e-ISSN 2409-0360
Zimbabwej.sci.technol

Dry season pre-impoundment water quality and the effects of anthropogenic activities: The case of Tokwe river, Zimbabwe

Caston Makaka[1]*, Tinashe Muteveri[1]. Paul Makoni[2], Crispen Phiri[3] and Trevor Dube[1]

[1]Department of Applied Biosciences and Biotechnology, Midlands State University, Bag 9055, Gweru, Zimbabwe;
[2]Department of Research, National University of Science and Technology, P.O. Box AC 939, Ascot Bulawayo, Zimbabwe.
[3]School of Wildlife, Ecology and Conservation. Chinhoyi University of Technology, Private Bag 7724 Chinhoyi, Zimbabwe, crispenphiri@gmail.com;

Email: cmakaka@yahoo.com, castonmakaka@msu.staff.ac.zw

ABSTRACT

Damming of rivers and the subsequent increase in human activities bring adverse changes to aquatic systems both downstream and upstream of the impoundment. Changes in physicochemical water quality are one such adverse change usually associated with impoundments, but, in Africa, no prior characterisation of the water body is usually done to provide baseline data. A pre-impoundment study was carried between July 2013 and July 2015 to assess the water quality of Tokwe River, Zimbabwe, in the cold dry and hot dry seasons. The study also aimed at assessing the effects of anthropogenic activities along the river on water quality and make inferences on the suitability of the water for freshwater aquatic life. Selected physicochemical parameters were assessed in situ using digital meters and in the laboratory using standard methods. There were spatiotemporal differences in water quality attributable to changes in water volume and anthropogenic activities. Except for sulphates and phosphates, there were no significant differences in water quality parameters amongst zones. Sulphates and phosphates were significantly higher in upstream than in inundated and downstream reaches ($p < 0.05$) whereas TDS, salinity and conductivity were relatively higher upstream than in inundated and downstream zones. Ammonia was higher in upstream and downstream reaches whereas pH was high in inundated area. There were significant ($p < 0.05$) seasonal changes in temperature, pH, total dissolved solids, salinity, conductivity and ammonia between seasons presumably because of local variations in input from runoff and anthropogenic activities. Major anthropogenic activities observed were agriculture, bathing, laundry, cattle grazing, and to some extent, mining and veld-fires used in land clearing for farming. The results of this study showed that water quality of Tokwe River was comparable to other rivers and within levels of good quality prior to impoundment and efforts should be maintained to keep it in good health.

Key words: physicochemical; spatial; temporal; impoundment; inundated

Received: 03.12.18 **Accepted:** 11.03.19

1. INTRODUCTION

Water quality refers to the chemical, physical and biological characteristics of water; it is a measure of the condition of water relative to the requirements of living organisms and human need. It is most frequently used by reference to a set of standards against which compliance can be assessed (Murwira *et al.,* 2014). Ambient Water Quality (AWQ) monitoring seeks to make a measurement of the pristine conditions of water bodies (Murwira *et al.,* 2014). The term ambient refers to the immediate, undisturbed surroundings of the environment.

In Zimbabwe, a statutory instrument empowers the Environment Management Agency (EMA) a role in water quality management (Murwira *et al.,* 2014). The Environmental Management Agency is mandated to maintain an extensive surface water quality monitoring network along major and minor water bodies across the country, which includes streams (rivers), dams and lakes but unfortunately it is yet to come up with quality standard guidelines for environmental, aquatic life, navigation and tourism water use (Murwira *et al.,* 2014). Assessment of environmental water quality in Zimbabwe can thus be only achieved by making comparisons with other country standards (Murwira *et al.,* 2014; Dube, pers. Com.).

The quality of any body of surface or ground water is a function of natural influences or human activities or both. Without human influences water quality would be determined by natural processes like weathering of bedrock minerals, the atmospheric processes of evapotranspiration and the deposition of dust and salt by wind. In addition natural processes like leaching of organic matter and nutrients from soil, hydrological factors that lead to runoff, and biological processes within the aquatic environment can alter the physical and chemical composition of water (UNEP, 2006). As a result, water in the natural environment contains many dissolved substances and non-dissolved particulate matter. Dissolved salts and minerals are necessary components of good quality water as they help maintain the health and vitality of the organisms that rely on this ecosystem service (Stark *et al.*, 2000). The availability of water and its physical, chemical, and biological composition affects the ability of aquatic environments to sustain healthy ecosystems. When water quality and quantity are eroded, organisms suffer and ecosystem services may be lost. The quality of water required to maintain ecosystem healthy is largely a function of natural background conditions. Water quality is important to aquatic fauna and the impact of human activities in and around rivers is felt on the unique physical and chemical properties of water on which the sustenance of fauna that inhabit the water is built as well the functions of water (Mustapha, 2008). Deterioration of water quality in rivers usually comes from excessive nutrient inputs, eutrophication, acidification, heavy metal contamination, organic pollution and obnoxious fishing (Mustapha, 2008). The effects of these “imports” into the river do not only affect the socioeconomic functions of the river, but also bring loss of structural biodiversity of the river (Mustapha, 2008).

