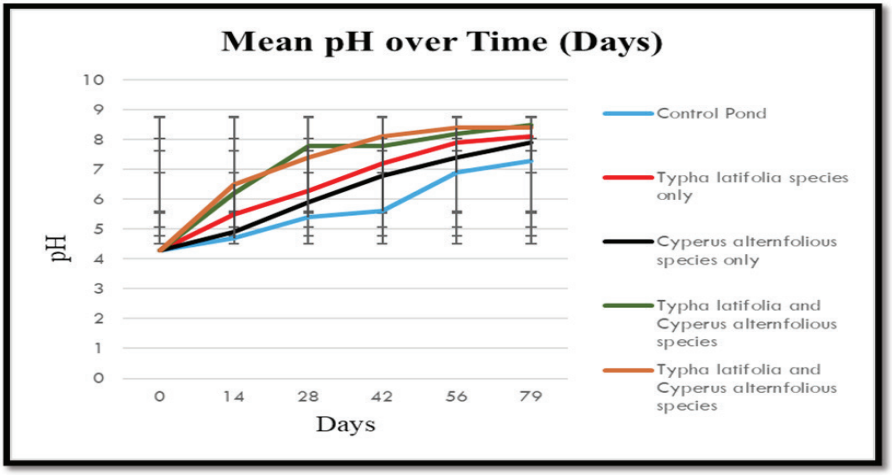


Figure 4: The graph of the mean pH of the Mukuvisi River water sample at 14-day intervals in ponds with different treatments.

3.5.4 BOD concentration in ponds with different treatments at 14-day intervals

There was a reduction of the mean BOD concentration in the Mukuvisi water sample all the ponds of the simulated wetland. There was a rapid decrease in BOD of the water in duplicated ponds with both the *Typha latifolia* and *Cyperus alternifolious* plant species including the water in the pond with *Typha latifolia* plants only shown in Fig 5.

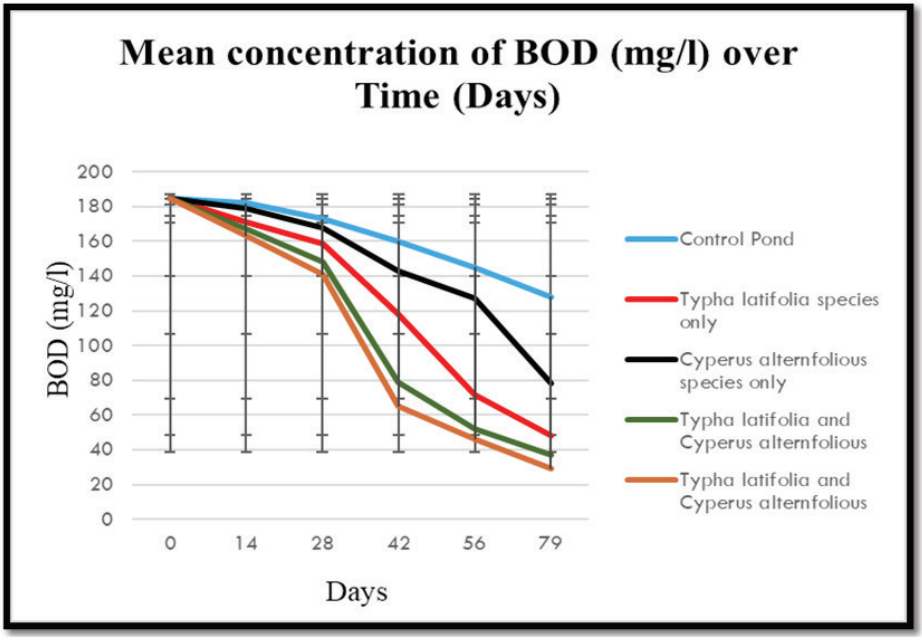


Figure 5: The graph of mean BOD concentration of the Mukuvisi River water sample at 14-day intervals in ponds with different treatments.

Studies have revealed that nitrifying bacteria of the autotroph group have lower respiration rates than the heterotrophs, which are responsible for BOD removal (Ahn, 2006). In constructed wetlands systems with the subsurface flow, the nitrification process does not take place before substantial BOD reduction (Maille *et al*., 2009). The other factors that influence the reduction of BOD concentration in wastewater which filters through wetlands are oxidation reactions of organic matter generating energy for microbial metabolism (Polomski *et al*., 2009).

3.5.5 COD concentration in ponds with different treatments at 14-day intervals

The COD concentration reduction in water in the ponds that were duplicated with both the *Cyperus alternifolious* and *Typha latifolia*, including the water in the pond that had *Typha latifolia* plants only, was rapid as shown in Fig 6. The water in the pond with the *Cyperus alternifolious* plant species only and the water in the control pond, COD concentration reduction was slow. Similar results were also reported by other researchers

(Prabu and Udayasoorian, 2007), who calculated the reduction COD concentration of pulp mill wastewater efficiencies, by semi-aquatic plants *Typha latifolia* and *Cyperus pangorei* which were 62.55% and 49%, respectively. The Hydraulic Residence Time of pulp mill wastewater during the study was 24 hours for 9 days, at stages where the plants had fully colonized the wetland.

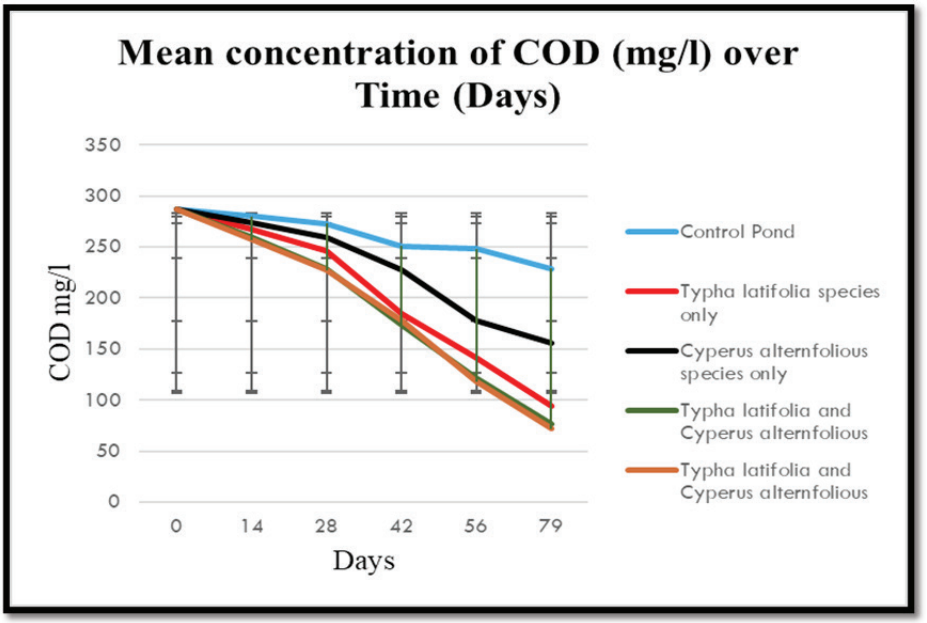


Figure 6: The graph of mean COD concentration of the Mukuvisi River water sample at 14-day intervals in ponds with different treatments.

3.5.6 Cadmium concentration in ponds with different treatments at 14-day intervals

The cadmium concentration decreases in water in duplicated ponds with both the *Typha latifolia* and *Cyperus alternifolious* plants including the water in the pond with *Typha latifolia* plants only was rapid as shown in Fig 7. The water in the control and water in the pond with *Cyperus alternifolious* plants only, cadmium concentration reduction was slow. Similar studies were done in India, in treating distillery and tannery effluent using *Typha angustifolia* and *Cyperus esculentus*, showed that these plants are root accumulators of cadmium (Yadav and Chandra, 2011).

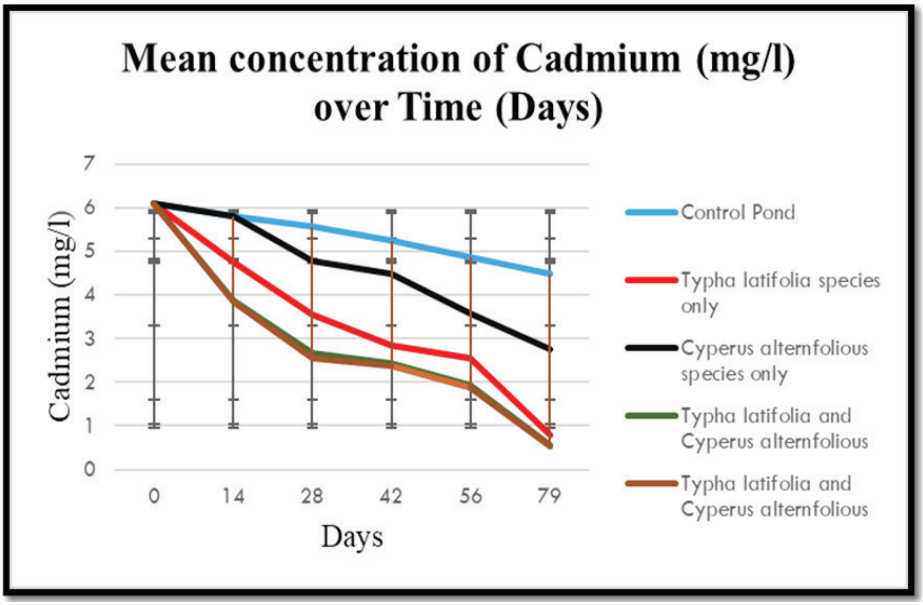


Figure 7: The graph of mean cadmium concentration of the Mukuvisi River water sample at 14-day intervals in ponds with different treatments.

3.5.7 Copper concentration in ponds with different treatments at 14-day intervals

There was a rapid decrease of the copper concentration in the water in duplicated ponds with both the *Typha latifolia* and the *Cyperus alternifolious* plants including the water in the pond with *Typha latifolia* plants. The water in the control pond and the water in the pond with the *Cyperus alternifolious* plants only, copper concentration decrease was slow. The results presented in Fig 8, suggests that there was an internal translocation scheme from roots to stems and from stems to leaves of both *Typha latifolia* and *Cyperus alternifolious*. In other related studies that used *Cyperus papyrus* and *Phragmites australis* plants to compare the efficiency of bioaccumulation of heavy metals including copper, the results showed that heavy metal accumulation in roots of both plants was also translocated to the shoots and accumulated in the harvestable plant parts (Raskin *et al*., 1997).

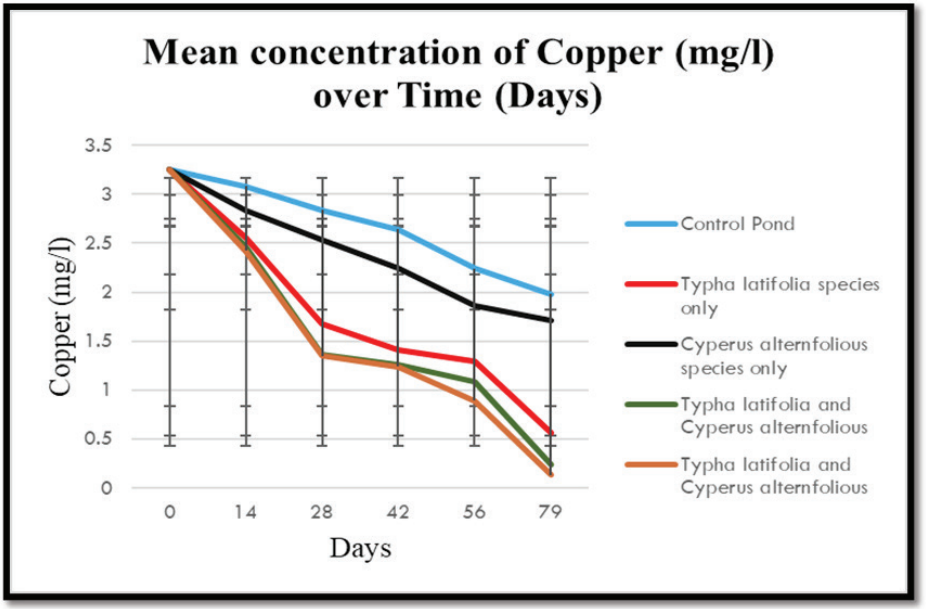


Figure 8: The graph of mean copper concentration of the Mukuvisi River water sample at 14-day intervals in ponds with different treatments.

3.5.8 Lead concentration in ponds with different treatments at 14-day intervals

The duplicated ponds with both the *Typha latifolia* and *Cyperus alternifolious* plants including the pond with the *Typha latifoilia* plants only had a rapid decrease in lead concentration. The lead concentration in water in the pond with *Cyperus alternifolious* plants only and water in the control pond showed a slow decrease as shown in Fig 9. During bioremediation, (Jan *et al*., 2014) listed the following mechanisms that may be used by microbes for reducing metal concentration:

1. Sequestration of toxic metals by cell wall components or by intracellular metal-binding proteins and peptides such as metallothioneins (MT) and phytochelatins along with compounds such as bacterial siderophores which are mostly catecholates, compared to fungi that produce hydroxamate siderophores.

2. Modification of biochemical pathways to block metal uptake.

3. Conversion of metals to innocuous forms by enzymes.

4. Reduction of intracellular concentration of metals using precise efflux systems.

The aforementioned mechanisms could have influenced the reduction of metals such as

lead in the simulated wetland, through the biofilms on the root surfaces of the aquatic plant used during the study.

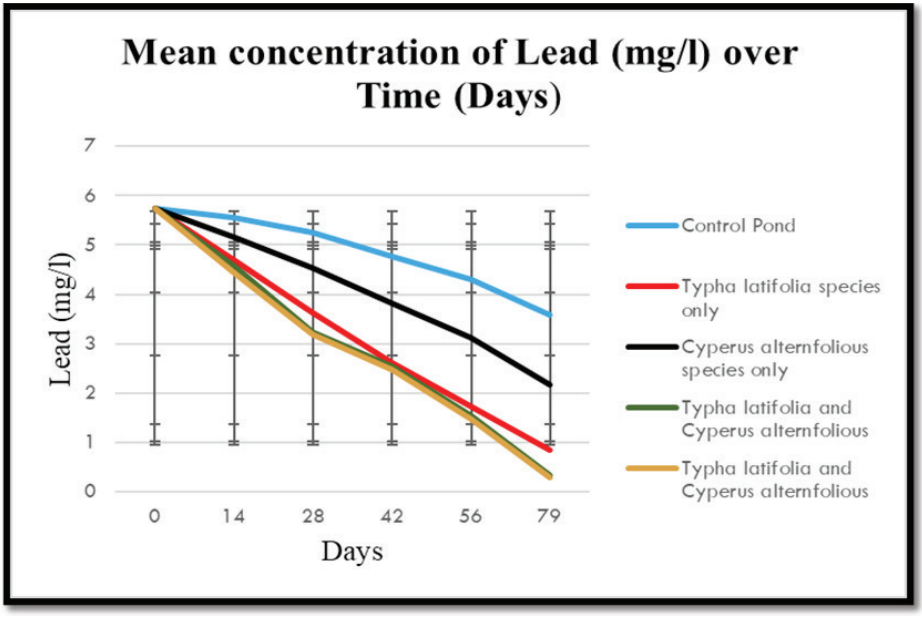


Figure 9: The graph of the mean lead concentration of the Mukuvisi River water sample at 14-day intervals in ponds with different treatments.

