An Integrated Watershed Approach to Water and Sanitation Hygiene priorities through a Narrative Review of Lake Chivero, Zimbabwe

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Abstract

This paper describes an integrated watershed approach to water sanitation and hygiene for a water supply reservoir near Harare, Zimbabwe`s capital city. From the construction of the lake to the present, considerable difficulties have been experienced in water quality and water treatment. Discharges from urban and rural agriculture, sewage treatment works and industries have caused severe stresses on the lake's water quality. To combat eutrophication in the mid-1970s, a Hydrobiology Research Unit was established to facilitate pollution research and a biological nutrient removal sewage treatment plant was also installed. This was successful for a decade but afterwards water quality started to deteriorate due to increases in population. The original sewage treatment plants were designed to handle 18 million liters of human waste a day for a population of about 500,000 people but now the estimated population has exceeded 2 million people therefore overloading the sewage works. Continued deposition of sewage effluents has contributed to the spread of aquatic weeds such as water hyacinth (*Eichhornia crassipes*), blue-green algae (*Anabaenopsis sp*) and spaghetti weed (*Hydrocotyle ranunculoides*). In 1997 there were recorded fish kills especially the green headed tilapia due to low levels of oxygen. A total of 11,735 cholera cases were recorded as of December 2008 due to poor sanitation and water shortages. For these reasons the objective of this review is to assess the integrated impacts of water quality on the environment and sanitation throughout the lake, watershed, and water supply service area. The watershed of the lake and its management has changed continually over time; consequently any analysis will have to be cognizant of a number of changing factors simultaneously. The area around the lake has been designated as a wildlife sanctuary, which offers the potential for managing water quality better. This study will implement International Lake Environment Committee, World Lake Vision principle of good governance, which is based on fairness, transparency and the empowerment of all stakeholders. To combat the situation in the lake, recycling of sewage to agricultural land, combined with pollution prevention and water re-use could be implemented as this will yield savings on chemicals, energy and mechanical costs needed to remove nitrogen at sewage treatment plants.

Key Words: Water supply, Invasive species, Wastewater and Water Quality

1.0 Introduction

Water supply in Harare, the capitol of Zimbabwe was insufficient in the 1950s leading to the construction of the Lake Chivero reservoir in 1952. The lake is located downstream from Harare on the Manyame River (Marshall, 1997). It is the primary water supply for the city with 416,000m^3/d of water abstracted (Nhapi, Siebel and Gijzen, 2004). Harare had 400,000 inhabitants in 1952 (Magadza, 2008) and according to the Central Statistics Office, the catchment area grew to an estimated population of 2,098,199 people in 2012. As a result of the growing population, there is rapid increase in wastewater generation resulting in water quality deterioration in the lake.

Lake Chivero is located on a longitude of 17^0 54` 42″ S and latitude of $30^0$ 47`15″E at an elevation that is 200m lower than the city (Figure 1). The lake has a surface area of 26.5 km^2 at full capacity, and the total catchment area is 2136km^2 with 27m being the maximum depth (Nhapi, Hoko, Siebel and Gijzen, 2002). Wastewater from the urban complex drains into the Mukuvisi, Marimba and Nyatsimbe rivers which are the main tributaries of Manyame River. The Manyame River drains into Lake Chivero making it a sink for the city's wastewater. Wastewater is believed to be the major direct and indirect source of pollution in the Lake Chivero resulting in a eutrophic system (Moyo, 1997; Nhapi I et al, 2001).

Eutrophication is one of the most significant causes of water quality deterioration in lakes and reservoirs around the world (Rast and Lee, 1983). Spellman (1996) defines eutrophication as the aging of a lake or land-locked body of water, resulting in organic material being produced in abundance due to a ready supply of nutrients accumulated over the years. Undesirable nutrient inputs are usually from wastewater discharge, land runoff, precipitation, dry fallout, and groundwater principally nitrogen.

In Zimbabwe, the permissible NP concentration is 0.3mgL-1 for Total Nitrogen (TN) and 0.01mgL-1 Total Phosphorus (TP) level as established by JICA, 1996. Above these levels the lake is considered to be eutrophic. Wastewater has detrimental impacts on both ecological and human systems.

1.1 Objectives

This review will attempt to reflect not only the measurements of lake conditions, but, to the extent possible, changes in the watershed at those times. The objective of this study is to (1) conduct a comprehensive review of the water quality and health issues in the Lake Chivero watershed and (2) in doing so develop recommendations and conclusions for how to take and Integrate Watershed Approach to Water and Sanitation Hygiene in the area. The current situation in the lake is detrimental to the environment and human health therefore the need to reduce nutrient loadings and this can be achieved through sound integrated water resource management and good governance.

