An Integrated Watershed Approach to Water Sanitation and Hygiene Priorities for Lake Chivero, Zimbabwe

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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 1.4 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*). The weeds strive under a constant supply of nitrogen and phosphorus as they are the major nutrients in the Lake. The area around the lake has been designated as a wildlife sanctuary, which offers the potential for managing water quality better. 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.

Introduction

Water supply in Harare, the capital of Zimbabwe was insufficient in the 1950s leading to the construction of the Lake Chivero reservoir in 1952 (Figure 1). The lake is the primary water supply for the city with 416,000m^3/d of water abstracted (Nhapi et al., 2004). Harare had 400,000 inhabitants in 1952 (Magadza, 2008) and according to the Central Statistics Office (2012), the catchment area grew to an estimated population of over 2 million 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 170°54' 42" S and latitude of 300°47'15" E at an elevation that is 200m lower than the city (Figure 2). The lake is located downstream from Harare on the Manyame River (Moyo, 1997). It has a surface area of 26.5 km^2 at full capacity, and the total catchment area is 2136 km^2 with 27 m being the maximum depth (Nhapi et al., 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 the lake 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 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 (Moyo, 1997; Nhapi et al, 2002).

In Zimbabwe, the permissible nitrogen and phosphorous concentrations is $0.3mgL^{-1}$ for Total Nitrogen (TN) and $0.01\ mgL^{-1}$ for Total Phosphorus (TP) as established by JICA, 1996 (Moyo, 1997). Above these levels the lake is considered to be eutrophic. The nutrients that are input through wastewater have detrimental impacts on both ecological and human systems.

Objectives

This review will describe the changing condition of the lake as it relates to environmental quality and human health. 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) develop recommendations and conclusions for developing and integrated watershed approach to Water, Sanitation, and Hygiene (WASH) in the area.

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, 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 the 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-Department of Agriculture, Ministry of Health & Child Welfare-Department of Environmental Health, Ministry of Local Government, Urban and Rural Department and Zimbabwe Natural Water Authority.

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

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–Dept. of Environmental Health	Provide quality and promote improved public safe health services and sanitation through a network of health facilities.
	Responsible for individual water supply facilities such as hand dug well, springs in the rural areas.

Table 1: Institutions responsible for water resources in the Lake Chivero Watershed (continued).	
Institution	Responsibility
Ministry of Local Government, Urban and Rural Development (MLGURD)	Responsible for the provision of water services in both urban and rural areas through local authorities.
Ministry of Water Resources Development and Management (MWRDM)	Overall responsibility of development and management of water resources in the country
Zimbabwe National Water Authority (ZINWA)	Provides technical support to decentralized management of water resources directly to catchment communities.
	Responsible for water supplies in the country

Key areas of research

Wastewater Treatment and Water Quality

Firle, Hatcliff, Crowborough, Marlborough and Donnybrook are the five major sewage treatment works in Harare. The sewage treatment plants were initially designed to handle approximately 18 million liters of human waste per day for 500,000 inhabitants. An estimated population of 1,850,000 was recorded in 2002 and this increased to 2,257,000 people in 2012 (Thebe and Mangore) representing over a fourfold increase of population from 1952. According to the previous mentioned authors, an estimated 600, 000 m^3/day of water is supplied to Harare. Furthermore, 390,000 m^3/day of wastewater is generated with an estimated 190,000 m^3/day treated, which leaves 51% of the wastewater untreated. Population growth is blamed for overloading and causing inefficiency of the wastewater treatment plants. According to the Magadza (2008), untreated wastewater was being discharged into the rivers through a retention tank or pumped directly for irrigation of farmlands. However, Thebe and Mangore point out that some industries that are located within the watershed area discharge partially treated or untreated wastewater into storm drains contributing to the direct pollution of streams and reservoirs with industrial effluents.