3.5. 9 Zinc concentration in ponds with different treatments at 14-day intervals

There was a rapid decrease in zinc concentration in water in the duplicated ponds with both *Typha latifolia* and *Cyperus alternifolious* plants including the water pond with *Typha latifola* plants only. The water in the pond that had the *Cyperus alternifolious* only and the water in the control pond, zinc reduction was slow as shown in Fig 10. Similar studies that were done by (Chayapan *et al*., 2014) in hydroponics to analyze how cadmium and zinc uptake in wetland plants namely *Colocasia esculenta*, *Cyperus malaccensis*, and *Typha angustifolia* plants, showed zinc and cadmium accumulation both in the above and below-ground parts of these plant species. The plant species with the highest zinc and cadmium uptake was *Typha angustifolia* during the study which accumulated 195.9-298.4 μg^{-1} in the plants, the three wetland plants had been exposed to zinc concentration of 50 mg/l^{-1} and 100 mg/l^{-1} for 15 days.

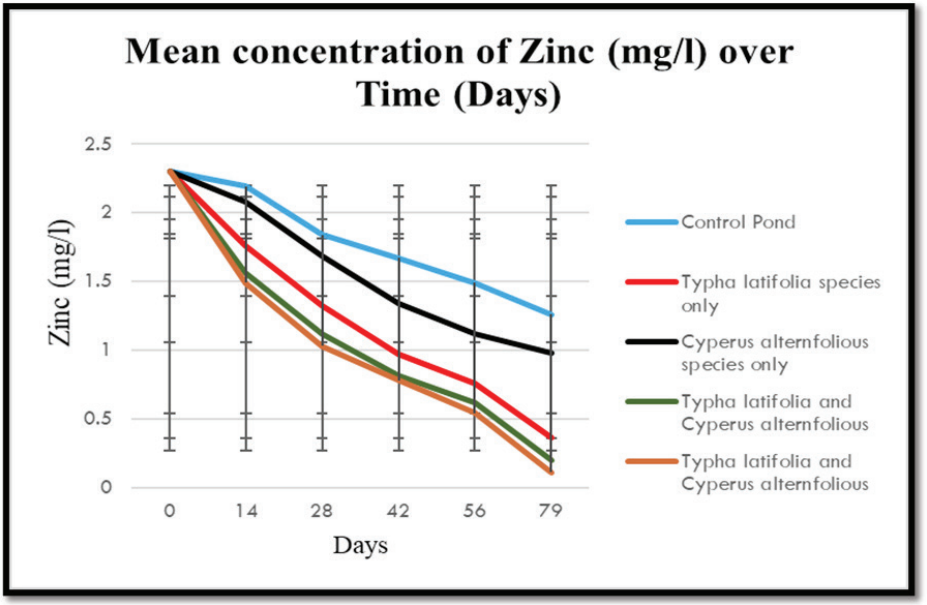
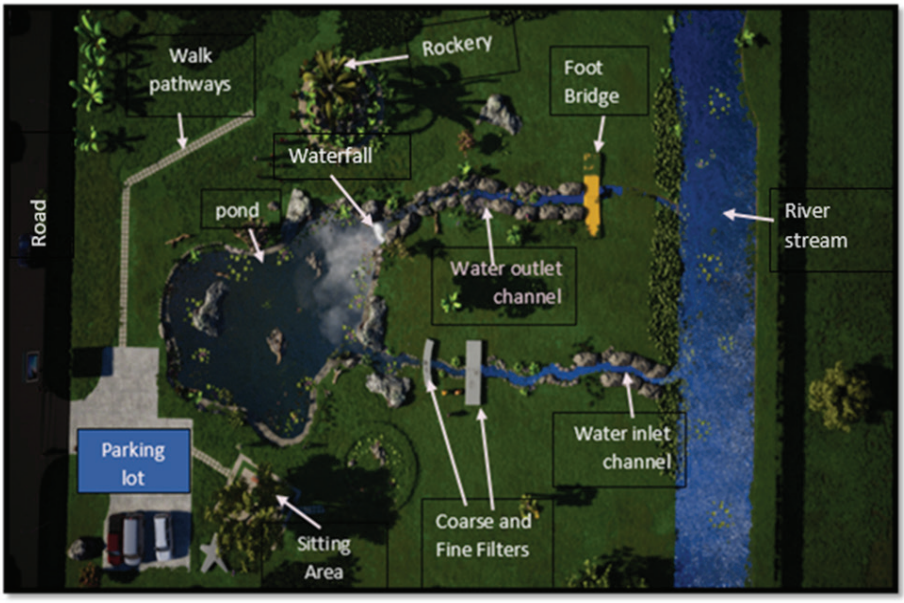


Figure 10: The graph of mean zinc concentration of Mukuvisi River water sample at 14-day intervals in ponds with different treatments

3.6 The proposed design of a full-scale model for the constructed wetland

The key features of the constructed wetland include the coarse and fine filters, remediation pond, and the waterfall. The river water gets entrapped through a filtration system that will strip excess nutrients from the water, dealing with issues that commonly plague large-scale water features such as algae blooms. The filtration systems that can be adopted for the constructed wetland, that are currently being used, have been manufactured and distributed by the Aquascape company in the United States of America. The filtration systems will allow a sufficient Hydraulic Residence Time for the bioremediation process. The constructed wetland area can be surrounded by studied exotic trees which act as bio monitors, the lawn will prevent soil erosion, whilst the walking pathway prevents people from stepping the lawn. The rockery in the surroundings of the constructed wetland area will be for aesthetic purposes. The parking lot will temporarily store vehicles and people will relax in the sitting area when they visit the site.

3.6.1 The 3D design of the full-scale model of the constructed wetland



Aerial view of the constructed wetland

4. Conclusion

Typha latifolia and *Cyperus alternifolious* are semi-aquatic plants that accumulate water pollutants and have been naturalized in Zimbabwe. These plant species are abundant in aquatic ecosystems in Harare and can be used to develop constructed wetlands since they have low ecological risks. Acidophilic bacteria and fungi which play a remediation role, exist in soil sediments of root surfaces of wetland plants. However, there is a need to identify areas that are suitable to construct wetlands to monitor air levels of air pollution, restoration of aesthetics, and filtration of water pollutants.

5. Acknowledgments

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A Framework For The Mainstreaming Of Elk For Resource Conservation And Environmental Sustainability In High Education Institutions (Heis): A Survey Of Selected Universities In Zimbabwe.

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Abstract

This research sought to design a framework for the mainstreaming of ecological local knowledge (ELK) in higher education institutions' curricula within the context of environmental sustainability and resource conservation. After exploring the perceptions of undergraduate students and key informants in four universities in Zimbabwe, on the adequacy; relevance and value of ELK in their biodiversity related degree programs, the research developed a framework that will inform and guide the mainstreaming of ELK. It adopted a mixed methods approach and a descriptive survey research design. The data was collected by means of questionnaires complemented by key informant

interviews. Document analysis was also done to augment and provide a framework within which to place the findings of the research in its theoretical context. Part of the intervention strategies recommended include a great need for political will to mobilize efforts towards implementation of policy imperatives and strategic mandates that inform and guide the ELK discourse. It is also critical that HEIs create partnerships and positive feedback loops with local communities and institutions, were there undertake ELK related research and scholarly work that will initiate, verify, validate, establish and document the knowledge capital that emphasis community impact and relevance. Furthermore, there should be increased advocacy and platforms to promote and support ELK best practices and its inclusion in biodiversity related HEIs' curricula to enhance environmental sustainability.

Keywords - *Ecological local knowledge (ELK); environmental conservation curricula; higher education institutions (HEIs) and intercultural dialogue*

1. Introduction

Mainstreaming and inclusion of ELK and traditional resource management practices in higher and tertiary institutions' (HEI) curricula, is imperative in the biodiversity conservation discourse (Joa, Winkel, & Primmer, 2018; Ndlovu, James, & Govender, 2019; Viriri, 2009). The importance of ELK cannot be disputed, especially now that the world is facing a plethora of challenges which cannot all be solved by mainstream science. ELK forms an indivisible, integral part of a society's culture, values, norms, beliefs and rules that can be tapped and integrated in modern-day natural resources management in Zimbabwe (Ndlovu et al. 2019, Hoppers, 2002). Berkes 2003 cited in (Shackeroff & Campbell, 2007) argues that engaging with ELK is surely a means for technical oriented experts to contextualize their practice to the local environment. Its inclusion in HEIs' curricula is a basis for sustainable comprehensive community based response to biodiversity conservation; environmental management and impacts of climate change (Manyanhaire, 2015, Songok et al. 2011). If it is blended with modern technologies, ELK can serve as effective intervention strategies that can mitigate the challenges faced in natural resources management (Reniko et al. 2018).

So its inclusion will contextualise HEIs' curricula and elevate it to a respectable level in Africa (Dube, Ngulube, & Mhlongo, 2015; Masinde & Thothela, 2019). Despite the enormous potential to develop local mitigation strategies from Africa's indigenous knowledge systems (IKS), it has been noted that African universities have extensively ignored and refuted such approaches (Neba et al., 2012; Shava & Nkopodi, 2020; Shizha, 2013). Most academic and research institutions in southern Africa are modelled and informed by alien content and norms, despite being positioned in self-governing states (Heleta, 2016; Ndofirepi & Gwaravanda, 2018; Shava & Nkopodi, 2017; Shizha, 2014).

While Zimbabwe has in place mechanisms and provisions that embrace and uphold the inclusion of ELK and best practices in local communities notable the Constitution, Zimbabwe's environmental policy document and EMA, the values and principles that are essential for environmental sustainability are deliberately omitted from curricula of HEIs (Muwanga-Zake, 2017). These laws and policies have been enacted but Chibememe et al. (2014) argues that to a large extent, ELK is underestimated and negated in biodiversity conservation, use and management. The Constitution as the supreme law of Zimbabwe in Section 3(1) d., page 16 recognizes varied ethnic, sacred and traditional ideals as part of its key tenets and standards. Section 16(3) page 19 of the Zimbabwe Constitution prescribes that the government and all its institutions to take actions to ensure the preservation and safeguarding of IKSs possessed by native and local populations. But in spite of such provisions, the research notes that in most of the HEIs studied, the Afrocentric norms and customs are blatantly absent from their curricula(Shizha,2013;Muwanga-Zake,2017).

Because the fundamentals of IKS emanates from practice situated in oral descriptions provided in local dialects; its utility value escapes from being captured in the conventional manuscripts and is therefore not endorsed by the mainstream educational platforms (Teffo, 2019). The materials articulated are entrenched within western philosophies and knowledge disciplines that are presented as impartial, universal and singular(Shava & Nkopodi, 2020; Shizha, 2014). ELK is critical in understanding traditional management practices and how there contribute to the safeguarding of natural resources and informing and guide the crafting of strategic environmental sustainability policies and strategy(Reniko, Mogomotsi, & Mogomotsi, 2018; Shackeroff & Campbell, 2007). This is confirmed by Hens (2006) who argued that there is loss and inadequate application of ELK in the present fluctuating cultures of sub Saharan Africa, Zimbabwe included. This points to a need for reframing the curriculum to highlight the interests and aspirations of Africa. The research is an attempt to develop a framework/model towards mainstreaming ELK for environmental sustainability in HEIs. This is premised on the pursuit to create a platform that will foster a change of mind-set among academic researchers to enable them to engage in collaborative iterative community action research that will draw indispensable biodiversity conservation knowledge capital that is entrenched in indigenous and local communities.

2. Method

A mixed methods paradigm was employed to afford opportunities for the study to have an informed conversation involving information that is generated by both qualitative and quantitative research components. The study adopted a non-probability sampling strategy, purposive (Acharya, Prakash, Saxena, & Nigam, 2013) and had access to eight key informants, five PhD holders and two Masters holders from the four HEIs that offer biodiversity conservation related degree programs in Zimbabwe. The key informants were purposively selected because there were perceived better positioned to contribute important and relevant insights in terms of ELK policy imperatives and

strategic directions that guide and inform biodiversity related degree programs in their departments. The designation and areas of specialization of the key informants is captured in the table 1 below.

Table 1: Institutions and areas of specialization of key informants with PhD

Institution	PhD	Area of Specialization
IA	PhD	Wildlife Conflict Resolution and Conservation Governance
IB	MSc	Natural Resources Management
IC	PhD	Key Informant 1: Plant Ecology and Aquatic Ecology Key Informant 2: Ornithology
ID	PhD	Animal Breeding

The study also administered semi-structured questionnaires to 56 undergraduate from the four HEI. The institutions and departments from which the respondents were derived is captured in the table 2 below.

Table 2: Institutions and departments from which the respondents were derived

Institution	Biodiversity Related degree	Sample		Population		Sampling Intensity %
		M	F	M	F	
IA	WEC	5	4	11	5	56
IB	AWS& Agronomy	7	7	16	26	33.3
IC	ESH	7	9	22	27	32.6
	FRWM	2	5	9	9	38.9
ID	BSAM& GES	2	8	6	16	45.5

Key:

WEC: Wildlife, Ecology and Conservation; **AWS**: Animal and Wildlife Science **ESH**: Environmental Science and Health; **FRWM**: Forest Resources and Wildlife Management; BSc Agriculture Management; **GES**: Geography and Environmental Sci.

3. Results and Discussion

3.1: Proportion of ELK related modules in the IA biodiversity related program

The BSc (Hons) in Wildlife, Ecology and Conservation degree offered at IA is a four year undergraduate program, designed to capacitate students on issues relating to conservation, sustainably management and utilisation of our biodiversity and natural resources. Table 3 shows the analysis of the proportion of ELK related modules in the biodiversity degree program offered at IA.

Table 3: Proportion of ELK related modules in the IA biodiversity related program

	Academic Year			
	Year 1	Year 2	Year 3	Year 4
Number of Modules	10	10	Industrial Attachment	9
Proportion of modules related to ELK per academic year	0	3	Industrial attachment may provide opportunities and experiences on ELK depending on the stakeholder to which the student is attached	2
% time allocated to ELK per academic year	0	30		22
Taught modules with ELK components	-	PAM SB EL&P	-	CBNRM EB
Modules that provide opportunities for the inclusion of ELK concepts	PoM IWM&SO T&ES AS&E EI&A	D&FMS QSM&ET		C&SD RP GH&T M&EBL

Key:
P&M: Principles of Management; **IWM&SO:** Introduction to Wildlife Managemnt and Safari Operations; **T&ES**: Taxonomy & Evolution of Species**; AS&E:** Animal Species and their Ecology; **EI&A:** Environmental Interpretation & Assessements, **QSM&E**: Quota Settings, Monitoring & Evaluation techniques; **C&SD:** Conservation and Sustainable Development: **GH&T:** Game Hunting & Taxidermy; D**&FMS**: Diversity and features of Mammalian Species;

The program has 29 taught modules, of which five are ELK related, notable Environmental Law and Policy; Protected Area Management; Social Biology; Ethno biology and Community Based Natural Resources Management. These constitute 17 percent (5 out of 29) in terms of overall content coverage and time allocation in the degree program. This is echoed by Shava and Nkopodi (2020) who observes that the research and teaching activities in universities are entrenched within western theories and knowledge disciplines that are presented as neutral, universal and singular. The higher education system in sub Saharan Africa, is still too academic and distant from the developmental challenges of African local communities (Kaya and Seleti; 2014).