1.3 Legislative Institutional Framework

From the 1890`s up to 1927, water in Zimbabwe was governed by a set of loosely coordinated pieces of legislation which were managed under the Water Ordinance of 1913. This ordinance was repealed by the 1927 and later the 1976 Water Act (Mtisi S, 2011). However, the 1976 Act was replaced by the Zimbabwe National Water Authority (ZINWA) Act of 1999. The 1999 Water Act set parameters of access and use of water and facilitated the establishment of catchment and sub-catchment areas based on hydrological boundaries (Mtisi, 2011).

In Zimbabwe, water pollution control is a responsibility of several agencies (Table 1). The management of Lake Chivero has been dissected into a number of institutional authorities such as the City of Harare, Department of National Parks and Wildlife Authority, Environmental Management Agency, Harare Municipality, Ministry of Environment and Natural Resources Management and Ministry of Health & Child Welfare.

Institution	Responsibility
City of Harare	• Use the lake as a source of drinking water and is responsible for bulk water supply.
Department of National Parks and Wildlife Authority	• Administers water and environment of the lake since it is a natural recreational facility. • Parks and Wildlife Act of 1975 gave them power to protect the state owned land and recreational parks. • Custodian of the lake fishery and regulates fishing and recreational activities.
Environmental Management Agency	• Responsible for water quality and environment
Harare Municipality	• Owns and manages waterworks and sewage disposal facilities.
Ministry of Environment and Natural Resources Management – Dept of Ag	• Controls the management of exotic and nuisance weeds.
Ministry of Health & Child Welfare	• Provide quality and safe health services through a network of health facilities.

Table 1: Institutions responsible for water resources in the Lake Chivero Watershed.