Concentrations of nitrate, phosphate and probably sulphate reflect the effect of human activity in the water shed e.g. leached fertilizers from farmland and washing of cow dung. Bathing and washing also contribute as non-point source nutrients (Mustapha, 2008; Wepener *et al.,* 2009; Nhiwatiwa *et al.,* 2007). Seasonality in nutrient loads due to diffuse pollution are quite common and these have drawn attention in Africa to the problems of water quality (Marshal, 1997; Nhapi and Tirivaraombo, 2004) but more research has focused on point pollution and very little of the former (Tafangenyasha and Dube, 2005). The ecological impacts of these pollutants range from simple nuisance substances to several effects involving macroinvertebrates, other aquatic fauna and human health (Tafangenyasha and Dube, 2005; Bere *et al.,* 2017). Carignan *et al* (2000) and Armengol *et al* (1999) reported that non-point source nutrient input from water shed are leading causes of eutrophication and water quality problems in rivers. The eutrophication could affect the water quality of the water by giving rise to unpleasant taste and odor, colors the water, and affects the dissolution of other gases, mostly dissolved oxygen as a result of algal bloom (Gombiro *et al.,* 2014). Eutrophication also affects macroinvertebrate diversity (Hanson and Butler, 1994), lead to disappearance of populations (Gliwicz and Warsar, 1992) and species composition and indices changes.

The physicochemical properties of water give a good impression of the status, productivity and sustainability of a water body. The changes in physical characteristics like temperature, transparency and chemical elements of water such as dissolved oxygen, chemical oxygen demand, nitrate , and phosphate provide valuable information of the water, the source (s) of the variations and their impact on the functions and biodiversity of the water (Mustapha, 2008). These physical and chemical factors have been used to assess the water quality of fresh water systems by many workers (e.g. Mathuthu *et al*., 1997; Manjojo, 1999; Mhere and Jonalagadda, 2001; Nhapi and Tirivarombo, 2004; Tafangenyasha and Dube, 2005; Nhiwatiwa and Marshal, 2007, Ndebele-Murise, 2008).

The growing need to preserve the physical and biological integrity of water bodies is implied in several studies (e.g. Novotny *et al*, 2005; Tafangenyasha and Dube, 2005; Bere *et al*., 2017). This has become necessary in order to maintain diversity of species and water quality. In southern Africa, concern has been expressed about the possible impacts of nutrients on conservation of biodiversity (Tafangenyasha and Dube, 2005). In Zimbabwe the seasonal changes of nutrients and other physicochemical parameters in rural areas are not well understood and this point is illustrated by the omission of impacts of seasonal changes on nutrients in most major studies. This study aimed at investigating the water quality of Tokwe River using some selected physicochemical parameters in light of an impending impoundment on the river. The study aimed at investigating the spatial and temporal changes in the physicochemical parameters and how the water parameters compare with other rivers and acceptable limits for unpolluted freshwater ecosystems. We also aimed to infer on the suitability of the water for aquatic life. The effect of anthropogenic activities was also investigated. We hypothesize that water quality in Tokwe River is polluted and compromised and not suitable for aquatic life given the high levels of anthropogenic activities along the river. We also hypothesize that there are changes in water quality between zones and seasons because of the differences in local anthropogenic activities along the river and the riparian areas.

2. MATERIALS AND METHODS

2.1 Study area

The study was carried out on Tokwe River, Zimbabwe from June 2013 to July 2015 to cover the cold dry and hot dry season. Tokwe-Mukosi Dam (30º56′E, 20º22′S and altitude 600 m a s.l) was being built (when study was carried out) on Tokwe River some 100 km from Masvingo, on the confluence of Tokwe River and Mukosi River across the Nyoni Hills. The dam, estimated to yield 1.8 billion cubic meters of water (IRADB, 2010) has the capacity for hydroelectric generation and irrigation for at least 25 000 hectares of land. Tokwe River, which is the major river feeding water into the dam, is a 3rd order stream that drains a large part of Masvingo Province. Its head waters are in Lalapanzi (30 º 16' 09", 19 º 25' 09"), in the Midlands Province and it empts its water into the Runde River (Figure 1). Tokwe River is part of the Runde catchment system (Figure 1), which is one of the seven catchment systems in Zimbabwe (ZINWA, 1995). The Runde catchment (41 000 km^2) (Figure 1) lies in the driest parts of the country, covering Zimbabwe's Natural Ecological Regions III, IV and V and major districts and towns. It constitutes 22% of the area of the country and 40% of this catchment is in communal lands (ZINWA, 1995) of low input peasant agricultural production (Tafangenyasha and Dzinomwa, 2005). Its mean annual rainfall is about 684 mm and droughts are frequent. Much of Runde catchment lies in the low-veld and its climate is hot wet from mid-November to April, cold dry from May to August and hot dry from September to mid-November (Tafangenyasha and Dzinomwa, 2005). The study area is underlain by granite and gneiss, but in the east volcanics and rocks of Karoo age form the geological template (Tafangenyasha and Dube, 2005).

Tokwe River passes through a rural area of low agricultural inputs (Tafangenyasha and

Dube, 2005). The upper reaches of the upstream zone (sites 1 and 2) are within a newly resettled area previously sparsely populated with commercial farms but now under intense modification due to the newly settled farmers. The lower reaches (sites 3 and 4) of the same upstream zone have a mining town (Mashava) and further down is a region of medium to dense settlement (Chibi Turnoff). Much of this zone is of high density rural settlements with poor sanitary facilities and presumably relatively high inputs of nutrients from agricultural activities, bathing and laundry, as well as domestic animal activities. The mid-reaches constitute the inundated zone (site 5, 6, and 7) covering the flood plain of Tokwe-Mukosi Dam. Though not flooded by the time the study was carried out, the local catchment and riparian area of this river reach was sparely populated as some households had moved off in response to calls to vacate the area and give way for dam construction. In the downstream zone of dam wall (sites 8 and 9) there were denser settlements and a sprawling semi-urban centre (Ngundu).

All the reaches of the river had been impacted by anthropogenic activities to varying levels. The river, therefore, acts as drainage for natural and anthropogenic inputs resulting from agricultural activities and waste from the riparian communities which have minimal sanitation services. The three river zones, which were hypothesized to be variously disturbed and having different water quality levels, were established in the river. There was no zone without anthropogenic disturbances and therefore there was no reference site.