The study also identified nine other modules that can be exploited to document and incorporate ELK related content; notable **P&M:** Principles of Management; **IWM&SO:** Introduction to Wildlife Management and Safari Operations; **T&ES**: Taxonomy & Evolution of Species**; AS&E:** Animal Species and their Ecology; **EI&A:** Environmental Interpretation & Assessements, **QSM&E**: Quota Settings, Monitoring & Evaluation techniques; **C&SD:** Conservation and Sustainable Development: **GH&T:** Game Hunting & Taxidermy; **D&FMS**: Diversity and features of Mammalian Species. This is premised on the fact that there are certain socio cultural imperatives and variables resident in local communities that can be captured and documented. Through citizen science, HEIs can foster synergies and collaborative work to documentation, monitoring and collection programs.

Despite ELK related modules constituting 17 percent of the overall course content and time, IA undergraduate students argued that the ELK modules were adequate and relevant in their degree program as indicated by mean scores of 3.50 and 4.13 respectively (see appendix). This view was echoed by a key informant at IA, who noted that there is adequate articulation and coverage of ELK best practices and concepts in their degree programs as pertaining to environmental sustainability. He argued that, it is a deliberate strategic policy direction in their department, to ensure that ELK best practices and concepts are adequately articulated and represented in the degree program.

3.2: Proportion of ELK related modules in the IB biodiversity related program

The BSc (Hons) in Natural Resources Management and Agriculture degree offered at IB is a four year undergraduate degree program, designed to advancing sustainable agricultural development and management of natural resources through training, community engagement and generation of research based knowledge. Table 4 shows the analysis of the proportion of modules related to ELK in the biodiversity degree program offered at IB.

Table 4: Proportion of ELK related modules in the IB biodiversity related program

	Academic Year			
	Year 1	**Year 2**	**Year 3**	**Year 4**
Number of Modules	15	13	Industrial Attachment	12
Proportion of Modules related to ELK per academic year	0	0	Industrial attachment may provide opportunities and experiences on ELK depending on the stakeholder to which the student is attached	0
Percentage time allocated to ELK per academic year	-	-		-
Modules that provide opportunities for the inclusion of ELK concepts	**SFM** **PoE**	**PSCP** **S&WC** **LI** **PoWM** **AH** **CC&A**		**IWPS** **SMNRs** **SWRM**

Key:
SFM: Soil Fertility Management; **PoE**: Principles of Ecology; **PoSCP**: Principles of Sustainable Crop Production; **S&WC:** Soil & Water Conservation; **LI:** Livestock improvement; **PoWM:** Principles of Wildlife Management; **AH**: Animal Health; **CC&A:** Climate Change & Adaptation; **IWPS**: Intensive Wildlife Production Systems; **SMNRs:** Sustainable Management of Natural Resources and **SWRM**: Sustainable Wildlife Resources Management

The program has 40 taught modules, with limited ELK related modules because of the STEM oriented focus of the program. With regards to the adequacy of ELK related learning materials and opportunities in their degree program, IB undergraduate indicated that ELK related learning materials and opportunities were not adequate in their degree program with a mean score of 1.92. This was also echoed by a key informant who observed that their curriculum is silent on ELK. She reiterated that what is emphasized in the lecture room is the techno oriented principles to environmental management. In articulating the history of natural resources management in Zimbabwe, there adopt a comparative analysis to allow their students appreciate the fact that without the formal systems of natural resources management, local communities lived in harmony with nature and sustainable managed their natural resources. This concurs with Murwira (2020)' study who found out that they are few courses in the Catholic University of Zimbabwe curriculum which include Indigenous African Knowledge Systems.

The study also identified ten modules that can be exploited to incorporate ELK related content; notable Soil Fertility Management (SFM); Principles of Ecology(PoE);

Principles of Sustainable Crop Production(PoSCP); Soil & Water Conservation(S&WC); Principles of Wildlife Management(PoWM); Animal Health(AH); Climate Change & Adaptation(CC&A); Intensive Wildlife Production Systems(IWPS); Sustainable Management of Natural Resources(SMNRs) and Sustainable Wildlife Resources Management(SWRM). This is informed by an understanding that local communities have best practices which made them sustainably manage their resources and lived in harmony with nature.

3.3: Proportion of ELK related modules in the IC biodiversity related program

The BSc (Hons) in Forest Resources and Wildlife Management degree offered at IC, is a four year undergraduate degree program, designed to cover issues related to resource use, protection and enhancement of environmental quality. Table 5 shows the analysis of the proportion of modules related to ELK in the biodiversity degree program offered at IC.

Table 5: Proportion of ELK related modules in the IC biodiversity related program

	Academic Year			
	Year 1	**Year 2**	**Year 3**	**Year 4**
Number of Modules	15	12	Industrial Attachment	14
Proportion of Modules related to ELK per academic year	3	1	Industrial attachment may provide opportunities and experiences on ELK depending on the stakeholder to which the student is attached	1
Percentage time allocated to ELK per academic year	13	8		7
Taught modules with ELK components	H&E H&W	SF&E		WM FM BC F&WPL
Modules that provide opportunities for the inclusion of ELK concepts	IC IF	AF VPD PS&FI VPP		PSFI FH&U

The program has 41 taught modules, of which five are ELK related, notable Human and Environment (H&E); Human and Wildlife (H&W); Forest and Wildlife Policy and Law(FWPL)Social Forestry and Extension (SF&E) ;Wildlife Management (WM); Forestry Management (FM) and Biodiversity Conservation (BC). These constitute approximately 15 percent (6 out of 41) in terms of overall content coverage and time allocation in the degree program

The study also identified nine other modules that can be exploited to incorporate ELK related content; notable Vertebrate Population Dynamics (VPD); Agroforestry(AF); Ornithology and Forest Harvesting and Utilisation (FH&U). This is premised on the

fact that local communities have lived in harmony and continuosly interact with nature. By fostering synergies and collaborating with them, will help document and tap into their experiences and best practices.

3.4: Proportion of ELK related modules in the ID biodiversity related program

The BSc (Hons) in Geography and Environmental Studies offered at ID is a four year undergraduate degree program, designed to articulate on environmental concerns within both the natural and the human environment. Table 6 below is an analysis of the proportion of modules related to ELK.

Table 6: Proportion of ELK related modules in the ID biodiversity related program

	Academic Year			
	Year 1	Year 2	Year 3	Year 4
Number of Modules	8	8	8	8
Proportion of Modules related to ELK per academic year	-	-	-	-
Percentage time allocated to ELK per academic year	-	-	-	-
Modules that provide opportunities for the inclusion of ELK concepts	IW&C TG&ES IGT&ES IP&SS	EM P&R M&C	EE EPL	RC&M RP

Key:
Introduction to Weather and Climate **(IW&C);** Techniques in Geography and Environment Science **(TG&ES);** Introduction to Geographical Thought and Environmental Science (**IGT&ES**); Environmental Management **(EM);** Population and Resources (**P&R**); Meteorology and Climatology (**M&C**); Environmental Education **(EE);** Environmental Policy and Legislation **(EP&L);** Resource Conservation and Management (**RC&M).**

The program has 40 taught modules, with limited ELK related modules. ID undergraduate students disagreed on the relevance of ELK in their degree program with a mean score of 3.22. They strongly disagreed that ELK learning and resource materials were adequate in their degree program, to allow for worthwhile learning opportunities and community engagement with a mean value of 1.22. Part of the reasons given include:'…training is module based; modular system is rigid and limits interaction and most of the content is based on scholarly materials which are foreign.

The study also identified eleven other modules that can be exploited to incorporate ELK related content; notable Introduction to Weather and Climate **(IW&C);** Techniques in

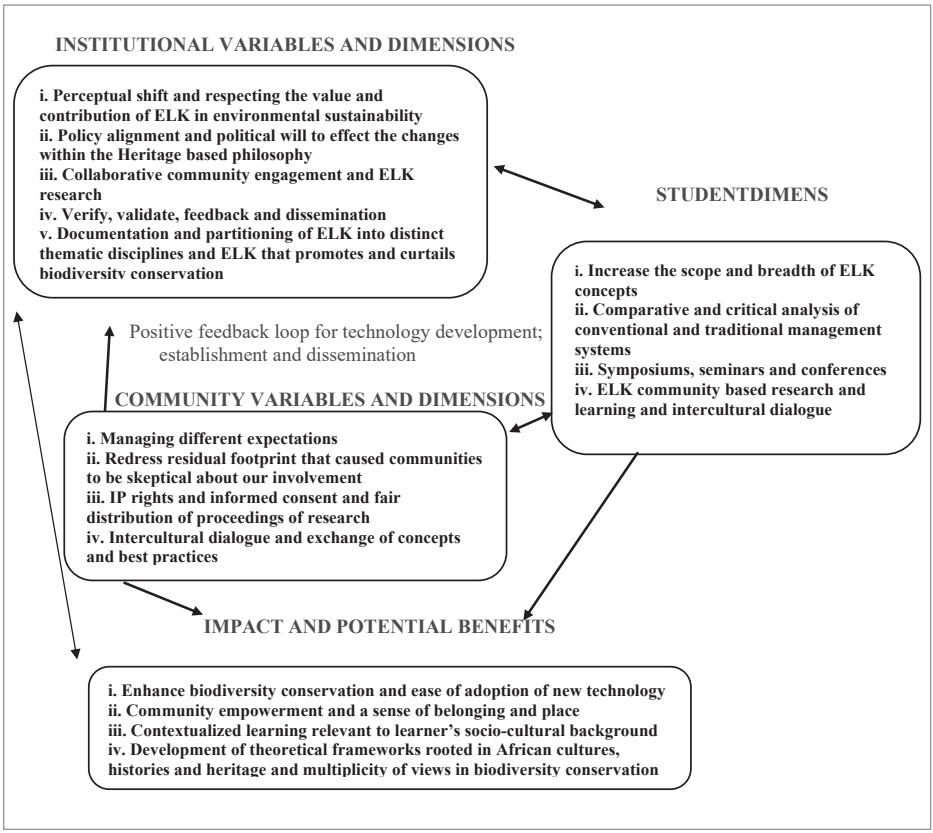
Geography and Environment Science**(TG&ES);** Introduction to Geographical Thought and Environmental Science(**IGT&ES**); Environmental Management**(EM);** Population and Resources(**P&R**); Meteorology and Climatology(**M&C**); Environmental Education**(EE);** Environmental Policy and Legislation**(EP&L);** Resource Conservation and Management(**RC&M).**

An analysis of the modules indicated a general bias towards Eurocentric perspectives. The study also observes that the authors of the course materials are inclined to preserve the dominant Eurocentric viewpoints in their articulation of issues. In general, Environmental Management thought and Environmental Management Tools notable Environmental Assessment; Environmental Impact Statements, Environmental Audits and Life Cycle Assessments are techniques conceived and cascaded after the enactment of the National Environmental Policy Act (NEPA) of 1970, in the United States. Key informant in the ODeL concurred noting: '...the perspective articulated is Eurocentric and is based on the body of scientific knowledge that is drawn from environmental management and geography.

4: Conceptual Framework for the mainstreaming of ELK in HEI curriculum

To address the need for crafting a framework that can be adopted to guide the mainstreaming of ELK for biodiversity conservation and environmental sustainability, participants were asked on what measures can be adopted to make the mainstreaming of ELK in HEIs' curricula feasible and effective. There was consensus amongst participants that HEI biodiversity related curricula should explore and exploit learning experiences and opportunities that reside in non-technical settings and context.

The results indicate that the basis for the mainstreaming of ELK in HEI biodiversity related curricula will be defined by a perceptual and mind-set change that acknowledges and respect the value and contribution of ELK in environmental sustainability consistent with provisions Article 8(j) and Principle 22 of the Rio declaration**.** It is imperative to include in the curricula of HEIs curricula processes and policy imperatives, practices that reflecting the voices, perceptions and priorities of local indigenous populations to enhance environmental sustainability.



HEI must create platforms that will seek to explore and exploit learning experiences and opportunities that exist in informal educational settings. Through creating collaborations and positive feedback loops with local indigenous communities, HEI should undertake ELK related research and scholarly work that will initiate, verify, validate, establish and document the knowledge capital that emphasize community impact and relevance. The documentation should capture and partition ELK concepts that enhance and curtail biodiversity conservation.

It calls for responsive, participatory engagement that involves university-community partnerships in creative approaches to problems that emphasize community impact and relevance. After such collaborative community engagement, it will increase the scope of local developed technologies. In this framework students will be allowed a comparative and critical analysis of conventional and traditional knowledge systems. This is meant to allow for constructive dialogue among the key stakeholders to foster tapping into the best innovative strategies from different knowledge domains for the safeguarding of biodiversity.

5. Conclusion

The study provided an analysis of course outlines and documents to establish the proportion and priority given to ELK concepts and best practices in biodiversity related HEIs degree programs offered in Zimbabwe. While ELK is vital and acknowledged in conservation of biodiversity, its potential has not been effectively utilised. It was evident from key informant interviews and course materials reviewed that, in general, our HEIs do not value, respect and acknowledge the significance of ELK in biodiversity conservation and environmental sustainability, in spite of policy imperatives and provisions that support its inclusion. Despite the enormous potential to develop community centred solutions and knowledge from Africa's ELK, it evident that, African universities have considerably shied away from comprehensively developing such approaches. Most of the undergraduate students across the institutions studied, indicated that ELK related modules do not take the most proportion of modules in their degree program. The study attributes this to the Science Technology Engineering and Mathematics (STEM) oriented mandate of the HEIs, with an emphasis on techno oriented solutions to biodiversity conservation and environmental management.

It is then imperative to create space and include processes and practices that reflecting the voices, perceptions and priorities of local indigenous populations to enhance environmental sustainability. It becomes important that HEI biodiversity related curricula should explore and exploit learning experiences and opportunities that reside in non-technical settings and context.

HEIs should create partnerships and positive feedback loops with local communities and institutions, were there undertake ELK related research and scholarly work that will initiate, verify, validate, establish and document the knowledge capital that emphasize community impact and relevance. Furthermore, there should be increased advocacy and platforms to promote ELK best practices; awareness and inclusion in biodiversity related HEIs' curricula to enhance environmental sustainability.

6. Acknowledgement

I would want to express my sincere gratitude to Dr. O.L. Kupika and Professor E. Gandiwa for their expertise and unwavering effort to encourage, correct and guide me throughout the whole project. I also want to acknowledge Environmental Management Agency (EMA) for granting me the 2018-2019 EMA Masters Research Grant for postgraduate studies.