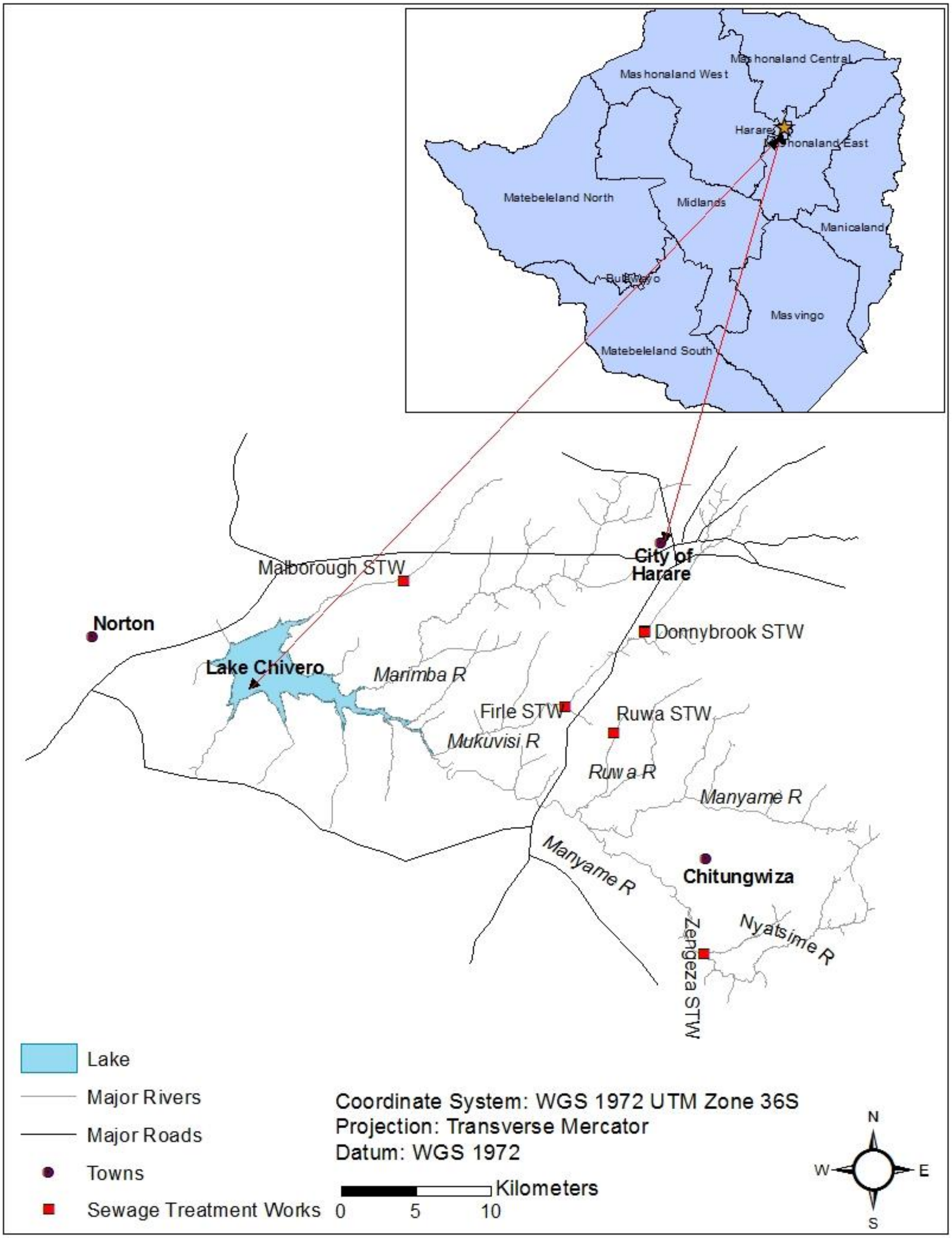

Figure 1: Location of Lake Chivero

2.0 Key areas of research

2.1 Wastewater Treatment and Water Quality

Firle, Hatcliff, Crowborough, Marlborough and Donnybrook are the five major sewage treatment works in Harare. The sewage treatment were initially designed to handle approximately 18 million liters of human waste per day for 500,000 inhabitants. However, population increased to an estimated 2 million, representing a fourfold increase, thereby overloading the sewage works. . According to the Magadza (2008), untreated wastewater was being discharged into the rivers through a retention tank or pumped directly for irrigation of farmlands.

2.2 Invasive Species

Water hyacinth (*Eichhornia crassipes*) is a free-floating, perennial, fast growing, and aggressive invader that can form thick mats. It is found in abundance in Lake Chivero and has been blamed for water quality deterioration, narrowing the river channel, as well as problems related to boat access such as motor jams, navigation and recreation (Shekede et al, 2008). Water hyacinth was observed in the 1940`s. The proliferation of invasive species such as water hyacinth is from the discharge of treated sewage effluent into the upstream rivers (Thornton and Nduku, 1982) as it thrives under a constant supply of nitrogen and phosphorus which are abundant in raw sewage.

According to Mhlanga (1995), the major outbreaks of water hyacinth were recorded in 1956, 1971 and 1989/90. Droughts, eutrophication and water hyacinth control methods were the major contributing factors. Seed dispersed at the bottom of the lake during drought periods, availability of nutrients from the sewage treatment plants and the ideal climate conditions also led to the proliferation of the weed. Discontinued use of chemicals to control the weed in 1986 and the failure of mechanical methods to eradicate water hyacinth contributed to the major outbreak in 1989/90 (Mhlanga, 1995).

Excessive amounts of water hyacinth and blue-green algae and other organic matter in the lake began to have a serious impact on the ability to obtain drinking water in terms of both raw-water abstraction and water treatment (Marshall, 1997). The cost of chemicals increased and filter runs decreased from 28h to 10h due to raw water quality deterioration, inefficiency and overloading of the treatment plants. In addition, algae concentrations and an increase of water pH from 8.0 to 9.6 led to unusual problems in the flocculation and clarification processes as large quantities were carried over to the sand filters.

In order to combat the hyacinth problem, 150,000 Neochetina weevils (Water hyacinth weevils) were imported from Australia (Kunatsa, Mufundirwa, 2013). Natural enemies of water hyacinth, *Neochetina Eichhornia* and *N. bruchi* are in the order of Coleoptera in the

Curculionidae family (Oberholzer, 2001). The weevil reduced water hyacinth vigor by decreasing plant size, vegetative and flower seed production, and facilitates the transfer of fungi and bacteria microorganisms into the plant tissues (Venter et al, 2012). According to Oberholzer (2001), the larvae bore into the petioles and the growth point causing water logging and ultimate death. The weevils eliminated about 95% of the plants but, died off when their food source diminished. However, because water hyacinth is a vigorous grower, it resurfaced again causing more problems in the lake.

According to the UNEP Global Alert Service the spread of water hyacinth declined from 42% in 1976 to 22% in 2000 but in 2005 a new invasive plant, spaghetti weed (*Hydrocotyle ranunculoides*) surfaced (UNEP, 2008). A study conducted in September 2000 on weed infestation pattern in the lake showed that the spaghetti weed has replaced water hyacinth as the main aquatic weed. Spaghetti weed, is a perennial herb which has dense growth over static or slowly-flowing water (Sainty and Jacobs, 2003), the weed has a potential to spread in nutrient enriched waterways. Observations by Chikwenhere in September 2000, showed that spaghetti weed formed a continuous fringe extending 3-4 m from the northern shoreline into the water. The entire weed belt around the lake was about 4m deep, and covered approximately 6.5% of the surface area (Villamagna and Murphy, 2010).