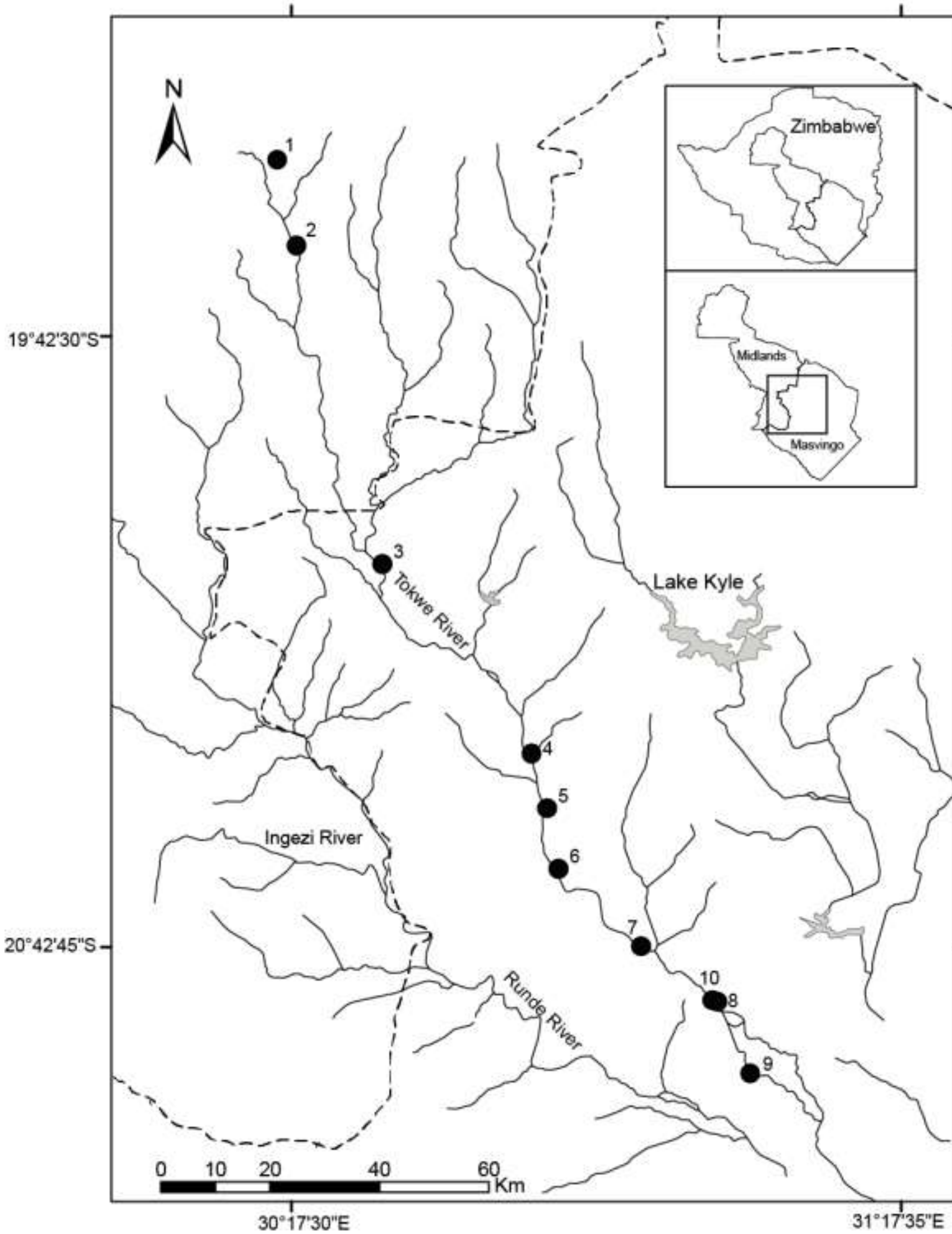

Figure 1. Selected sampling sites (1 – 9) on Tokwe River in relation to the Runde Catchment, Zimbabwe (Source: Makaka *et al*., 2018)

2.2 Data collection

Data collection was carried out from July 2013 to July 2015. Sampling was carried at nine randomly selected sites (1 - 9) along the Tokwe River (Figure 1) starting from Zvarota area just south of Lalapanzi to Nyahombe near the confluence of Tokwe and Runde River. A total of 15 sites were selected and their GPS coordinates recorded. From these coordinates, 9 were randomly selected for sampling. The sites fell into three zones: upstream (sites 1, 2, 3, and 4) inundated area (sites 5, 6 and 7) and downstream (sites 8 and 9). Altitude and surrounding vegetation type were also noted. Sampling was done from July 2013 to July 2015 over nine sampling visits to cover the cold dry and hot dry seasons.

2.2.1 Assessment of anthropogenic activities and water quality

2.2.1.1 Water quality

At each site, water temperature, pH, conductivity and dissolved oxygen were measured *in situ* using digital meters. Dissolved oxygen (DO) was measured using a DO meter (HANNA instrument1943). The DO meter was also used to measure temperature and pH. Conductivity was measured with a conductivity meter (HANNA Combo pH and EC multi meter Hi 98129). Total dissolved solids, salinity and concentrations of ammonium-nitrogen, sulphates and phosphates were determined in the laboratory using standard methods. The levels of these physicochemical parameters were compared to other local and international rivers that pass the standard of good water quality. These were complimented by comparisons to environmental water quality standards for countries with such standards like Morocco and South Africa.