Appendix

SPSS mean score values on the Descriptive Statistics of undergraduate students' perceptions on the adequacy, relevance and appropriateness of ELK related modules in their curricula

Items related to the Adequacy; Relevance and Appropriateness of ELK	IA	IB	IC 1	IC 2	IE	ID
1. **Proportion** of ELK related modules taught	**2.75**	**2.00**	**2.40**	**2.14**	**2.00**	**1.89**
2. Percentage of ELK related modules in relation to other courses	1.00	1.00	1.07	1.00	1.25	1.33
3. The focus of their academic training and practicum	3.63	1.85	1.67	2.86	1.88	1.78
4. Relevance of ELK related courses	4.13	2.92	3.00	4.14	3.25	3.22
5. Adequacy of ELK related learning and resource materials	3.50	1.92	1.87	2.43	1.25	1.22
6. Adequacy of community engagement and field work	2.63	2.00	1.93	2.57	2.00	3.44
7. Amount of ELK related concepts established in their degree program	3.88	1.46	1.33	4.29	2.13	1.89
8. Need to widen the scope and depth of ELK related concepts in their degree program	3.75	4.62	4.87	4.43	4.88	5.00

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Community perceptions and attitudes on treated excreta products in peri-urban agriculture: Case of Dzivarasekwa-extension, Zimbabwe

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Abstract

In Zimbabwe, population growth and urbanisation are increasing the burden on metropolitan municipalities' basic sanitation. The proportion of urban population is high (66%) in Zimbabwe compared to the regional rate of 39 percent and has a significant burden on the already overstretched and limited sanitation systems. Therefore, a paradigm shift in the way human waste is managed and perceived is required as well as the provision of solutions to the challenges of poor sanitation. However, there is

anecdotal evidence on farmer's attitudes and perceptions on treated human excreta fertilisers in agriculture. The study sought to unpack farmer's perceptions and attitudes towards the use of treated human excreta in peri-urban agriculture. Data were collected from 100 randomly selected individuals using a structured questionnaire. Both inferential and descriptive statistics analysed the data. The results show that 71percent of the respondents had an understanding of how human excreta fertilisers can be used to boost agriculture and ensure food security in peri-urban areas. Further analysis shows that there was no statistically significant difference (P=0.062) between the level of education and gender. However, there was a moderate association (Cramer's' V=0.62). Out of the 100 respondents, 40 percent agreed that human excreta is suitable only for disposal and not as a resource for agricultural production, while 15 percent didn't know, and 45 percent disagreed. Fear of diseases outbreaks such as cholera, typhoid, HIV and AIDS were found to be the main reasons people had negative perception towards human excreta products in agriculture. Based on the results, 49 percent of the respondents preferred to use both faeces and urine products, while 38 percent preferred faeces only, and 13percent preferred urine only. The study concluded that people are not comfortable to use human excreta products in agriculture, as human excreta is associated with dirtiness and diseases. The paper recommends that there is need to educate people about the proper handling, use and hygienic issues on the harvesting of human excreta for agricultural purpose.

Keywords: *Attitudes, Food Security, Human Excreta, Perception, Urban farming*

1. Introduction

The growing food demand and increase in the use of human excreta caused by the ever-growing urban population has resulted in development researchers to focus on the relationship between human excreta and human excreta derived fertilisers (Pedzisai et al., 2014). Due to rapid population growth and food demand, huge investments have been made on fertilisers in Zimbabwe. Financial constraints facing most of the poor farmers in the country makes fertilisers inaccessible, yet there is a need to ensure sustainable food and nutrition security in the country. International trends suggest the use of low-cost, ecologically suitable alternative fertilisers, such as human excreta (Moilwa, 2007).

Rapid population growth and urbanisation coupled with natural resource depletion and the need to feed the rising global population has placed resource recovery and re-use on top of the worldwide development agenda (di Mario et al., 2018). In Zimbabwe, the percentage of urban population which is 66 percent is higher than the sub-Saharan Africa rate, estimated to be around 39 percent in 2017 (World Bank, 2018). As a result of rural-urban migration and growing population, the urban population in Zimbabwe is projected to reach 71 percent by 2030 and 80 percent by 2050 (Angelopulo, 2017; CoGTA, 2016; Mlambo, 2018). Rural-urban migration often leads to overpopulation and expansion of informal settlements which have unplanned waste management and disposal practices. This leads to environmental threats in community pollution and

various sanitation-related illnesses, especially among children. The growing urban population poses a threat to urban food security through increased food demand and environmental degradation through increased human excreta (Pedzisai et al., 2014; Sovereignty, 2019). This places a considerable burden on public funds whose budgets are already overstretched and inadequate to maintain the basic sanitation systems in urban areas and meet the food requirements of people.

Experiments on the effects of human excreta fertilisers on soil and yield show that human excreta fertilisers are effective alternatives to commercial inorganic fertilisers, especially when complementing chemical fertilisers (Odindo et al., 2016). Additionally, the effect of wastewater effluent on banana and taro crops showed increased crop growth, nutrient uptake, and yield (Musazura, 2018, Odindo et al., 2016). Urine is rich in nitrogen, while faeces are rich in, potassium, phosphorus, and organic matter (Simha & Ganesapillai, 2017). Therefore, a transformation of human excreta into soil amendments and their wide-scale adoption could help improve soil health, environmental sustainability, wastewater management, food security and solve the sanitation crisis in Zimbabwe. Moilwa (2007) effectively sums up the benefits of human excreta fertilisers as; (1) improved food security, (2) increased productivity, (3) decrease in the burden of social services, and (4) enhanced natural resources such as water and soils.

Despite the role of human excreta fertilisers to food security and economic development, the social acceptability of the products is a problem (Moilwa, 2007). Across Africa, there is a perception challenge around human excreta derived fertilisers because of the harmful components they contain, such as pathogens and heavy metals (Mariwah & Drangert, 2011). Human excreta fertilisers are associated with dirtiness and spread of diseases such as cholera, typhoid, and HIV and AIDS (Mariwah & Drangert, 2011). Therefore, the study attempts to address these research gaps and give insights into the various elements of Human Excreta Derived Material (HEDM) demand such as attitudes, perceptions, and preferences of farmers and to provide essential information for agricultural policymakers.

2. Materials and Methods

Dzivarasekwa which was designed by the colonial government to introduce the home ownership scheme to African is located on the western side of Harare's Central Business District, with an estimated population of 22 324 people (ZimStat, 2012). Dzivarasekwa Extension suburb was equally established by the post independent government in the 1993 to house those who were evicted from slums in Mbare. . Till today, the suburb has remained predominantly a working-class residential area characterized with high poverty and food insecurity levels which feed into the urban and peri urban farming practice. Residents practice farming in two main ways, which are farming plots on open City Council land and cultivation within individual residential stands (Figure 1). However, there is an emerging form of agriculture which is gaining momentum, the

planting on undesignated land-open space and wetlands. Farming on these illegal zones often poses serious urban planning challenges as well as environmental, social, health and infrastructural risks.

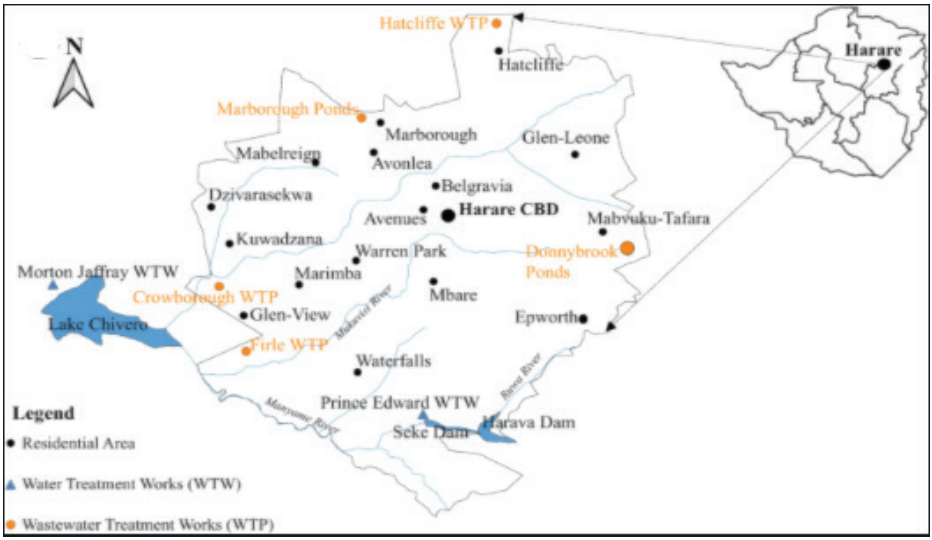

Figure 1. Dzivarasekwa Map. Source: Google Earth, November 2018)

2.1 Theoretical Framework

This study was guided by Ajzen (2002) theory of planned behaviour, which provides a framework for studying human action as illustrated in Figure 2. Human behaviour is guided by three kinds of considerations: beliefs about the likely outcomes of the behaviour and the evaluations of these outcomes, beliefs about the normative expectations of others and motivation to comply with these expectations (normative beliefs), and beliefs about the presence of factors that may facilitate or impede performance of the behaviour (control beliefs). The combination of the three considerations (attitude towards the behaviour, subjective norm, and perception of behavioral control) guide an individual to form a behavioral intention (Ajzen, 2002). Generally, the more favourable the attitude and subjective norm, and the higher the perceived control, the stronger should be the person's intention to perform the behaviour in question. The purpose is assumed to be the immediate antecedent of expression or action.

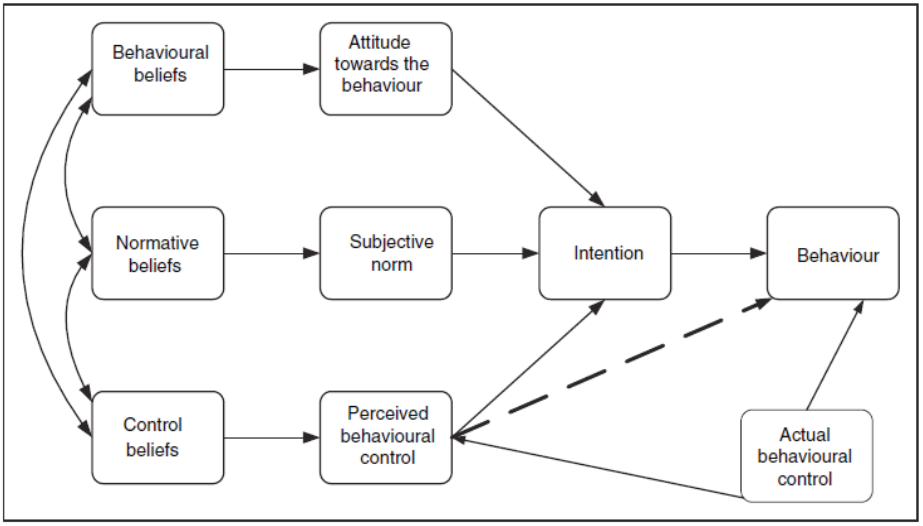

Figure 2: Theory of Planned Behavior (TPB) ***Source: Adapted from*** **(Ajzen, 2002)**

The theory of planned behaviour is useful to this study because perceptions, are influenced by one's knowledge, beliefs, values, and norms. The more knowledgeable human are about human excreta, the more precise opinion are held and the stronger attitudes and perception built. Similarly, being informed about an issue is even more likely to influence human behaviour particularly where knowledge is gained from the first-hand experience.

2.2 Research design

The data were collected between November and December 2018 using a pre-tested structured questionnaire. Enumerators with good knowledge about food systems and conversant in the local language Shona administered the questionnaire. Key Informant Interviews (KIIs) supported and supplemented the data from the questionnaire. Before the main study, a pilot study involving ten farmers checked the questionnaire for consistency, errors and ensured the enumerators familiarised with the research design. Hassan et al. (2006) argue that a pilot study is an important stage in research and is conducted to identify potential problem areas and deficiencies in the research instruments and protocol before the implementation of the main study. All this was done with in a mixed methods research design which allowed for the collection of both qualitative and quantitative data.

The study employed a multi-stage sampling technique to come up with the sample for the study. First, Dzivarasekwa was purposively selected for the study. The criteria used for the inclusion of the suburb were (1) the unemployment rate, (2) the number of urban farmers and (3) the poverty and food insecurity levels. Second a list of the

households was compiled through the assistance of the district officer. After compiling the list, the Cochran formula determined the ideal sample size given a desired level of precision, desired confidence, and the estimated proportion of the attribute present in the population (equation 1). The Cochran formula is expressed as:

$$n = \frac{p(100-p)Z^2}{e^2} \quad \frac{p(100-p)Z^2}{e^2} \quad \textbf{equation 1}$$

Where n is the required sample size, p is the percentage occurrence of a state or condition, e is the percentage maximum error required and Z is the value corresponding to the level of confidence required. The top hat method randomly selected the respondents for the study. The method involved attaching a number to each of the household on the list then put the numbers in a hat and randomly select. All procedures were undertaken with formal approval from the Women University Ethics Committee. Primary data were collected using structured questionnaires. Information on basic characteristics of household head such as sex, age, marital status, education level, perceptions and attitudes were collected using the questionnaire.

3. Results and discussions

3.1 The influence of gender towards the use products derived from human excreta

The gender split of the 100 respondents in the field research was 70% female and 30% male (Figure 3). Men and women in households interviewed also had different ideas and opinions regarding human faeces. The results show that 70% of the women constituency were aware of the value of human faeces as a fertilizer while the remaining 30% were either ignorant or unwilling to appreciate issues to do with human waste. Comparably, 57% of men did not have much of an opinion, while 10% viewed human waste as a useless resource and 6% believed that it was unhealthy. Thus 60% of both men and women shared the same view that human excreta could be handled and used as a form of organic fertilizer that enhance crop production.

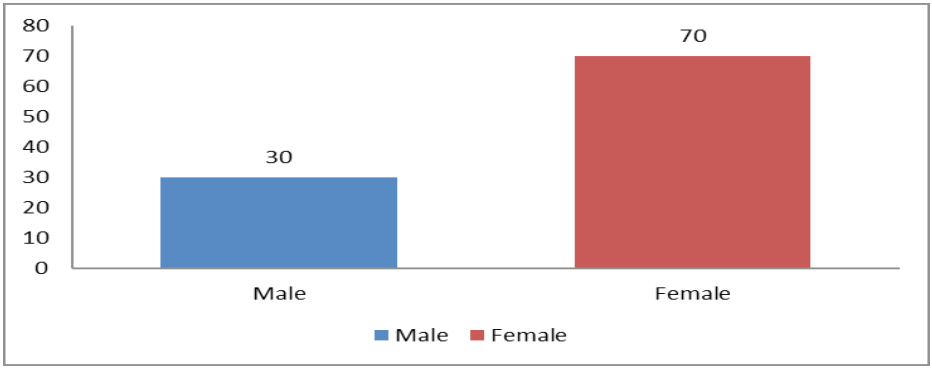

Figure 3: Gender of participants

3.2 The influence of level education towards the use of human excreta derived products

Literacy was a common characteristic among the respondents with 54% having a tertiary level of education, while 31% had a secondary level education and 11% had a primary level of education. Only 4 % of the respondents did not have any form of formal education (Figure 4). The level of education of the respondents varied from household to household. Based on a chi-squared test- χ^2 test, there was no significant difference (P=0.062) amongst education level and gender, but there was a moderate association (Cramer's' V=0.62) between gender and education. The results indicate that the level of education among farmers in Dzivarasekwa is not affected by their gender. Zimbabweans, regardless of gender are ranked as the most literate in Africa (Stewart *et al.,* 2013; ZimStat, 2012).