Invasive Species

Water hyacinth is listed as one of the most productive plants on earth and is considered one of the world's worst aquatic plants (Malik, 2007). It has invaded freshwater systems in over 50 countries in five continents and its distribution is still expanding as the aquatic plant is prevalent in tropical and sub-tropical water bodies where water nutrient concentrations are often high as a result of agricultural runoff, deforestation and insufficient wastewater treatment (Villamagna and Murphy, 2009). Water hyacinth (*Eichhornia crassipes*) is a free-floating, perennial, fast growing, and aggressive aquatic invasive plant that can form thick mats. It was first observed in Lake Chivero in the 1940's but it was not considered a management threat at that time. The sudden explosive growth of water hyacinth and other aquatic plants in the early 1960's was the first visible sign of eutrophication in the lake. Water hyacinth 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). The proliferation of invasive aquatic species such as water hyacinth is from the discharge of treated sewage effluent into the upstream rivers (Moyo, 1997)) as the plant thrives under a constant supply of nitrogen and phosphorus which are abundant in raw sewage. As a control measure, effluent from the municipal sewage treatment plant was used for agricultural irrigation which led to a reduction in the nutrient load thereby improving the water quality. Also, the establishment of the Hydrobiology Research Unit at the University of Zimbabwe, the then University of Rhodesia in 1968, facilitated water quality improvement and research on the lake (Moyo, 1997). To combat the eutrophic status of the lake, in 1974 the City of Harare installed the Biological Nutrient Removal Sewage Treatment plant to treat municipal wastewater. However, new settlers continued to increase the population of the town. With no provision or funding for a new wastewater treatment plant, partially treated wastewater was again discharged into Lake Chivero watershed streams.

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, the availability of nutrients from the sewage treatment plants and the ideal climate conditions 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, blue-green algae, and other organic matter began to have a serious impact on drinking water in terms of both raw-water abstraction and water treatment (Moyo, 1997). The cost of chemicals increased and the filter runs decreased from 28 h to 10 h 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.

Recently, in order to combat the hyacinth problem, 150,000 Neochetina weevils (Water hyacinth weevils) were imported from Australia (Kunatsa and 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 successfully reduced water hyacinth vigor by decreasing plant size, vegetative and flower seed production, and facilitating 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, they died off when their food source diminished. 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 patterns 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 (Chikwenhere, 2001). The entire weed belt around the lake was about 4m deep, and covered approximately 6.5% of the surface area (Villamagna and Murphy, 2010).

Fish Kills

In 1956, green headed tilapia (*Oreochromis macrochir*) was introduced to the lake. This breed flourished because it fed and digested the plentiful blue green algae (Moyo, 1997) thereby making it a major fish species from Lake Chivero, important for food production. 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 (Moyo, 1997). Oxygen levels below 5mgL-1 have been cited as unsuitable 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.

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 resulted in the accumulation of nutrients, toxins, and bacteria in the lake, which not only pose an environmental risk but also a health risk. For example, the chemical control of water hyacinth, using 2.4 Dichlorophenoxyacetic acid (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 (Moyo, 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 1μgl 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 with access to sewage facilities or drinking water (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 the 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 et al., 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 *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 in Harare were reported with 484 deaths since August 2008 (The Cape Argus (SA) 2008). The 2008/09 cholera outbreak affected 52 out of 62 districts throughout Zimbabwe and resulted in 98,531 cumulative cases and 4,282 deaths (UNICEF, 2011). The water and sanitation-related diseases such as Cholera, diarrhea and typhoid outbreaks in the country was as a result of poor state of the health and WASH sectors. According to the UNICEF Factsheet "Small towns, Water, Sanitation and Hygiene Program," an estimate of 46% of Zimbabweans have access to improved sanitation facilities with Harare having an overall coverage of water supply and sanitation estimated to be 60% and 40% respectively.

Recommendations

Over much of the last decade, access to safe water supply and basic sanitation in Zimbabwe has been greatly affected by the general economic decline, reduced institutional and community capacity, power shortages, cyclical droughts and the effects of HIV and AIDS (UNICEF, 2011). 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 seeking greener pastures out of the country.

Political Influence

Dominance exercised by political functionaries, who have little understanding of the consequences of environment deterioration, has 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 breakdown (Magadza, 2003). This can be addressed by implementing the International Lake Environment Committee, World Lake Vision principle 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 sewage to agricultural land. This combined with pollution prevention and water re-use could yield savings on chemicals, energy and mechanical costs needed to remove nitrogen at sewage treatment plants.

Nutrient Control

Excessive nutrients in Lake Chivero have resulted in many environmental problems including invasive species, algae blooms, fish kills, and human health issues. Controlling and reducing nutrient inputs into the lake is the first step in improving water quality for human use and aquatic life.

Water supplies are becoming scarce in the lake Chivero catchment area. Most residential towns, rural villages and farms have limited or no access to WASH facilities resulting in people using unhygienic alternatives for waste disposal which poses the risk of both human disease and environmental harm. However, the use of flush toilets leads to more wastewater generation and more water use. The Practical Action Website suggests a variety of technologies that promote WASH facilities without increasing the demand for water treatment. Technologies such as the use of bio-latrines, which makes use of dry technology thereby reducing the demand for water, ventilated improved latrines which are odorless and easy to clean, ecological sanitation approach which is based on the nutrient cycling where urine and waste are regarded as resources and can be used as organic fertilizer if they are treated and well composted and finally, the use of twin pit latrine to help solve, address and improve sanitation and health of these communities.