2.2.1.2.Assessment of anthropogenic activities

Field observations were made to determine human activities that might affect water quality. Particular attention was paid to activities such as bathing, washing, car wash, oil spills, and garages, roads, quarrying, mining and agricultural activities like gardening, food crop farming and non-food crop farming like cotton growing and forestry etc. Domestic animal activities like grazing, drinking, as well as animal facilities such as dip tanks, cattle kraals, and cattle pens were also noted.

2.3 Data analysis

The water quality data was tested for normality with Shapiro–Wilk test and homogeneity of variance with Leven’s test. The data did not meet the assumptions of normality and homogeneity of variance hence a non-parametric test, Kruskal–Wallis was used to test for differences in physicochemical variables between zones and seasons. Post Hoc pairwise comparisons were performed with Dunn test to select zones and seasons with differences in water quality variables. The statistical tests were performed in STATISTICA version 12.0 (StataCorp 2011).

3.RESULTS

A total of nine sites were sampled on the Tokwe River starting from Chengegomo area (30^{o}16' 09'', 19^{o}25' 09'') in Lalapanzi down to Nyahombe (31^{o}02' 45'', 20^{o}55' 15'') in Triangle close to the confluence with Runde River. There was a drop in altitude of 840 m from 1 352 to 512 m.a.s.l. Site 3 in upstream zone, sites 5, 6, 7 in midstream zone, and sites 8 and 9 in downstream river reach had their riparian areas mostly covered by acacia vegetation. Sites 1 and 2 in upstream zone had mainly grasslands and miombo type of vegetation, respectively (Table 1).

3.1 Anthropogenic activities.

Table 1 summarizes the human and domestic animal activities noted at various sites along the river. All zones were characterised by human activities such as bathing and washing except for sites 1 and 3 in upstream zone, 7 in midstream zone, and 9 in downstream reach, which were shunned by the locals because of fear of crocodiles or being far away from homesteads. Site 1 was near a busy dust road for humans and scotch carts, and occasionally motor vehicles. Veld fires used in clearing of virgin land were also a common site during the study period. Human and sledge pathways criss-crossed the riparian area. The riparian areas for most sites were used as grazing pasture lands and low intensity subsistence crop farming and gardening.

Table 1.1 Altitude, vegetation type, human and domestic animal activities in river and riparian area.

Zone	Site	Altitude (m)	Riparian vegetation	Human or animal activity in river	Riparian human or animal activity
Upstream	Chengegomo (Site 1)	1352	Savanna grassland, with acacia trees	Dust road	Scotch cart and sledge pathways, widespread veld fires
	Chitora (Site 2)	1181	Miombo woodland	Washing and bathing	Very low intensity subsistence farming, cattle and goat grazing area
	Mashava (Site 3)	917	Acacia trees	Goat and cattle grazing area	Mining, settlement
	Chibi (Site 4)	764	Clear of vegetation	Bathing and washing; Cattle grazing and drinking point	Settlement (rural and semi urban) and subsistence farming, cattle and goat grazing area
Inundated	Sese (Site 5)	754	Acacia trees	Extensive washing and bathing zone, cattle and goat grazing and drinking point.	Settlement and subsistence crop farming; cattle and goat grazing area
	Meringue (Site 6)	716	Acacia trees	Extensive washing and bathing zone; Cattle grazing and drinking zone	Settlement and subsistence crop farming and gardening
	Zing (Site 7)	639	Acacia trees	Cattle grazing and drinking zone	Settlement and subsistence crop farming, cattle grazing area
Downstream	Matandamaviri (Site 8)	560	Acacia trees	Washing and bathing restricted zone, cattle grazing and drinking point	Settlement (rural and semi-urban) None, gardening
	Nyahombe (Site 9)	512	Acacia trees	No human activity, heavy cattle grazing and drinking point with numerous animal droppings	Brick moulding, maize and cotton farming.

3.2 Spatial variations in physicochemical parameters

The means of the physicochemical parameters of Tokwe River are presented in Table 1. There were no significant differences in temperature, pH, TDS, salinity, conductivity, ammonia and DO across sites ($p > 0.05$) but sulphate and phosphate differed significantly among sites ($p < 0.05$). Temperature was highest in the inundated area (25.9±5.5°C) followed by the downstream (24.3±4.7°C) and lowest in the upstream zone (23.5±5.0°C). pH was slightly neutral to alkaline along the entire long profile of the river (Table 1). The pH ranged from 8.0±0.5 to 7.8±0.7, being highest in inundated area and lower in both downstream and upstream reaches.

Upstream reaches had the highest TDS, salinity, DO, sulphate and phosphate concentrations and downstream reaches had the lowest levels of these parameters. There was a general decrease in TDS, salinity, DO, sulphate levels and phosphate concentrations from headwater to lower reaches. TDS declined from 159.9±87.9 to 151.1±57.4 ppm, salinity from 123.0±68.5 to 117.8±51.1 ppm, DO from 6.5±1.7 to 6.1±1.9 mg/l, sulphate (68.4±108.4 – 11.1±17.9 ppm) and phosphates (0.44±0.5 – 0.15±0.15 ppm). Downstream reaches had significantly lower levels of sulphate than the inundated and upstream reaches, whereas phosphates levels were significantly higher in the upstream river reaches than the inundated and lower reaches ($p < 0.05$). Conductivity and ammonia levels were lowest in the inundated area and highest in the upper reaches although the differences were insignificant ($p > 0.05$).