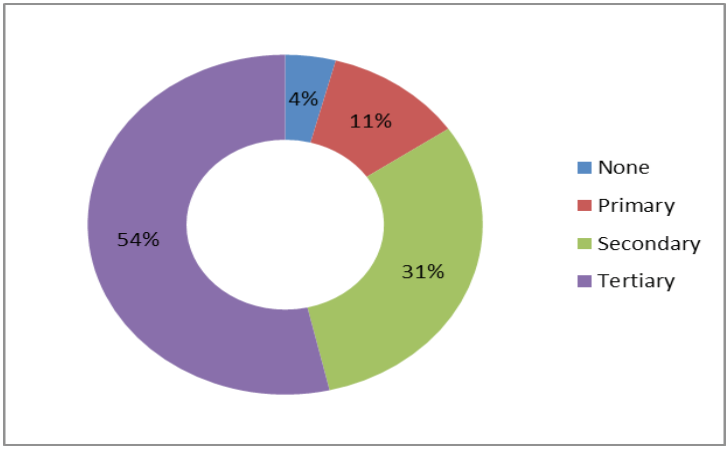

Figure 4: Level of education

3.3 Fear of Diseases

The survey indicated that 55 % agreed that to handle human excreta is a high health risk, 10% did not know 35% disagree that is of health risk. It was also noted that 40% said human excreta is a waste and only suitable for disposal (Table 1). Higher percentage said if human excreta are treated, it is not a taboo to touch it.

Table 1: Residents' attitudes and perceptions of human excreta products

Attitudes and perceptions	Agree (%)	Do not know (%)	Disagree (%)
Human excreta are a waste and suitable only for disposal	40	15	45

Human urine has no benefit to humans	34	5	61
Handling excreta is a high health risk	55	10	35
Human excreta should not be handled in any way	29	11	60
It is a taboo to handle urine	20	14	66
Human faeces have no benefit to humans	19	20	61
It is a taboo to touch faeces	38	6	56
It is a taboo to touch treated faeces or urine	23	15	62

Basing our analysis on data from able 1, it is evident that that both residents and farmers in the study site were afraid of diseases associated with the use of human excreta fertilizers. The main point they raised was that there was no guarantee that all the pathogens could be dead in the stuff. One of the greatest fears was handling a stranger's human excreta they argued that theirs and their family really bothered. Thus the majority who constituted 55% agreed that handling human excreta was a high health risk and therefore, human excreta could not be used in always. This attitude and perception also came out loudly during focus group discussions with the farmers. They argued that improper use of human excreta causes water-borne disease like cholera and typhoid. Those with positive attitudes towards utilising human excreta argued that maintaining a high standard of hygiene worked for the good of the project. . In the discussion, one participant said "People have different health conditions and using their poop for agriculture purposes is like sitting on a time bomb". This showed that when it comes to health issues, people are not comfortable with the use of human excreta as fertilisers; Similarly, the Department of Agriculture Forestry and Fisheries (2014) in Mozambique examined the possibilities of using Human excreta in agriculture and found that most of the people feared the diseases associated with the use of such fertilizers. There were general feelings that touching or handling excreta, especially faeces, should be avoided. Some respondents also worried that the faeces could be infected with the HIV/AIDS virus. (Department of Agriculture Forestry and Fisheries, 2014).

3.4 Potential use of Human Excreta

During the study it was noted that farmers have resorted in the use of human excreta in agriculture due to the expensive and scarce fertilisers. They argue that human excreta are readily available and are good manure. The study established that 90% of the respondents were involved in urban farming and consumed agriculture from that process. The study shows that some people have knowledge that treated human excreta can be used as fertilizer successfully. Of the 200 respondents, 71% agreed that treated that human excreta can be used as a fertilizer, while 29% disagreed that treated human excreta can be used as a fertiliser, refer to ***Figure.3*** refers. The results concur with Guzha et al. (2005) who found that most farmers in Zimbabwe agree that human excreta

could be used as fertiliser.

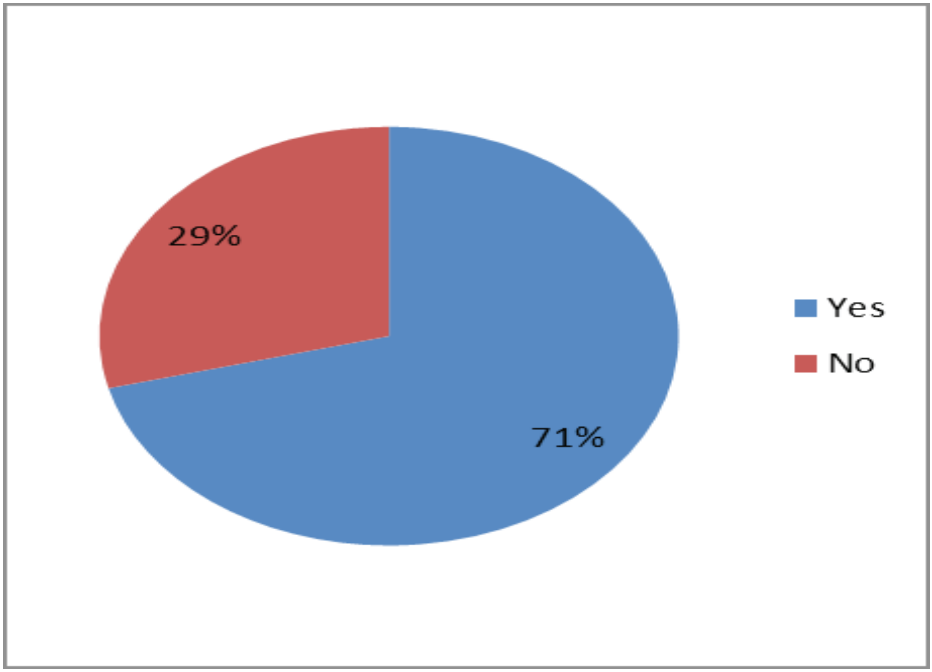

Figure 5. Knowledge of Human Excreta as a Fertilisers Source: Field Visit

The survey also shows that while human excreta is abundantly used in open space plots by farmers, it had potential of being used even in backyard gardens where vegetables and flowers are planted. The survey showed that 62 % of the farmers used the human excreta organic fertilizer on products they intended for selling despite 30% consumed the products. This shows that farming in the area is mainly for both consumption and sale purpose, as depicted below ***Figure 4***. Like other high density suburbs, Dzivarasekwa farmers do their marketing at the local sale point. There was potential that products from the human excreta fed plots could be put on the larger market in greater Harare and the concept of converting human excreta be further refined and used on a larger scale. The study showed big potential in the project more so if the private corporates which are into fertiliser production could have the buyin.

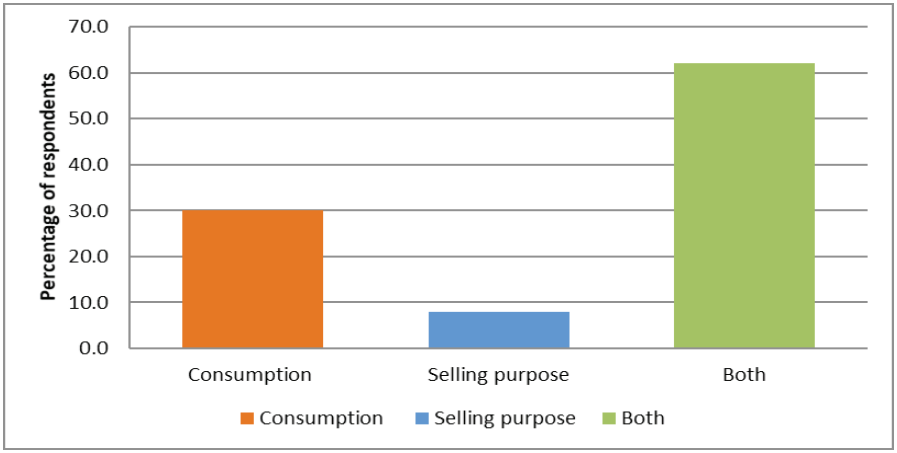

Figure 6: Consumption and Selling Percentages Source: Field Visit and Data Analysis

Attitudes and Perceptions of Farmers Towards the re-use of Human Excreta in Agriculture

Evidence from the study show that there is a lot of farming activities in the environments of Dzivarasekwa suburb which support the view that urban and peri-urban farming contributes to the uphold of urban food security. . The views of the research respondents were that this project could be supported and used for the furtherance of urban food security if done correctly. Our literature review have shown that this is a practice done in many parts of the globe. However, for Dzivarasekwa residents, due to their economic circumstances, we argue that both the consumption and selling is done out of desperation. The continuous usage of the human excreta products eventually contributed to their change of attitude. Even the attitude of other consumers and customers equally changed to being positive. Interviews with consumers revealed that a big percentage appreciated the quality of crops and vegetables.

Table 2: Attitudes and perceptions of farmers towards the re-use of human excreta in agriculture.

Question	Agree (%)	I do not know (%)	Disagree (%)
Human excreta are a resource for the soil	77	10	13
Sanitised human excreta can be used as fertilizer	57	26	17
I will use human excreta on my crops if sanitized	53	12	35
Taste of vegetables will change when fertilised with urine	21	39	40
The smell of vegetables will change when fertilised with urine	17	35	48
Crops can be killed when fertilised with urine	8	40	52
Crops fertilised with human excreta are suitable for consumption	52	21	27
I will never consume plants fertilised with human excreta	43	4	53
Animal manure can be used as fertilizer	87	5	8
Treated human excreta can be used for other purposes like Energy, Fertilizer for forest etc	69	23	8

Consumers also indicated that at times they just bought vegetables, even excreta have been used or not they do not know. Our observation was that farmers did not raise any form of awareness since all residents knew about what was happening in the open farming plots. Unless such services would be engaged by the relevant organisations like the Environmental Management Agency, no individual farmers would do so. However, it was cases of Cholera outbreak which forced consumers to avoid products sold on open markets and subsequently affected activities of entrepreneurial farmers in Dzivarasekwa.

According to the survey, 77% of the respondents know that human excreta is a resource for the soil and 57% agreed that treated human excreta could be used as a fertiliser. Although most agreed that treated human excreta could be used as a fertiliser, 53% of

the respondents would use human excreta on their crops as shown on ***Table 2***. This was better explained by another farmers responds who said, 'human excreta are suitable for the soil, it is manure when there are treated human excreta on the ground and crops germinate there like, amaranths, pigweed and tomatoes'. Some said they do not even care what manure is used for plants in the market, but they buy and eat, and nothing has ever happened. They also noted that those crops with chemical fertiliser, especially vegetables, taste bad than fertilised with human manure because humans eat a lot; therefore, his or her manure is rich in nutrients. This can also be supported by United States of America (USA) Experiments in the USA that found that maize, which was grown using substantial quantities of urine grew 50% taller than corn is grown using no urine at all (Mackie Jensen et al*.,* 2008). Thus, 40% disagree that human excreta will change the taste or destroy crops; they argued that it would taste perfect see ***Table 2.*** One respondent during the survey said human excreta do not damage plants, look at public toilets crops or grass nearby seems very green and healthy and tempting to eat but due to the perception we people have towards human excreta most people do not eat such crops because it is associated with dirtiness. They argue that they are not willing to use it due to attitudes and perception they have on human excreta. Therefore, they say that there is a need for attitude change.

Some also pointed out that there are many diseases people suffer some which are contagious thus prevent people from using human excreta on crops, especially vegetables; instead, they would use human excreta on flowers. Guzha (2001) in Dzivarasekwa extension, Zimbabwe reveal that most of the residents will not use human excreta for growing vegetables as they are not comfortable eating vegetables fertilised by human manure. Other community members said they would use excreta for planting flowers, maize, and fruit trees.

3.5 Cheap Sanitation Facilities

A number of research participants in Dzivarasekwa reasoned that pit toilets were cheap sanitation facilities easy to construct, manage and extract human excreta from them. They knew human excreta could be used as a fertiliser due to the knowledge that they were given during the program (Guzha et al., 2005). A table below indicates a series of likened questions to evaluate the perception and attitudes towards the re-use of human excreta. Out of 100 respondents, 40 percent agree, while 15 percent did not know and 45 percent disagree that human excreta were not suitable only for disposal and not a good resource for agricultural fertilisers *see* ***Table 3*** There was variation in response to selected residents. The majority of the population of respondents constituting 55 percent agreed that handling human excreta is a high health risk and therefore human excreta should not be handled.

Table 3: Residents' attitudes and perceptions of human excreta products

Residents' attitudes and perceptions towards human excreta products	Agree (%)	I do not know (%)	Disagree (%)
Human excreta is a waste and suitable only for disposal	40	15	45
Human urine has no benefit to humans	34	5	61
Handling excreta is a high health risk	55	10	35
Human excreta should not be handled in any way	29	11	60
It is a taboo to handle urine	20	14	66
Human faeces have no benefit to humans	19	20	61
It is a taboo to touch faeces	38	6	56
It is a taboo to touch treated faeces or urine	23	15	62

In the area where human excreta was used abundantly, they used diversion canals to tape into the human waste and eventually used it as fertiliser. However, they acknowledged that was it not for their poor backgrounds, they would have had like proper flushing toilets. They also stated that the emptying process of buckets with human excreta was laborious and cumbersome as well as tiring the mind that it was mostly done during the night.

3.6 Appearance, Religious, Fear of being Stigmatised and the Smell

Our study established that the majority of residents of Dzivarasekwa could use human excreta for fertilizing their backyard gardens and open space plots but were held buy a number of issues. Religiously, certain sects of the local religious groups believe that handling human waste on a daily basis brings and open windows for the entry of evil spirits. We argue that religion and its belief systems control a reasonable percentage of people in the context of African spirituality and cosmology. As a result, our study concluded that sections of the population that did not use human excreta despite their dire economic conditions was an outcome of religious beliefs. In that context, respondents would take up a certain behaviour for the purpose of keeping up appearance and be acceptable in the community religiously. Compounded with the issue of stimatisation as well as the issue of bad smell that comes from human excreta, many would not use the human waste for fertiliser. **Table 4** below helps illustrate the issues discussed here.

Table 4: Reasons why residents do not like human excreta.