Wastewater has been successfully used in the past for pasture irrigation. For example, 87% of the wastewater effluent from Firle was used for pasture irrigation (Nhapi et al., 2006). However, only three farms were designated for this treatment method (1,500 ha) (Thebe and Mangore). With a limited area for application along with a growing population wastewater has been over applied to these farms making them unproductive. Pasture irrigation can be implemented again but the responsible authorities need to allocate more land and possibly introduce effluent irrigation of other crops such as maize for animal feeds. According to Nhapi et al., 2006, maize has a high nutrient uptake compared to other pasture grass such as Kikuyu grass (*Pennisetum clandestinum*) and star grass (*Cynodon plectostochus*).

Other recommendations for nutrient control include constructing an alternative water source for the city and recycling nutrients in urban areas. Currently, the lake is both the water supply source and the wastewater sink for the city. Nhapi et al., (2002), suggested the construction of another water source to supply the City of Harare that is out of the catchment area or upstream from the city. The previous authors also recommend recycling nutrients in controlled urban agriculture to reduce fertilizer runoff.

Human health

According to Hranova et al., (2001), one of the four main principles at the core of Integrated Water Resources Management (IWRM), as enunciated in the Dublin Principles, is that water development and management should be based on a participatory approach that involves users, planners and policy makers at all levels. In order to improve WASH in the area, people in and around the catchment area should be educated through outreach programs. This can be achieved if government agencies such as the Ministry of Environment and Natural Resources and the Ministry of Health sponsor workshops on water sanitation solutions. Example solutions may include providing simple and effective ways to treat water such as providing each household with water treatment pills or filters, encouraging communities together to reduce accumulation of wastes and arrange clean-up programs, and boiling water.

Water Hyacinth

Water hyacinth is listed as one of the most productive plants on earth and is considered one of the world's worst aquatic plants (Malik, 2007). Measures to control it have resulted in environmental problems and risks to human health. There is a need to adopt some of the beneficial use of water hyacinth to address and control its problems. Malik (2007), argues that people's participation and government interventions can help the utilization and control strategies of water hyacinth while at the same time benefitting the community through job creation and poverty reduction.

Biological control of water hyacinth using the Neochetina weevils has proved to be successful in Lake Chivero. According to the Kunatsa and Mufundirwa (2013), 95% of the weed was eradicated but unfortunately the weevils died as the food source diminished. This method can be used again but long-term adaptive management strategy needs to be implemented that is aimed at reintroducing the weevils every 3-5 years to compensate for the loss and death of weevils from food source shortages.

Invasive species such as water hyacinth have been blamed for water quality deterioration, narrowing river channels, problems in boat access, navigation and recreation. They also pose a threat to human health as the mats act as habitat for mosquitos. In the past, total eradication of the weed has proved not to be the best option as it has resulted in high costs and negative effects to the environment and human health through the use of chemicals. However, the invasive species, may well become the cornerstone of raw material production to the growing industries in resource-poor economies (Ojeifo et al., 2013), especially in the developing countries such as Zimbabwe. The invasive plant has the ability to grow in heavily polluted water and can be used as a phytoremediation agent cleaning up contaminated waters. It is speculated that water hyacinth biomass can be used in waste water treatment, heavy metal and dye remediation, as substrate for bioethanol and biogas production, for electricity generation, industrial uses, medicines, animal feed, agriculture and sustainable development (Patel, 2012). Water hyacinth could serve as "nature's kidney" for proper effluent treatment and also be used for decontaminating inorganic nutrients, toxic metals as well as persistent organic pollutants (Malik, 2007). If these beneficial uses of water hyacinth are implemented, jobs may be created through harvesting the weed. In order to make the beneficial uses of water hyacinth more profitable there is a need for institutional support from the government and non-governmental organizations to translate the benefits into income generating projects.