3.3 Temporal variations in physicochemical parameters

The seasonal means of the water parameters for the cold dry and hot dry seasons are given in Table 2. Temperature, pH, TDS, salinity, conductivity and ammonia levels were significantly higher in the hot dry season than in the cold dry season (Table 2). Phosphates were also relatively higher in the hot dry season than in the cold dry season. Temperature ranged from 21.7±3.9 to 27.8±4.5°C with a mean water temperature of 24.7°C, whereas pH ranged from 7.7±0.6 in the cold dry season to 8.0±0.5 in the hot dry season with a mean of 7.9. TDS ranged from 121.3±44.8 to 198.4±79.1 ppm, salinity (94.1±40.9 – 151.8±62.6 ppm), conductivity (161.6±65.4 – 270.1±107.4 μScm^{-1}), ammonia (0.043±0.03 – 0.28±0.5 ppm), and phosphate (0.29±0.4 – 0.32±0.4ppm.

On the contrary, DO and sulphate levels were higher in the cold dry season than the hot dry season (Table 2), with cold dry season DO levels significantly higher than the hot dry season levels (Table 2). DO varied from 5.7±1.7 (hot dry season) to 6.9±1.9 (cold dry season) and sulphate from 29.9±69.5 (hot dry season) to 57.3±93.8 ppm (cold dry season), respectively.

Table 1. Means (± SD) of selected physicochemical parameters in three zones (Upstream, inundated and downstream) of Tokwe-Mukosi Dam wall site

Zone	Temp (°C)	pH	TDS (ppm)	Salinity (ppm)	Conductivity (μScm^{-1})	Ammonia (ppm)	DO (mgl^{-1})	Sulphate (ppm)	Phosphates (ppm)
Upstream	$23.5^a±5.0$	$7.8^a±0.6$	$159.9^a±87.9$	$123.0^a±68.5$	$218.1^a±121.2$	$0.18^a±0.3$	$6.5^a±1.7$	$68.41^a±108.37$	$0.44^a±0.50$
Inundated area	$25.9^a±5.5$	$8.0^a±0.5$	$154.4^a±62.0$	$118.3^a±50.8$	$203.4^a±86.3$	$0.14^a±0.3$	$6.2^a±2.1$	$35.89^a±64.05$	$0.23^b±0.34$
Downstream	$24.3^a±4.7$	$7.8^a±0.7$	$151.1^a±57.4$	$117.8^a±51.1$	$205.2^a±78.9$	$0.18^a±0.4$	$6.1^a±1.9$	$11.06^b±17.98$	$0.15^b±0.15$

Different letters in the same column denote significant difference ($p < 0.05$)

Table 2. Seasonal means (± SD) of selected physicochemical parameters.

Season	Temp (°C)	pH	TDS (ppm)	Salinity (ppm)	Conductivity (μScm^{-1})	Ammonia (ppm)	DO (mgl^{-1})	Sulphate (ppm)	Phosphates (ppm)
Cold dry	21.7a±3.9	7.7a±0.6	121.3a±44.8	94.1a±40.9	161.6a±65.4	0.043a±0.03	6.9a±1.9	57.27a±93.8	0.29a±0.4
Hot dry	27.8b±4.5	8.0b±0.5	198.4b±79.1	151.8b±62.6	270.1b±107.4	0.28b±0.47	5.7b±1.7	29.85a±69.5	0.32a±0.4

Different letters in the same column denote significant difference (p < 0.05

4. DISCUSSION

This study aimed at investigating the physicochemical parameters of Tokwe River prior to impoundment through damming of the river. Damming alters aquatic ecosystems by altering the flow of water both upstream and downstream thereby increasing or decreasing sediment accumulation. The breeding and migratory patterns of aquatic organisms are also interfered with (Wepener *et al*., 2009). Damming also alters the industrial and agricultural activities of the surroundings which in turn impinge on the physicochemical characteristics of the water .It is therefore important to assess the baseline quality of a water body prior to impoundment for future planning and management purposes (Dube, pers. Com.). The study thus aimed at assessing the water quality of Tokwe River using some selected physicochemical parameters by making comparisons with water quality standards and acceptable tolerant levels for aquatic life. The study also aimed at making an assessment of both spatial and temporal variations in the selected physicochemical parameters in light of both natural and anthropogenic activities along and in the riparian areas of the sampling sites. The results of this study showed that although there were spatiotemporal variations in the water quality of Tokwe River, these were within acceptable standards and within limits suitable for aquatic life prior to impoundment. Of the nine parameters assessed only phosphates were above acceptable limits for all zones and the two study seasons. Significant spatial variations in sulphates and phosphates and temporal variations in all water quality parameters were observed, indicating the important role played by anthropogenic activities like agriculture and vehicular traffic as well as natural phenomena like water replenishments through runoffs in summer. The general spatial uniformity in most of the physicochemical parameters may point to the uniform geological template of granitic and volcanic rocks in the study area (Tafangenyasha and Dube, 2005). Temporal variations may be largely attributed to natural differences in water levels, climatic conditions and anthropogenic activities.

4.1 Spatial and temporal variations in physicochemical parameters

Water temperature is one of the most important regulators of life processes in aquatic ecosystems (Deas and Lowney, 2000). It affects all aspects of stream ecology directly and indirectly (Onozeyi, 2013). Photosynthetic activities by algae and aquatic plants are largely influenced by water temperature. As Boulton (2012) noted, as water temperature increases, the photosynthetic rate of algae and aquatic plants also increases, thereby increasing nutrient levels in the water. Water temperature for Tokwe River varied from 23.5±5.0 to 25.9±5.5^{o}C between zones and ranged from 21.7±3.9 to 27.8±4.8 ^{o}C between sampling seasons. Water temperatures observed in this study were close to those observed by Fafioye et al (2005) and Benjamin (2014) in rivers with fine to good quality water. Fafioye et al (2005) recorded minimum and maximum stream temperatures of 26.5^{o}C and 31.5^{o}C in Omi water body, a tropical river in Ogun State, Nigeria. Benjamin (2014) also studying a Nigerian river (River Ogun) noted a range of 26.9 to 32.1^{o}C. Chakona and Marshal (2008) studying pristine waters of Nyahode and Haruni River in the Eastern Highlands of Zimbabwe recorded mean water temperatures from 19.6±0.4^{o}C to 24.4^{o}C. The water temperature obtained in this study is within range of good water quality to moderately polluted water by Morrocan Environmental Water Standards of 20 – 30^{o}C (Barakata *et al*., 2016). In the present study, the highest and lowest water temperatures were recorded in cold dry and hot dry seasons respectively, and this is in consonance with seasonal changes in atmospheric temperature. The very high temperature in the hot dry season were probably in response to a record breaking sweltering heat wave that hit Zimbabwe and neighbouring countries in over 60 years during the period of sampling. However, the temperature fluctuation were still within the background water temperature proposed by Kuhn (1991) cited in Beurmann (1995).