Option why residents do not like human excreta	Per cent
Appearance, Health R, Mock, Patronage, Religious", smell	58.0
Appearance, Health R, Mock, Religious", smell	3.0
Appearance, Health R, Religious"	4.0
Appearance, Health R, Religious", smell	8.0
Appearance, Mock, Religious"	4.0
Health R, Mock, Religious"	3.0
Health R, Mock, smell	5.0
Health R, Patronage	6.0
Health R, Patronage, smell	4.0
Mock	5.0

Most people during the research argued that they fear being mocked and this prevents them from using human excreta. Women participants also pointed out that religiously, cleanliness is next to God and hence human excreta are considered very dirty. Others argued that some might not want their faeces or urine re-used fear of black magic and witchcraft. This was also noted in other studies. In Uganda, an eco-san project carried out in Kampala showed that 22 farmers had been identified and agreements signed with them to carry out demonstrations and trials on their farms. These farmers will be involved in the plot demarcation and decision making on the types of crops to be grown. One of the challenges experienced in this study was the unacceptability of using faeces products (Niwagaba, 2009). In Nigeria prohibit the collection of urine by strangers for fear that the urine may be used against the people through 'black magic' or 'evil spirits' (Akpan-Idiok, Udo, & Braide, 2012).

4. Discussion

The study sought to unpack farmer's perceptions and attitudes towards the use of treated human excreta in peri-urban agriculture. The use of human excreta for agricultural purpose internationally is an old and well-known practice. However, in Zimbabwe, the handling of human excreta and its use for food production is still generally not acceptable. In Dzivarasekwa, human excreta are seen as waste products, unhealthy, unhygienic, and detrimental to humans (Moilwa, 2007). However numerous ancient Arab, Chinese, Greek, Roman and Spanish authors extolled the benefits of human manure, and some gave specific instructions on how to process it and get a product that is odorless and useful as a fertiliser. From the survey, it can be noted that the use of treated human excreta for agricultural purposes is not widespread in Zimbabwe. Yet this essential organic manure is thrown away; the government spends scarce foreign

exchange importing chemical fertiliser.

Using urine is considered harmless and inoffensive, since urine is indistinguishable from the water in the ground and stepping into it is quite different from stepping onto human faeces. Positive attitudes towards the use of excreta need to be reinforced with practical demonstrations on the safe use of human manure. Production of human manure should be associated with the safe use of animal manure. Good agricultural practices should also be encouraged to ensure that faeces do not meet the edible portions of crops. Excreta-related diseases are prevalent in developing countries since excreta contain high concentrations of pathogens that can cause infections in humans. Therefore, there is a need to practices proper hygienic ways of handling human excreta.

The results from the research indicated that the level of education of the respondents did not have a direct effect on farmer's perceptions and views of the use of human excreta for food production. It was clear that the level of information and knowledge regarding the use of human excreta for food production had a significant impact on the views and perceptions of the respondents. The more the respondents knew about the value of human excreta, the more willing they were to use it as a fertiliser in their gardens. In general, the male respondents had a lower level of knowledge regarding the fertiliser. However, the traditional gender roles in the communities were still observed and sanitation was regarded as a women's issue. Men, therefore, did not have much of an opinion regarding the use of human excreta.

Most of the respondents said that people would change their minds and use human excreta as fertiliser in their vegetable gardens if they were adequately informed on the advantages of doing so. Some also said that to lead by example was the best way; therefore, councilors and development practitioners should fund and implement human excreta fertilizer projects in the communities. Only a few respondents said that it would be impossible to change people's minds as it was culturally a taboo to handle human excreta. There is a general norm of not handling human excreta as it is considered unhygienic is still influential among the respondents. Even though they said that they would use human excreta in their gardens and eat the food produced, it remains to be seen whether they will do so. Use of human excreta cannot be entirely accepted, understood, and preserved well without identifying peoples' attitude and perception in the community (Bryant *et al.,* 1997). For instance, the level of understanding of the use of human excreta in agriculture varies among different groups, such as farmers and end-users. This theory of Planned Behavior (TPB) maintains that an individual's intention to perform a behaviour is predisposed by a combination of behavioral attitude, subjective norms, and behavioral control (Ajzen, 2011). It postulates that attitude, norms, and perceived behavioral control, however, determine environmental behaviour. Human attitude towards the environment is centered on complex moral and social values and comprise behavioral intention, beliefs, and affective responses people hold pertaining environmental issues and activities (Langergraber & Muellegger, 2005; Mariwah & Drangert, 2011). This is imperative in understanding how community and farmers

from the valuation of a decision or an object based on their perceived attitude and participation on use of human excreta in agriculture (Mariwah & Drangert, 2011).

Key informants from Ministry of Agriculture (Agricultural Extension and Technical Services-AGRITEX), Harare City council and Environmental Management Agents (EMA) highlighted the importance of re-use of human excreta in agriculture as a fertiliser and potential use in energy. During the interviews with key informants, most of them acknowledged the importance of human excreta to circle economy, maybe a relief to poor management of sewage in urban areas and then improve agriculture production by providing alternatively treated fertilisers from human excreta. All key informants indicated the importance of a political will to take re-use of treated human excreta in agriculture. A nexus approach of including farmers, consumers, farmer's union, researchers, and government with the aid of political will help the adoption of human excreta for clean cities and improve food security. They illiterate the formation of policy which tackles health issues associated with human excreta, environmental impact assessments and social accessibility of human excreta by the communities (Gillespie, 2009). Therefore, there is a need to understand the circular economy and opportunity cost to adopt human excreta as a strategy to improve agriculture production in urban areas.

5. Recommendations

The most fundamental thing that might be needed for people to have a better understanding for the use of human excreta in agriculture is to educate them about the proper handling, use and hygienic issues on the harvesting of human excreta for agricultural purpose. In addition to this, there is a need to educate people on the safest process of changing human excreta into usable manure free from pathogens, for example, through composting and how it is appropriately done. There is also a need to teach people on ecological balance and sustainable development one that values our environment while at the same time boosting Agricultural production.

It is of great importance to change human perceptions to ensure the success of human excreta diversion sanitation technology where there are no sewers and properly serviced stands especial for illegal settlers. Education and an integrated approach where everyone is included and able to participate should be used. This can be achieved by involving all the stakeholders to participate in such projects, coupled with institutional monitoring and evaluation. There is a need also to intensify awareness programs with practical demonstrations to show the beneficial aspects of using human excreta fertilisers. The government should play a pivotal role in widely promoting the technology through various media and ensure that there are marketing approaches that use different mediums of communication giving the relevant information that reinforces the uptake of human excreta fertilisers. Those who market and promote the use of human excreta fertilisers should be expertise with correct information and knowledge of the subject to ensure that users of this sanitation system understand it well. Furthermore, there is a need to target

all farmers in urban and rural farmers and commercial farmers to promote technology through the eco-village concept will also create some "status" for the technology.

The health and hygiene education should emphasize the safe use of human excreta on food production from the start to reinforce householders' choice of re-use of nutrients. To ensure success in acceptance and marketing ecological sanitation solutions for food production requires a change in the way people think about, and act towards, human excreta. Acceptability of use of human excreta vary from one country to another and looking at Zimbabwe given issues of WASH projects there is a lot that needs to be done because people associate human excreta with diseases and is considered of significant harm and should not be handled in any way. It also should be noted that generally, some cultures do not accept the handling and direct use of human excreta. Cultural taboos indeed need to be changed for people to allow using their faeces and urine as fertiliser for food crops. Therefore, adequate education and hygiene awareness campaigns in communities should be a prerequisite for the maintenance of public health. It must be taken into consideration that for those countries that succeeded in changing people's attitudes towards the use of human excreta used demonstration toilets, peer education and peer pressure and adequate information that address people's fears towards the use of human excreta.

Local authorities spend vast sums of money to dispose of human excreta as waste yet re-using human excreta for agricultural purposes can save expenditure for chemical fertilisers, improves soil fertility, reduces poverty and ensures food security (Schouw, Danteravanich, Mosbaek, & Tjell, 2002). Therefore, the study recommends city council authorities to investigate this and establish a cheap and safe way of harnessing human excreta into agriculture. A study on the factors that are vital in changing the perceptions and views of people regarding the use of human excreta for food production will be of great value People are willing to opt for affordable fertilisers and protect the environment while at the same time boosting agricultural production. Such a study should focus on the areas where urine diversion sanitation projects were successful, commercial farmers in major crop-growing regions (2A,2B) and sustainably implemented and where households are actively using human excreta in their vegetable gardens. There is also a need for medical assurance that the use of human excreta has been proved that it works and has been used long back in other countries which now have improved food security.

6. Conclusion

The study investigated what exactly prevent farmers and residents from using human excreta in their field and what may prevent community as consumers from eating crops fertilised from human excreta derived products. Also investigated key informants' stakeholder why treated human excreta is not used in Zimbabwe. Human excreta regarded the" dirtiest" fertiliser due to unethical issues. However, studies have shown its importance in energy, agriculture, and nutritious values to improve food security and sanitation in urban areas hence there is need to consider the use of human excreta

derived products in Agriculture. A proper study on social attitudes, perceptions and preferences of farmers will provide valuable information for agricultural policymakers in the use of human excreta. People understand that organic manure is an excellent idea of re-use of nutrients and can boost agriculture. But when it comes to the use of human excreta, people are afraid of diseases such as cholera, typhoid, HIV and AIDS that may be passed to others using human excreta. Many are aware that human excreta can be used as manure, yet most of the people are not willing to use someone's poop unless it was their own. Some people (38%) said they preferred urine rather than faeces were as 18% said they preferred faeces because they view urine as having less pathogen than faeces. The survey indicated that some people are not yet comfortable in the use of human excreta derived products since they associate human excreta with dirtiness and diseases. Others feared witchcraft and black magic; thus, they would not want their faeces or urine collected. One of the challenges experienced in this study was the unacceptability of using faecal products (Niwagaba, 2009). In Nigeria prohibit the collection of urine by strangers for fear that the urine may be used against the people through 'black magic' or 'evil spirits' (Akpan-Idiok et al., 2012). Generally, faeces are perceived quite differently and are regarded as offensive and unpleasant to handle as they may contain a variety of pathogens. Generally, faeces are perceived quite differently and are regarded as offensive and unpleasant to handle as they may contain a variety of pathogens

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Environmental impacts of illegal mining activities in Mazowe District - A Remote Sensing based approach for environmental protection.

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ABSTRACT

The growth of illegal mining activities in Mazowe District is putting the environment under threat of degradation. The main objective of this study was to assess the environmental impacts of illegal mining activities using remote sensing techniques. The study used time series satellite data from 2000 to 2016 during the periods May to June. Land use land cover (LULC) and Normalized Differences Vegetation Index (NDVI) maps obtained from Landsat imagery from 2000 to 2016 were used in change detection. The images were classified using ArcGIS software based on the maximum likelihood classifier algorithm. Results show that grasslands had a rapid decrease in area of 17.24 % and forests had a minimal decrease of 2.58 % during the period 2000 to 2016. However, bare land had an increase of 7.64 % during the same period and this was attributed to illegal mining activities. NDVI results show that there has been a

huge decrease of 0.30 in the value of the index during the period 2000 to 2016. Markov Chain analysis was used for computation of the transition matrix for future land use prediction through the Idris selva software. The population dataset of 1992, 2002,2012 and projected 2016 and 2030 population of Mazowe District and the LULC maps were used to determine whether population growth can be used to predict land cover changes. A correlation coefficient of 77 % was obtained, which showed the dependence of land cover change on population growth. Results show that cultivated areas have a probability of 0.29 to change to bare land by the year 2030. Grasslands have a high probability of 0.33 of changing to bare land for the projected year of 2030. It was concluded that information obtained from remote sensing could be used to generate valuable information for assessing environmental impacts of illegal mining activities.

Key words

Land change modeller, Land use/land cover, Mazowe District, Normalized Differences Vegetation Index, Remote Sensing.

1. INTRODUCTION

Illegal mining activities are viewed as an environmental threat rather than an activity with economic potential. This phenomenon is influenced by many factors such as declining economy, poor agricultural yields due to drought and the need for decent living conditions (Bhebhe et al. 2013). In many African countries, mineral exploration and production constitute a vital part of their economies and remain key to economic growth. In Africa, illegal mining has caused negative impacts on physical, biological and hydrological environments. The illegal miners use various methods interchangeably from open pit to bed panning and this leads to deforestation and soil erosion (Woldai, 2001). Similar negative impacts of illegal mining operations are spread throughout Africa into smaller mining countries such as Zimbabwe. In 2001 an estimated 350 000 people in Zimbabwe were participating in illegal small scale mining (Bhebhe et al. 2013). In areas such as Mazowe, illegal mining activities have taken precedence over any other economic activities thereby undermining the importance of the environment. Many illegal miners are busy digging for gold using picks and shovels and this negatively affects the environment. The paneers leave behind big yawning craters filled with stagnant mercury polluted water, mounds of sand and fallen trees. A systematic and multi-disciplinary approach of mapping, monitoring and controlling the impact caused by illegal mining activities is necessary so as to assess the character and magnitude of these hazardous events.

A number of methods have been used to monitor the environment in light of illegal mining. One of the methods employed is direct field observations and interviews. In this approach, the researcher visits the informal mining areas to observe and experience the environmental situation. Data is collected using face to face interviews especially

with the elderly who would clearly state the land cover changes that would have occurred with time as a result of illegal mining activities (Bhebhe et al. 2013). Another method used to monitor the environment is that of using aerial photographs. In this method, a camera is mounted on an aeroplane and flown over the area of concern to collect data. This method is very expensive and time consuming as it requires intensive data processing. Aerial photography has a limited ground coverage. Improvements in technology have shown that remote sensing can be used to monitor the environment and at the same time overcoming the limitations associated with direct field observations and aerial photographs. For example, Toren (2001) used Landsat Thematic Mapper imagery to monitor environmental impacts induced by mining activities around Soma open pit coal mine in Turkey using change detection. The objectives of this study are:

(i) To delineate the spatial extent of key land use activities associated with illegal mining activities in Mazowe using Remote Sensing.

(ii) To determine land cover changes due to illegal mining activities using digital image processing techniques.

(iii) To predict future land use/land cover changes in the District of Mazowe due to continued illegal mining.

(iv) To develop a geospatial database for managing and rehabilitation of the environment in Mazowe District.

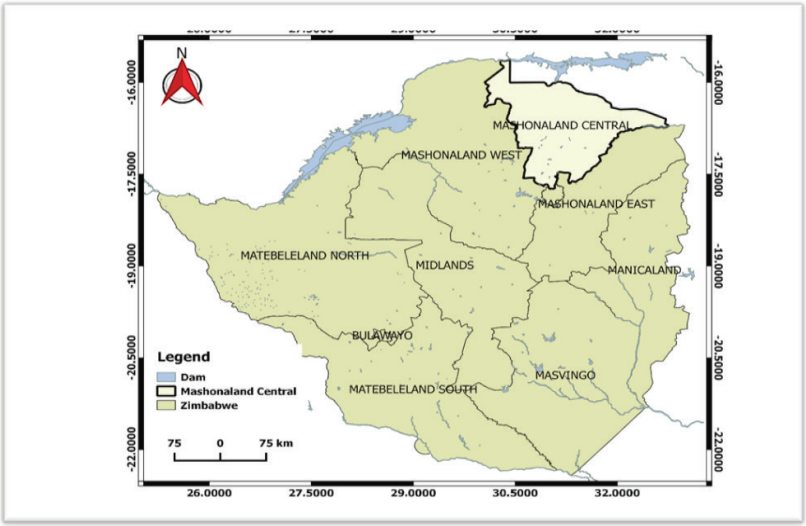
Section 2 presents a description of the study area and the datasets available. The methodology used in the study is described in Section 3. Results are given and described in Section 4. Finally, the conclusions are outlined in Section 5.