Biogas for Nutrient and Water Hyacinth control

Most sewage treatment plants in the catchment area are aging and overloaded resulting in inefficiency. This problem can be addressed by channeling municipality and industrial waste for biogas production. According to Jingura and Matengai (2009), Zimbabwe has abundant biomass from agriculture, municipal and industrial wastes that can be used to develop biogas technology. In Harare an estimate of 660 tons of waste is produced daily with an estimate of 588 tons collected daily. In addition, Harare produces approximately 300,000 t/day of sewage sludge (Jingura and Matengai, 2009). Anaerobic digestion for biogas production has been practiced and there are already more than 400 bio-digesters in the country (Jingura and Matengai, 2009). However, there is need for research on the performance of the digesters and the cost benefit analysis as there is little information available.

According to the study conducted by Malik (2007), water hyacinth can be converted to biogas and furthermore, it yields better if it is mixed with animal waste. Unfortunately, the previous author argues that using water hyacinth for digestion in traditional digesters presents some problems such as large digester size and lower conversion efficiency from high water content. However, these problems can be addressed by designing appropriate water hyacinth digesters.

Conclusion

From the narrative review of Lake Chivero and its watershed it is evident that the area has been suffering from excessive nutrient loading from both point and non-point sources over 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. The reduction of nutrient loading into Lake Chivero requires a sound integrated water resource management that includes monitoring, the implementation of technologies and practices, and good governance.

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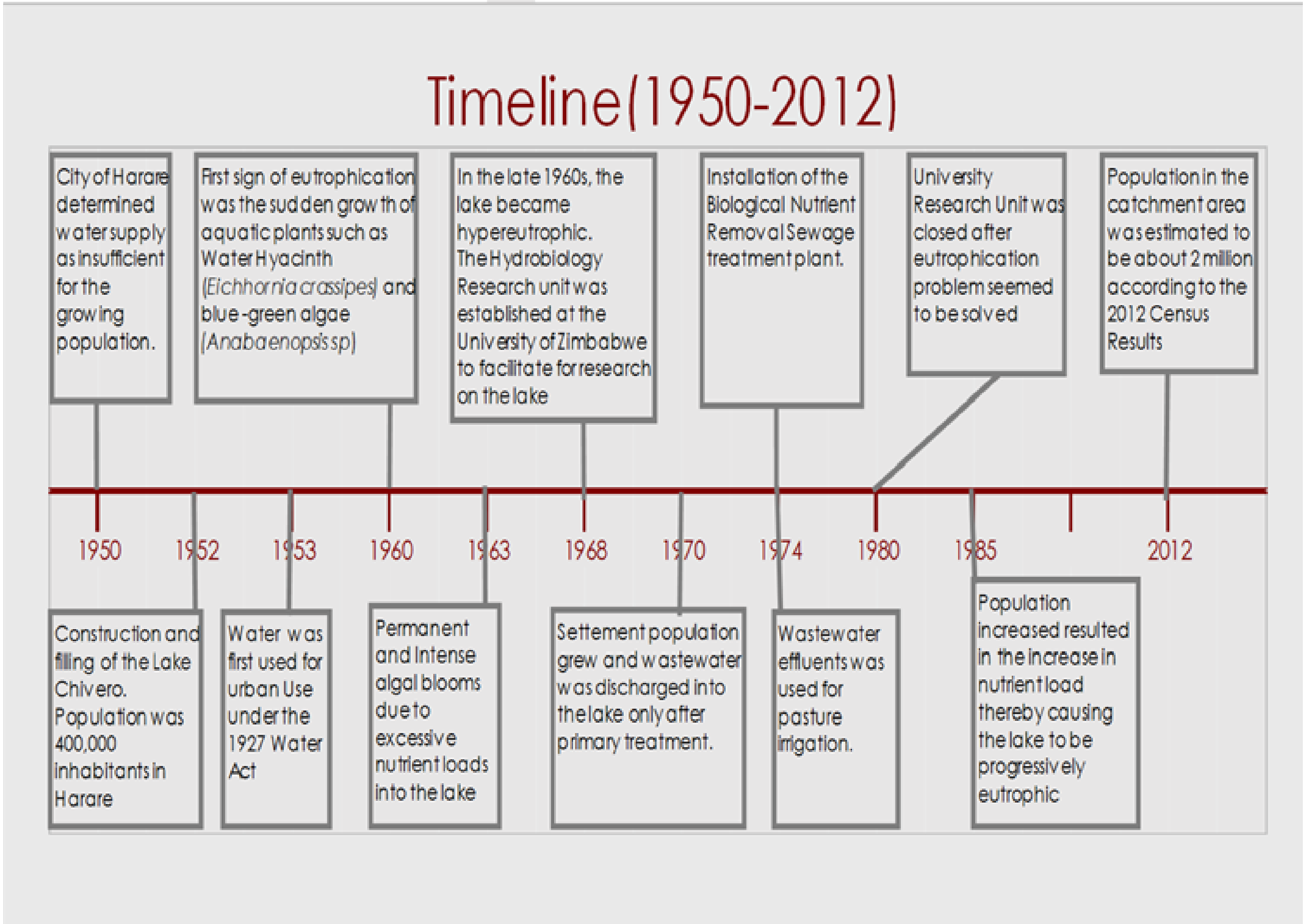

Figure 1: Background and timeline of Lake Chivero from construction (1950) to 2012.