pH is a very important parameter of freshwater ecosystems as it determines the limits in which aquatic life occurs (Kelly-Addy *et al*., 2004). Not only does pH determines the solubility of other solutes in the environment but it also determines the activity of life by determining enzyme function and thereby the distribution and diversity of animals and plants. pH also affects the dissolved oxygen level of the water, photosynthesis of aquatic organisms (phytoplankton) and the sensitivity of these organisms to pollution, parasites and disease (Ngodhe *et al*., 2013). A change in pH also affects aquatic life indirectly by altering other aspects of water chemistry. The slightly neutral to alkaline pH ranges of 7.8±0.7 to 8.0±0.5 observed between zones and the range from 7.7±0.6 to 8.0±0.5 observed between seasons in this study are quite within ranges of good quality water. The pH levels are within the 6.1 – 8.2 range expected for most surface freshwater systems (Tafangenyasha and Dzinomwa, 2005) and within the 6.5 – 8.5 range recommended as excellent by the Moroccan Water Standards for Environmental Waters (Barakata *et al*., 2016). Our findings in this study are also comparable to those of Nyahode River (7.2 – 7.9), a lotic system of pristine water (Chakona and Marshal, 2008). Studies done show that many species of aquatic animals favour slightly alkaline pH (basic) habitats. The USEPA (1986) indicated that a pH range of 6.5 to 9.0 provides adequate protection for the life of freshwater fish and bottom-dwelling invertebrates. Clenaghan (1998) reports that taxa richness, density of invertebrates and diversity increases along a river continuum with increase in pH. Highly acidic water generally results in impoverishment of fauna, and lower acidities reflect better buffering and higher productivity (Busulwa, 2004). Acidification can alter community structure by being acutely or chronically damaging to tissues of invertebrates particularly for species that easily loose sodium ions when pH is reduced (Boulton, 2013). Secondly, it alters algal communities, upon which some invertebrates depend for food and shelter, altering predation on invertebrates by decimating numbers of other crustaceans, fish, and amphibians, and by altering the bioavailability of some other potential stressor, such as heavy metals. Such effects may reduce invertebrate species diversity, increase the abundance of tolerant species and reduce the numbers of sensitive ones (Busulwa, 2004). The relatively uniform pH recorded in this study may be attributed to uniform buffering effect of the water in Tokwe River although this needs further investigation.

Closely correlated to water temperature is dissolved oxygen (DO). Factors causing a decrease in DO (hypoxic condition) in rivers include elevated temperatures and salinity and the respiration of aquatic organisms, among others (Barakata *et al.,* 2016). The dissolved oxygen levels of freshwater ecosystems are largely determined by water temperature. This is so because solubility of gases, unlike those of solids, increases with decrease in temperature. Hence the ability of water to maintain oxygen in dissolved state decreases with increasing temperature. When the temperature of water increases, a portion of the oxygen gets out of solution. In this study DO varied from 6.1±1.9 to 6.5±1.7 mg/l between zones and from 5.7±1.7 to 6.9±1.9 mg/l across seasons. In two comparable Savana rivers (Haruni and Nyahode, Zimbabwe), Chakona and Marshall (2008) observed slightly higher DO levels ranging from 6.3±0.6 to 8.8±1.6 mg/L. The water quality obtained in the present study is within the standards for other countries. For example, standards in South Africa require that DO concentrations should be > 4.0mg/l and the target guideline for warm water aquatic species is 5.0 mg/l (Beurmann *et al*., 1995 cited in Tafangenyasha and Dzinomwa, 2005) and the Morrocan Water Standards for good quality surface water ranges from 5 -7mg/l) (Barakata *et al*., 2016). The high DO in the upstream zones observed in the present study could be attributed to the low water temperature in this river reach as well as higher water turbulence due to the steep gradient in this zone. The steep gradient promotes the dissolution of oxygen in the water by increasing water and oxygen mixing at the air-water interface. The high DO in the cold dry season could also be attributed to the low water temperatures associated with this season in this study. Changes in DO in water has a very important bearing to aquatic life in rivers and streams (Manora, 2012) as it determines the productivity of an aquatic ecosystem. DO is of fundamental importance in maintaining aquatic life and is therefore one of the most widely used water quality variables (Tchobanoglous and Schroeder, 1985).