2. Description of study area and data

2.1 Study area

Mazowe District presented in Fig 1, is a district situated in Mashonaland Central province in Zimbabwe and it is the southernmost and capital district of the seven districts in this province. It is located at 17°10′00″S and 31°0′00″E (Fig 1). Mazowe has an elevation of 1 217m above mean sea level. It has a total surface area of almost 453,892 hectares. The population in Mazowe District is about 233 450 inhabitants according the Census Report of 2012. The average household size is four people (Zimstat, 2012). In terms of gender in the district, females are the majority (51 %) and the remaining 49 % are male (ZimStat, 2012). The dominant ethnic group in this district is the Shona speaking VaZezuru people. The prevailing agricultural activities in the District of Mazowe are horticulture, dairy farming, citrus farming, seed and crop production. Maize, wheat, soya beans, Virginia tobacco and burley are the main crops

grown in the district. The perception that Mazowe is a farming district is reinforced by the fact that one of the largest silos of the Grain Marketing Board of Zimbabwe is located in this district. Mazowe District is also rich in minerals such as gold, limestone and chrome and this has stimulated mining activities on a larger scale though agriculture also plays a significant role in causing some of the LULC changes. There are also some tourist attraction places in the district but they are not yet fully developed. The dominant soil type in Mazowe District is the fersiallite deep red clay soil which is derived from ipidiorite. Over basic greenstone lithology and mafic intrusive rock soils are moderately shallow to moderately deep, reddish brown to greyish brown, silty sandy clay loams and clay loams. Most of the area is underlain by meta-volcano sedimentary rocks of the Harare Greenstone Belt which are encircled and intruded by a variable suite of granite rocks, the oldest of which may have been co-eval with the youngest felsic volcanic rock of the belt (Tazvivinga, 2012). There is also evidence of a small remnant area of gneissic basement to the greenstone belt. Mazowe District is part of the Highveld of Zimbabwe and receives an average rainfall of 800 to 1000mm per annum which normally falls between November and April (Tazvivinga , 2012). Mazowe River runs through a range of mountain called the Iron Mask Mountain Range, which stretches from the Iron Cap Mine area in the south to the Shamva area in the North East (Ravengai, 2005). Farmland covers a large part of the study area and indigenous vegetation is confined to the less easily cultivated ground. The commercial crops grown include citrus, tobacco, cotton, vegetables, wheat, maize and floriculture farming. The dominant tree species include Brachystegia spiciformis, Brachystegia bohemii and Julbernadia globiflora with some acacia scattered within the woodland (Tazvivinga, 2012). Along the Mazowe, riverbanks there are patches of dense and impenetrable Lantana camara. During the wet season, tall thick grasses characterize the area.



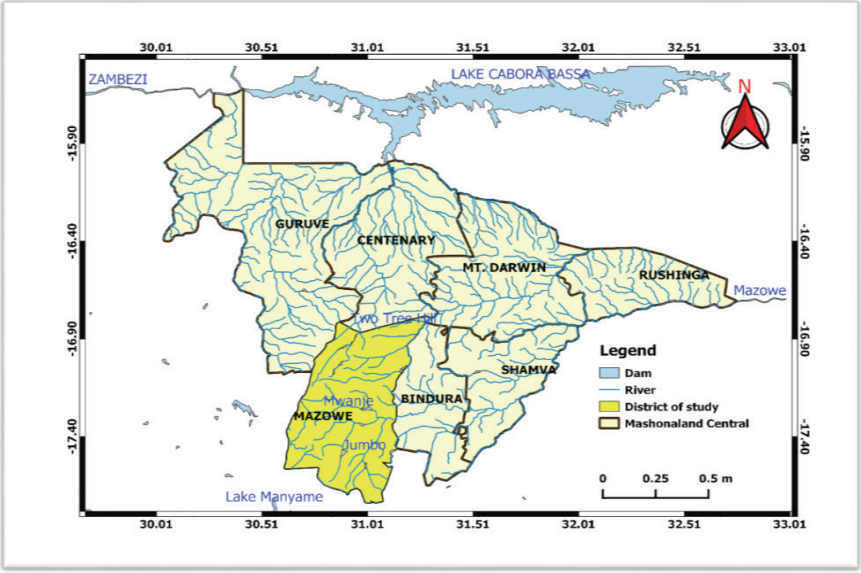


Fig 1: Geographical location of Mazowe District, Zimbabwe showing water bodies and surrounding districts

2.2 Population data

For this study, population data for 1992, 2002 and 2012 is used. This data is used to predict the population for 2016 and 2030. The population data was provided by ZIMSTAT reports.

2.3 Satellite data

Landsat satellite imagery for 1992, 2000, 2005, 2009 and 2016 of the study area was downloaded from www.glovis.usgs.gov/ Available satellite data for this research include classified images of land cover in Mazowe District for the years 1992, 2000, 2005, 2009, 2016.

3. Methodology

3.1 Image pre-processing

The downloaded Landsat imagery were resampled using the nearest neighbour resampling method in ILWIS. The satellite images were corrected for atmospheric and radiometric corrections in QGIS. They were re-projected to UTM 36S coordinate system using the WGS84 datum.

3.2 Maximum Likelihood Classification

Maximum likelihood classification, which assumes normal or near-normal distribution for each feature of interest, was used to classify the Landsat TM images into thematic maps. This was carried out in ArcGIS 10.3. A prior knowledge of the study area and the ground trothing enabled the development of a classification scheme. Six LULC classes were identified from the classification and these include bare land, built-up, water, forest, grassland and cultivated. Supervised classification techniques have the advantage that they allow the integration of expert knowledge, field observations and pattern recognition (Verburg, 2011). On the other hand, these techniques introduce an element of subjectivity, which makes interpretations dependent on the observer. This however cause problems in replication and therefore change detection and to curb this, the researcher sought confirmation from key informants. In this research, maximum likelihood was used since it is a robust method which only requires 60 training pixels to reach its highest accuracy unlike most supervised algorithms that require more than 200 sample pixels (Sample & Imagery 2014). The accuracy of the classification results was validated using the confusion matrix.

3.3 Vegetation indices

The normalized difference vegetation index (NDVI) is a numerical indicator used to show the health of vegetation focusing on spectral pattern response of vegetation in the Near Infrared and Red band of the electromagnetic spectrum. This was calculated in ArcGIS 10.3 using the Raster Calculator. The following formula was used to compute the NDVI:

$$NDVI = (NIR - R) / (NIR + R) \quad [1]$$

Where: NIR = band 4

Red = band 3

3.4 Prediction of future LULC changes

This was carried out in Idris selva software. The classified images of 2000 and 2016 were used as early and later images respectively. A population dataset was used as the driver variable for the changes in LULC. Regression analysis was carried out to determine whether population growth can be used as a driver variable to predict changes in land cover. This was done through the formulation of regression equations.

3.5 Developing of a Spatial Database

A spatial database was developed in Post-GIS and this database stored all the findings from the study. The database was linked to QGIS for the visualisation of data.

4. Results and discussion

4.1 Spatio-temporal variation of areas

The classified images were used to compute the changes in areas of land cover for the six land cover classes over the period under study. Table 1. shows the results of the changes in area.

Bare land has the largest increase of 20.05 % from 17.8 % to 37.85 % from the period 2000 to 2005 respectively. This trend corresponds to a decrease in cultivated areas, grassland and forest. This can be explained by the increase in illegal mining activities and crop cultivation hence high rates of deforestation. Between the period 2005 and 2009 there was a gradual decrease in bare land of 10.04 %. This can be explained by the increase in cultivated areas, which therefore occupied most of the bare land. Results show that there was a 2.37 % decrease in bare land from 27.81 % to 25.44 % during the period 2009 and 2016 respectively.

Table 1: LULC areas for 2000, 2005, 2009 and 2016

Class	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Bare land	769.72	17.80	1636.04	37.85	1202.13	27.81	1099.456	25.44
Built-up	544.08	12.59	748.15	17.31	336.84	7.79	948.61	21.95
Cultivated	372.39	8.62	229.90	5.32	1069.34	24.74	512.15	11.85
Forest	1505.46	34.83	1308.70	30.28	1166.22	26.98	1393.95	32.25
Grassland	1085.57	25.12	382.07	8.84	507.59	11.74	340.60	7.88
Water	45.09	1.04	17.41	0.40	40.18	0.93	27.43	0.63
Total	**4322**	**100**	**4322**	**100**	**4322**	**100**	**4322**	**100**

Reduction can be due to conversion of bare land into cultivated land and built-up areas. In the study the increase in built up areas is linked to illegal mining activities were small scattered settlements are built by the illegal miners for temporary shelter.

Built-up: The results showed an increase of 4.72 % in built up areas from 12.59 % to 17.31 % during the period 2000 and 2005 respectively. This can be linked to an increase in population hence more need for shelter. However, there was a sudden decrease in built up areas of 9.52 % between 2005 and 2009. This increase can be explained by the huge increase in cultivated areas and can be related to less mining activities during that period hence the destruction of the illegal settlements of gold paneers. A large increase in built up areas of 14.16 % is shown by the results from the year 2009 to 2016. This increase can be explained by the decrease in grassland and cultivated areas. This conversion is because of increase in illegal mining activities hence a corresponding increase settlement to cater for paneers some of whom come from outside Mazowe District.

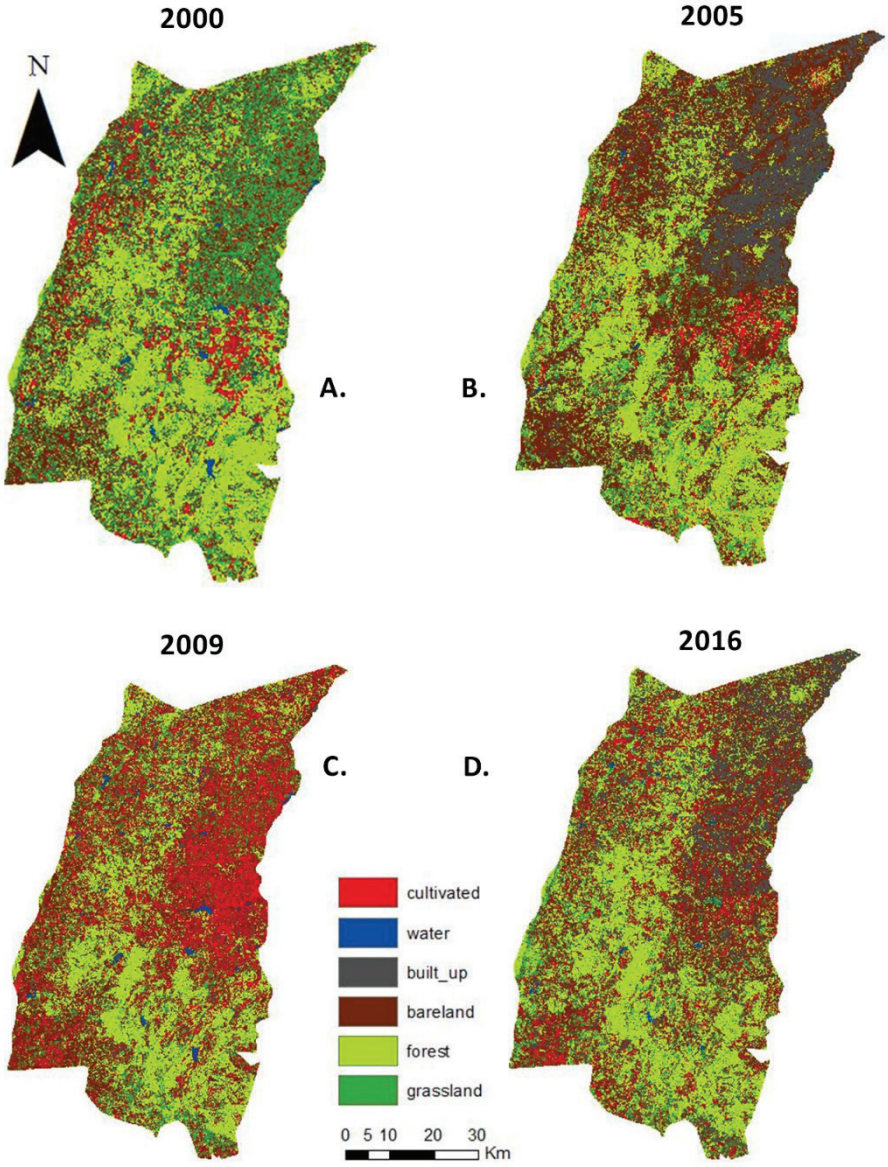


Fig 1: LULC classification results

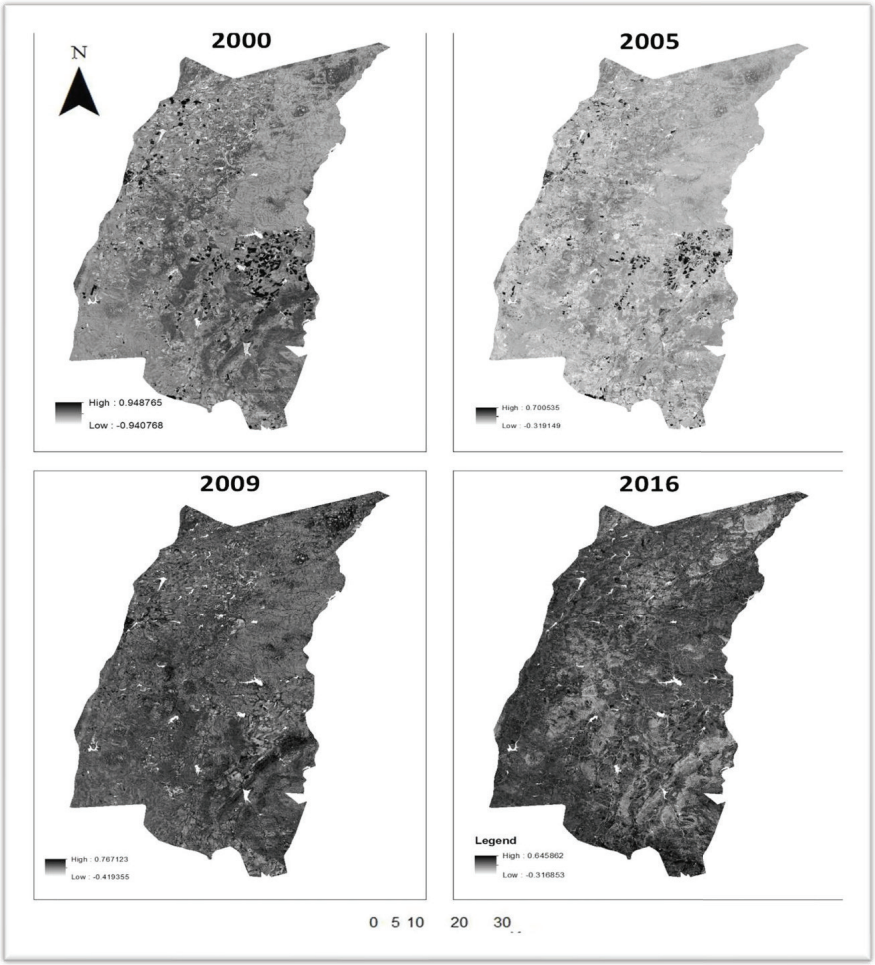


Fig 3 : NDVI maps for 2000, 2005, 2009 and 2016

4.4 Regression analysis

Population data and areas of land cover classes were used to formulate regression equations so as to determine whether population can be used in predicting land cover changes. The graph and equations below were obtained