2.3 Fish Kills

In 1956, green headed tilapia (Oreochromis macrochir) was introduced to the lake. This breed flourished because it fed and digested blue green algae (Moyo, 1997; Minshull 1978) thereby making it a major fish species consumed from Lake Chivero. On the contrary, the same breed is very susceptible to low dissolved oxygen and is often the only fish species to die under low dissolved oxygen conditions (Marshall, 1982). Oxygen levels below 5mgL-1 have been argued not suitable for aquatic life

Fish deaths have occurred since 1971 and during the last week of March in 1996, there was a cold spell that triggered a lake turnover which resulted in massive fish kills (Moyo, 1997). The turnover brought low levels of dissolved oxygen and toxic levels of ammonia to the surface (Moyo, 1997). A study conducted by Magadza, (1997) showed ammonia poisoning as the primary cause of the fish kills and observed that unacceptable levels of ammonia also exposed fish to higher incidences of bacterial gill disease.

2.4 Human Health

As population increased in Harare and the Lake Chivero watershed area, the proportion of wastewater returns to rainfall/runoff inflows increased to the extent that wastewater return is now the main inflow into the lake during the dry season (Magadza, 2003). Inadequate investment in wastewater treatment facilities and poor infrastructure maintenance have resulted in the accumulation of nutrients, toxins, and bacteria in the lake, which not only pose environmental risk but also a health risk. For example, the chemical control of water hyacinth, using 2.4 D, increased the incidences of still births and malformed babies. The increase of Cyanobacteria was also coincident with a surge in enteritis in the City of Harare (Marshall, 1997). Microcystin-LR is the most toxic cyanobacteria in eutrophic freshwater and can form harmful algal blooms (HABs). The recommended level of microcystin in lake for potable water supply is 1µg/L but a study conducted in Lake Chivero showed an average concentration of 19.9µg/l (Ndebele and Magadza, 2006) and has been linked to liver cancer incidences.

Water treatment has also become costly to the extent that the Harare City Council is no longer able to supply all of the residents (Moyo, 1997). The proportion of households with access to excreta disposal in Harare declined by about 2.5% from 2002-2009 (ZIMDAT, 2010). During periods of municipal water supply failure some residents from Chitungwiza obtain water from open sources, such as Manyame River which carries partially treated and often undertreated sewage. There has been a high incidence of waterborne diseases in areas of Norton and Chitungwiza as a result of untreated water finding its way into drinking water sources (Masere, Munodawafa and Chitata, 2012). The discharge of raw or partially treated sewage exposed a greater Harare population to a variety of water borne parasites such as Protozoa (e.g. Trichomonas sp), Strongiloides sp of nematode parasites which are discharged as cysts, Trematoda (e.g. Clonorchis sp) transmitted by ingestion of inadequately cooked fish and lastly the Schistosomes transmitted by making contact with water containing cercaria e.g. during fishing (Magadza, 2003). Cholera is closely linked to inadequate environmental management and is transmitted mainly through contaminated water and food via the Cholera Bacteria. As of December 2008, a total of 11,735 cholera cases were reported with 484 deaths since August 2008 (The Cape Argus (SA) 2008).

Recommendations

Population increase, inadequate urban planning and lack of financial resources has contributed negatively to the provision of basic sanitation in Harare as most sewage treatment facilities are aging and overloaded. According to Magadza (2003), major problems leading to the discharge of inadequately treated wastewater in Lake Chivero are frequent power outages, inadequate funds to procure supplies of water purification chemicals and depletion of technical staff.

Solutions

Dominance exercised by political functionaries who have little understanding of the consequences of environment deterioration have negative environmental impacts. For example, poor salaries, under-funding of essential works and diversion of ratepayers` funds to self-aggrandizement projects contribute to environmental damage through poor public services such as waste collection, infrastructure and city hygiene broke down (Magadza, 2003). This can be addressed by implementing the International Lake Environment Committee, World Lake

Vision principles of good governance, which is based on fairness, transparency and the empowerment of all stakeholders (Magadza, 2008). Encouraging citizens and stakeholders to participate in identifying and resolving critical lake problems can also be beneficial. This can be achieved by developing a strategy to educate youth and the community on integrated water resource management and by making use of research findings to develop simple but cost effective and efficient water quality analysis techniques and bio-monitoring techniques. According to Nhapi *et al.*,(2004) a rational approach for the lake is recycling of sewage to agricultural land, combined with pollution prevention and water re-use as this could yield savings on chemicals, energy and mechanical costs needed to remove nitrogen at sewage treatment plants. If these approaches can be implemented, Lake Chivero can be restored back to its original status of serving as the primary supply of adequately treated water.

Conclusion

From the study it is evident that Lake Chivero has been suffering from the excessive loading of nutrients from both point and non-point sources for many years. The situation in the lake is not only affecting the environment but also, to a larger extent, human health. Contamination of the main water sources has led to human illness and death, fish kills and a large amount of money invested in water treatment and control of invasive species. Without sound integrated water resource management and good governance, the reduction of nutrient loadings into Lake Chivero is impossible.

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