The present study observed water conductivity levels of 203.4±786.3 (inundated zone) to 218.1±121.2 μScm^{-1} (upstream zone), and seasonally from 161.6±65.4 μScm^{-1} in the cold dry season to 270, 1±163.6 μScm^{-1}in the hot dry season. Marked reduction in water volumes in the hot dry season (unpublished data of this study) could explain the high conductivities in the hot dry season. Reduced dilution in the hot dry season could be the cause of the significantly high conductivities as compared to the cold dry season (Wepener *et al*., 2009). Conductivities recorded in this study are higher than those observed by Chakona and Marshal (2008) in Haruni and Nyahode rivers of 9.2 to 73.5μScm^{-1}. This is expected as these two rivers have relatively undisturbed riparian areas covered by forests of pine and gum (Chakona and Marshal, 2008). However levels of water conductivity obtained in this study are well within excellent water quality in some countries. For example, the Moroccan standard for excellent water quality ranges from 100 - 750 µScm-1. Although conductivity does not have any deleterious effects to human health, high conductivities may lead to lowering of the aesthetic value of the water by giving a mineral taste (Rahmanian, 2014). In addition certain plant species are also eliminated by excessive water conductivity resulting in differential distribution of plant species (Fawel, 1993).

TDS concentrations are used to assess the quality of freshwater systems (Manora, 2012) and are a measure of organic and inorganic matter dissolved in water and a host of other dissolved materials (US Environmental Protection Agency, Office of Water, 1986). Total dissolved solids (TDS) obtained in the study varied from 159.9±87.9ppm (upstream), 154.4±62.0 ppm (inundated) and 151.1±57.4 ppm (downstream) and seasonally from 121.3±40.9 in the cold dry season to 198.4±62.9 ppm in the hot dry season. The dilution effect would explain the differences observed between the cold dry and hot dry season as the former is largely influenced by relatively higher carryover volume from the preceding wet season (Wepener *et al*., 2009). The values obtained in this study are however well within range of the tolerance levels of aquatic organisms (Tafangenyasha and Dzinomwa, 2005). The limit tolerance range of organisms in fresh water is between 350 – 550 ppm, with a threshold of 800 ppm cited for some lowveld rivers such as the Olifants River Kuhn, (1991) cited in Beurmann et al. (1995). The levels recorded in this study do not overshoot these thresholds and are thus quite conducive for freshwater organisms.

Salinity is closely related to conductivity and TDS, and it's a measure of the total inorganic ions dissolved relative to the amount of water. Large fluctuations in salinity impinge on freshwater animals by causing osmoregulatory challenges and this may not be manageable for some animals (Schmidt, 1982). Wide changes in salinity thus tend to limit the geographical distribution of stenohyaline invertebrates and favour those that are euryhyaline. This therefore limits certain environments to the highly adaptable species. In this study, salinity levels fluctuated between zones and seasons. It varied from 123.0±68.5ppm (upstream) to 118.3±50.8ppm (midstream) to 117.8±51.1 (downstream sites) and seasonally ranged from 94.1±40.9 in the cold dry season to 151.8±62.6 ppm in the hot dry season. These salinity levels are within levels of freshwater aquatic systems of less than 0.5ppt (500ppm) (https://www.epa.gov/sites/production/files/2015-09/documents/2009). This indicates that Tokwe river water is good quality for freshwater plants and animals. The significantly low levels of salts in cold dry season could be explained in terms of the high dilution effect (Beurmann *et al.,* 1995) owing to the heavy rains received in the preceding 2014/15 summer season. On the other hand the high salinity levels recorded in the hot dry season could have been a result of the very low dilutions owing to the low water levels during that season (Wepener *et al.,* 2009)

Ammonia is very important form in which nitrogen occurs in nature. Besides ammonia, nitrogen also occurs as nitrites and nitrates (USEPA, 2012) and ammonia is the most toxic form of the three (Benjamin, 2013). It therefore determines to a great extend the variety of organisms, especially animal life that can thrive in the aquatic environment (Benjamin, 2013). In the present study ammonia levels ranged from 0.14±0.30 ppm in the inundated zone to 0.18±0.3ppm in the downstream and upstream zones and seasonally from 0.043 ±0.03 ppm in the cold dry to 0.28±0.5 ppm in hot dry season. Other authors have also observed comparable results. For example Murwira et al (2014) obtained ammonia levels of 0.011 to 0.21ppm from seven rivers with good quality water in Munyame catchment of Zimbabwe. Chakona et al. (2008) also observed comparable results in the pristine waters of Nyahode and Haruni River of the eastern highlands of Zimbabwe. In addition, the Moroccan Water Quality Standards for Environmental Water sites a range of 0.1 - 0.5 ppm as good water quality (Brakata *et al.,* 2016).

Sulphates varied from 11.1±17.9 (downstream) to 68.4±108.4ppm (upstream) and seasonally from 26.9±69.5 ppm in hot dry to 57.3±93.8 ppm in cold dry season. These levels are quite within the acceptable limits for freshwater systems of 0 to 630 ppm and even below the safety maximum for drinking water of 500 ppm (Merano *et al.,* 2009). In studies of the Mazoe catchment in Zimbabwe, Muwira et al (2014) obtained comparable sulphate concentrations ranging from 3.6 to 98.2 ppm in seven rivers considered to be largely unpolluted.

Phosphates ranged from 0.15±0.15 (downstream) to 0.44±0.50 ppm (upstream) and temporally from 0.29±0.4 in the cold dry season to 0.32±0.4 ppm in the hot dry season. In their 2008 studies in Ogun Reservoir in Nigeria, Mustapha and co-workers observed even higher levels of phosphates ranging from 0.7±0.0 to 2.2±0.2ppm. Tokwe River however exceeds the 0.1mg/l (0.1ppm) set by the Environmental Quality Standards for Water Pollution as the limit for protection of the environment (https://www.env.go.jp/en/water/wq/wp.pdf). Phosphates, in moderate amounts are known to provide a medium conducive for growth of algae in water which gives the water undesirable odours and taste (Gombiro *et al*., 2014). However in high amounts it results in massive eutrophication (Nhiwatiwa *et al*., 2018)

4.2 Impacts of anthropogenic activities on water quality

Although most physicochemical parameters were within acceptable water quality standards and tolerable ranges for aquatic life, there were significant variations in some parameters between seasons and across sites. These could be attributed mainly to variations in local riparian land uses and anthropogenic activities given the uniform geological template underlying Tokwe River (Tafangenyasha and Dube, 2005). Significant spatial variations in sulphates and phosphates and temporal variations in all water quality parameters were observed, indicating the important role played by anthropogenic activities like agriculture and vehicular traffic as well as natural phenomena like water replenishments through runoffs in summer. Temporal variations may be largely attributed to natural differences in seasonal water levels (Wepener *et al.,* 2009).