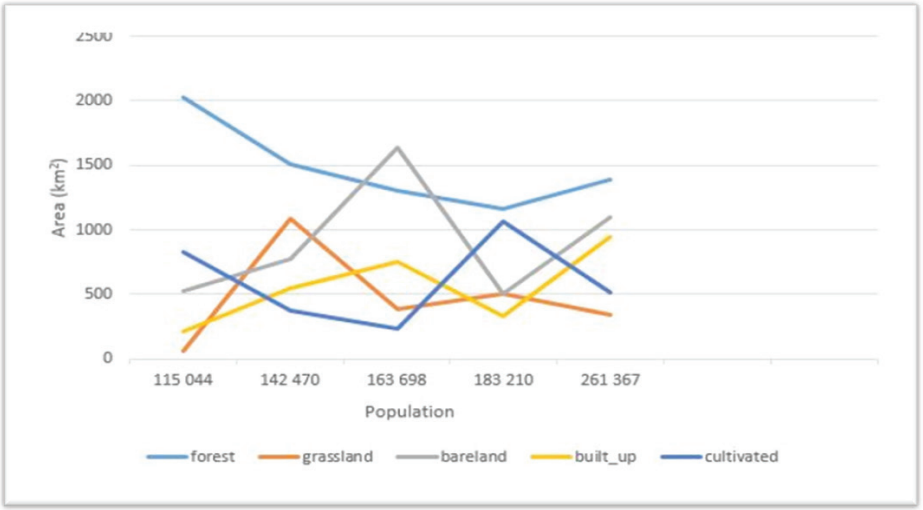


Fig 4: Regression analysis graph

$$A_{\text{bare land}} = 89.399P + 638.65 \quad [2]$$

$$A_{\text{forest}} = -160.18P + 1960.50 \quad [3]$$

$$A_{\text{grassland}} = -1.618P + 479.96 \quad [4]$$

$$A_{\text{built-up}} = 126.11P + 180.09 \quad [5]$$

$$A_{\text{cultivated}} = 6.215P + 584.02 \quad [6]$$

The regression coefficient was computed from the graph to show the accuracy of using population to predict changes in land cover. The value of the regression coefficient obtained for forests was $R^2 = 0.5924$. The correlation coefficient shows

the strength of relationship between population and land cover (forest), it was derived from the square root of the regression coefficient and its value was R = 0.77 (77 %). These values give evidence that increase in population is a driving force for changes in land cover.

4.5 Prediction of LULC changes

The study could not predict future LULC changes for 2030 for the study area due to limited time and resources. However, a transition probability matrix was formulated. This shows the probability of each land cover class to change to another land cover by the year 2030. Table 4 shows the transition matrix obtained. A figure of 25 percentage depicts a probability of change from cultivated to built-up and vice-versa, whereas a figure of 29 % depicts a change from cultivated to bare land and vice-versa.

Table 3: Transition probability matrix for 2030

LULC	Cultivated	Water	Built-up	Bare land	Forest	Grassland
Cultivated	0.24	0.00	0.25	0.29	0.11	0.12
Water	0.00	0.70	0.02	0.02	0.13	0.12
Built-up	0.24	0.00	0.29	0.33	0.08	0.07
Bare land	0.08	0.00	0.18	0.43	0.20	0.11
Forest	0.03	0.00	0.04	0.25	0.64	0.03
Grassland	0.13	0.00	0.30	0.33	0.12	0.12

4.6 Developing a spatial database

The spatial database created was linked to QGIS software where the data is visualized. The database can be run on any computer with Posture independent of the operating system type. It is password secured and has GIS functionality including zooming in and out, panning, zooming to a particular polygon and also to full extent. The database is able to:

1. Query spatial and attribute information

2. Edit and update the database components

3. Check geometry of new entities

4.7 The Multi-Client login

The login windows as shown in Figure 1.6 will appear prompting authorised users to enter their credentials. There are no limitations as to how many users can login to the database. The user password can easily be changed by going to the password manager.

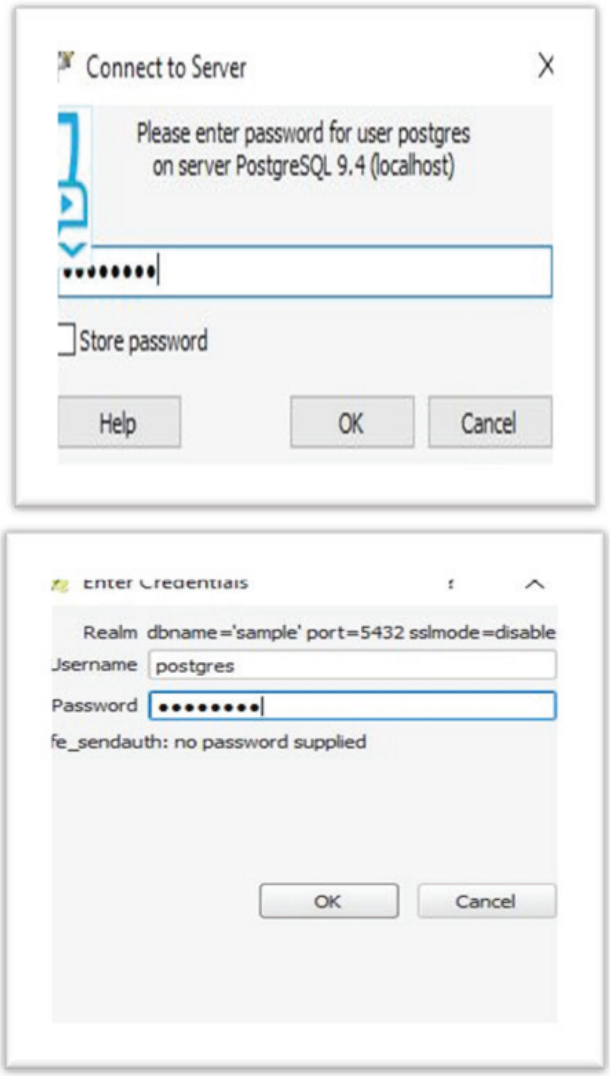
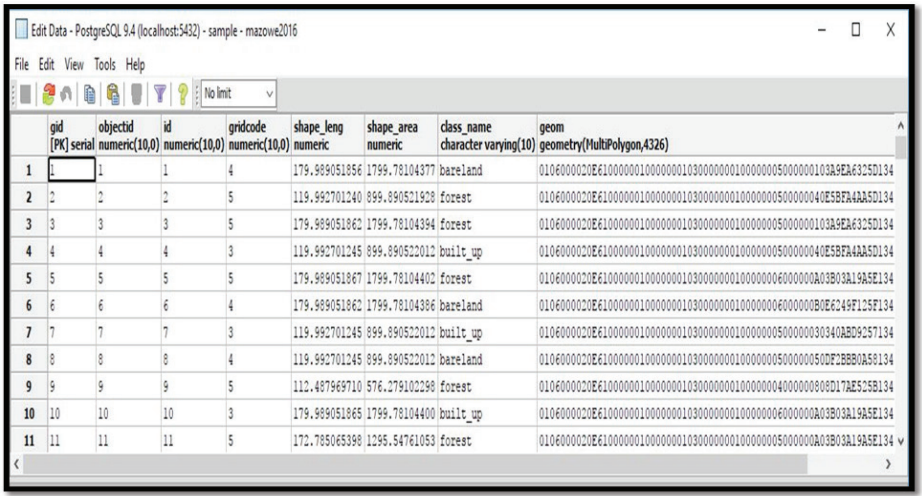


Fig 6. Access window to database

4.8 Addition of new LULC records

The database offers an authorised user the privilege to access the relations to view and edit the data within them. If standard methods are used, different stack holders can be added and access the same geospatial database. For example, the Environmental Management Agency (EMA) can collect and add environmental monitoring information to the database whilst and Zimbabwe National Water Authority (ZINWA) can add water quality information to the database. This however reduces costs on duplication of data collection efforts. Fig 7 shows a relation of the database which the user can update and manipulate the records within the relations.



	gid [PK] serial	objectid numeric(10,0)	id numeric(10,0)	gridcode numeric(10,0)	shape_leng numeric	shape_area numeric	class_name character varying(10)	geom geometry(MultiPolygon,4326)
1	1	1	1	4	179.989051856	1799.78104377	bareland	0106000020E6100000100000001030000000100000005000000103A9EA6325D134
2	2	2	2	5	119.992701240	899.890521928	forest	0106000020E6100000100000001030000000100000005000000040E5BFA4AA5D134
3	3	3	3	5	179.989051862	1799.78104394	forest	0106000020E6100000100000001030000000100000005000000103A9EA6325D134
4	4	4	4	3	119.992701245	899.890522012	built_up	0106000020E6100000100000001030000000100000005000000040E5BFA4AA5D134
5	5	5	5	5	179.989051867	1799.78104402	forest	0106000020E6100000100000001030000000100000006000000A03B03A19A5E134
6	6	6	6	4	179.989051862	1799.78104386	bareland	0106000020E6100000100000001030000000100000006000000B0E6249F125F134
7	7	7	7	3	119.992701245	899.890522012	built_up	0106000020E6100000100000001030000000100000005000000303 40AED9257134
8	8	8	8	4	119.992701245	899.890522012	bareland	0106000020E6100000100000001030000000100000005000000050DF2BBB0A58134
9	9	9	9	5	112.487969710	576.279102298	forest	0106000020E6100000100000001030000000100000004000000808D17AE525B134
10	10	10	10	3	179.989051865	1799.78104400	built_up	0106000020E6100000100000001030000000100000006000000A03B03A19A5E134
11	11	11	11	5	172.785065398	1295.54761053	forest	0106000020E6100000100000001030000000100000005000000A03B03A19A5E134

Fig 7: Adding new LULC information into the database

4.9 Extraction of LULC Data

Changes in LULC are important in monitoring the environment. PostgreSQL data management system provides a high-level query language through the Structured Query Language, which enables the database user to retrieve information from the database. In the geospatial database,

LULC can be queried for each land use class and year. Fig 8 shows an example of a query run to retrieve the land use with the largest area for the year 2016 in the spatial database developed.

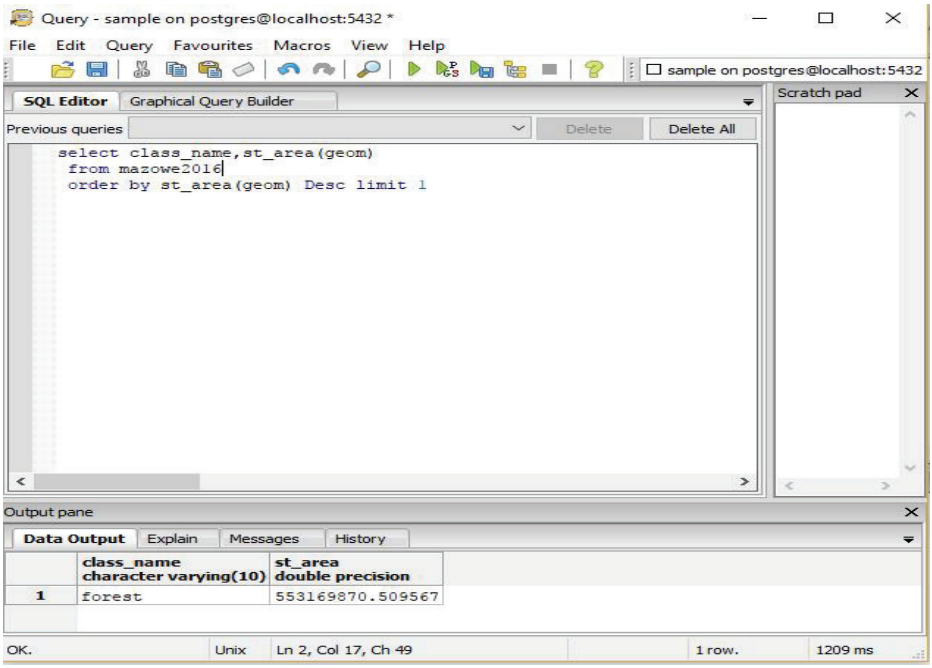


Fig 8: Spatial query for 2016

5. Conclusions

In this research, the conclusions drawn are listed below.

Environmental impacts of illegal mining can result in erosion, sinkholes, loss of biodiversity, or the contamination of soil, groundwater, and surface water by the chemicals emitted from mining processes.

1. Results of land cover classification show that Grasslands decreased by 17.24 % from 2000-2016 and Forest decreased by 2.58 % during the same period. The decrease in grasslands and forest were linked to an increase in bare land and built-up of 7.64 % and 9.36 respectively which however negatively impacts the environment through erosion of exposed hillsides, mine dumps, tailings dams and resultant siltation of drainages, creeks and rivers can significantly impact the surrounding areas.

2. Results of the NDVI show a decrease of 0.30 from 2000-2016. This change is attributed to the deforestation activities carried in the area because of mining

activities and other activities like clearing land for agriculture. Deforestation causes major problems for one simple reason; it decreases the number of trees, which clean the environment, provide oxygen and also affect rain patterns. This is the major reason why there are calls for tree plantation; it is to make up for this loss.

3. Projecting the transition probabilities of land use and land cover was successful using the Markov Chain analysis. Results show that cultivated areas have a probability of 0.29 to change to bare land by the year 2030. Grasslands have a high probability of 0.33 of changing to bare land for the projected year of 2030. The predicted maps of 2030 could not be obtained because of software problems.

4. Population growth is a driver force for changes in land cover as shown by the correlation coefficient of 77 %, showing the relationship between population growth and land cover change.

5. Mining processes produce an excess of waste materials known as tailings. The materials that are left over after are a result of separating the valuable fraction from the uneconomic fraction of ore. These large amounts of waste are a mixture of water, sand, clay, and residual bitumen. Tailings have great potential to damage the environment by releasing toxic metals by acid mine drainage or by damaging aquatic wildlife.

6. There are also many occupational health hazards that miners face. Most of miners suffer from various respiratory and skin diseases such as asbestosis, silicosis, or black lung disease.

7. Sand mining and gravel mining creates large pits and fissures in the earth's surface. At times, mining can extend so deeply that it affects ground water, springs, underground wells, and the water table.

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Notes

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