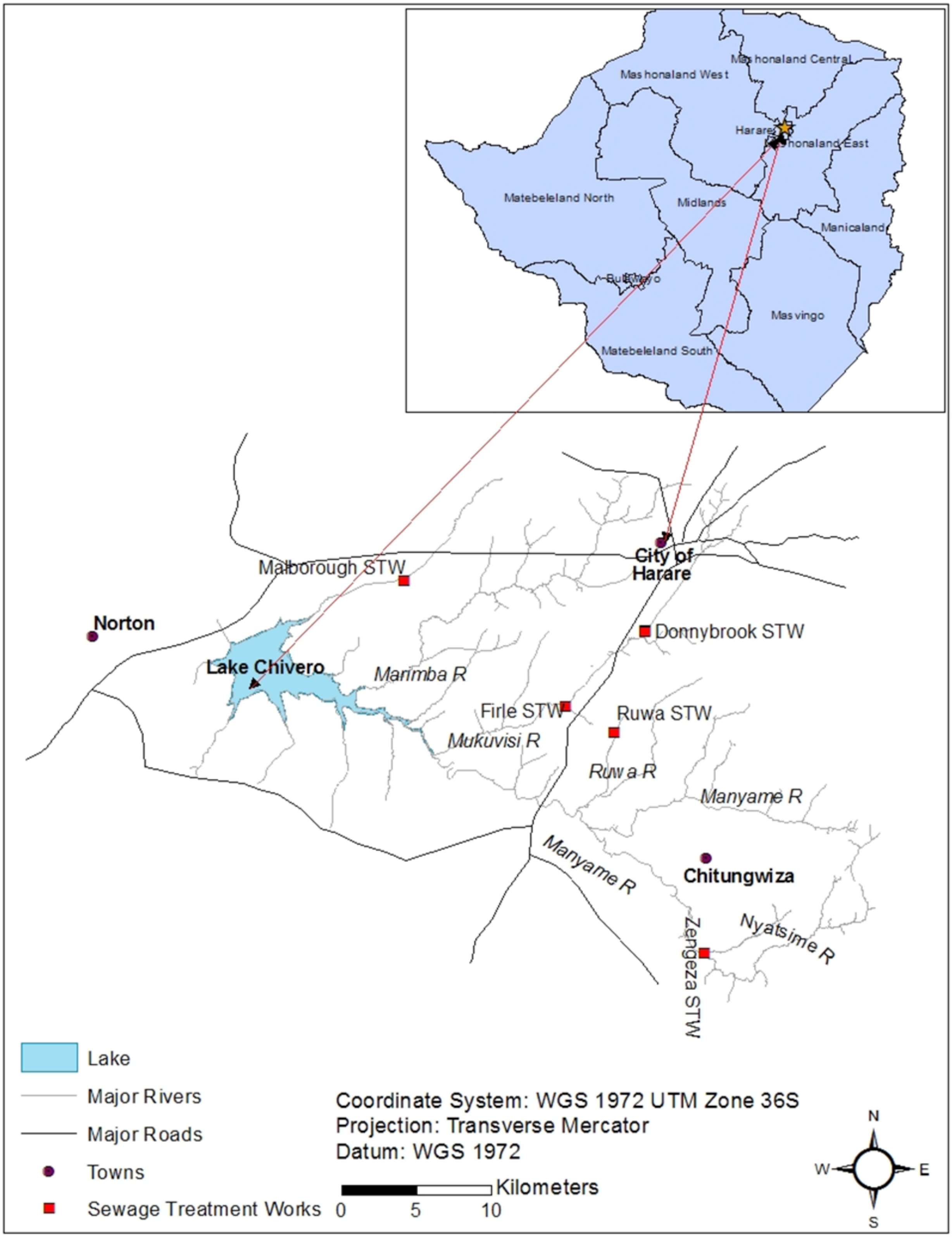

Figure 2: Location of Lake Chivero