The relatively lower pH in the inundated zone is a result of high organic matter load into the river owing to a temporally induced flooding to scare off residents from the flood plain. In an attempt to push off residents who were resisting displacement from the flood plain, the contractor temporally closed the holding weirs to cause flooding of the flood plain (Paradzai, pers. Comm). The low pH observed in this study is in agreement with lower pH levels noted by Hussain and Pundit (2012) in river reaches exposed to high organic loads by flooding from the riparian areas.

The general but insignificant decrease in TDS, salinity and conductivities from upper reaches to lower reaches could be a result of differences in land use (Allan *et al.,* 1997; Wepener *et al*., 2009) Scatena (2000) explained differences on these parameters based on various factors such as agricultural activities, land use and industrial activities, which affect the mineral contents of the water and thus its electrical conductivity. The upstream zone has some sites close to dust roads, sledge pathways and a mine. In addition veld fires used in agricultural land preparation were a common site. The headwaters of Tokwe River are in catchment which was newly settled and veld fires were a major tool used in clearing land for agricultural activities. These human activities result in the loading of both organic and inorganic materials into the water. An increase in TDS and salinity has been shown to be directly correlated with stripping of land and riparian zones for crop planting (Allan *et al.,* 1997). This is usually amplified by the low water volumes and hence less dilution in upstream reaches of rivers (Wepener *et al.,* 2009). The decrease in TDS, salinity and conductivity downstream indicates a dilution effect as water volume increases (Tafangenyasha and Dzinomwa, 2005).

The major source of ammonia in river systems is non-point pollution from agricultural activities (CCME, 2009). Ammonia is constantly being converted to nitrites and nitrates by nitrifying bacteria under aerobic conditions. Hence the ammonia levels in surface water are normally low, but can reach high levels from agricultural and industrial runoff or from contamination by human or animal waste (CCME, 2009). Its high concentrations in water thus indicate high human contamination. The high ammonia levels upstream and downstream of the inundated area could have resulted from high inputs from the surrounding agricultural areas as well as human and animal wastes from the riparian areas (Mokaya *et al*., 2004). Some sites in the upstream zone and downstream zone were close to rapidly growing Rural Growth Points (urban centres) with low sanitary facilities. Pollutants in the form of human and animal waste could have found its way into the water body. In addition, the same sites had extensive bathing and laundry zones. Our results are also in consonance with those obtained by in a tropical river Mokaya *et al*., (2004). On the other hand, the generally low ammonia in the inundated area could be attributed to low pollution levels because of the of the reduced populations owing to the fact that some households had heeded the call to vacate their ancestral homes and give way to dam construction.

The significantly high levels of sulphate and phosphate levels in the upper reaches especially in the upstream could have been a result of the extensive use of artificial fertilizers in that zone (Wepener *et al.,* 2009). The riparian upstream zone was a newly resettled area at the time of sampling and was prioritized in the Zimbabwe government sponsored agricultural input distribution schemes. The sampling activities coincided with widespread distribution of artificial fertilizers under the Presidential Agricultural Input Support scheme rolled out by the Zimbabwe government. Leaching from the riparian agricultural areas could have contributed to nutrient loading into the river (Mokaya *et al*., 2004). Wepener *et al*., (2009) also observed higher levels of nutrients in the Elands River, South Africa, in areas whose riparian areas had extensive use of fertilizers. Heavy leaching due the sporadic heavy rains associated with this catchment has also been reported by Tafangenyasha and Dzinomwa (2005) in Runde River.

The significantly increase in TDS, salinity, conductivity and DO from the cold dry season to the hot dry season could be attributed to seasonal changes in water volume (Qader, 1998). The seasonal decrease in water volumes results in less dilution effect as water volume changes from high to low flow (Wepener *et al*., 2009). Data from this study agrees with studies done by Qader (1998) who found that reduced flows were correlated with an increase in conductivity and salinity concentrations as a result of the reduced dilution capacity of the river.

CONCLUSIONS

In conclusion, except for phosphate, the ranges of physicochemical parameters of Tokwe River considered in this study are comparable to those found in non-polluted rivers in Zimbabwe and elsewhere. Thus, on the overall, water in Tokwe River is of good environmental quality and within acceptable ranges of tolerance for freshwater organisms. There were spatiotemporal variations in water quality that could be attributed to seasonal changes in water flow and anthropogenic activities. The relatively higher levels of TDS, salinity and conductivity and significantly higher sulphate and phosphates in upstream zones than in the inundated and downstream zones could be attributed to increased organic and inorganic nutrient loading due to land uses like roads, sledge pathways, mining and rampant veld fires as well as increased use of agricultural fertilizers. Dense populations and hence increased human activities like river bathing, laundry as well as wastes from humans and animals could explain the relatively higher ammonia-nitrogen in upstream and downstream zones. The upstream and downstream zones stand in contrast to the inundated zone where the majority of the people had been displaced to make way for the dam. Changes in water levels as well as anthropogenic activities could also have resulted in the significant seasonal variations in water quality. However, this study only considered riparian land use and human activities along the river without considering the catchment-wide human activities. There is need to investigate the differences in local catchments and infer on their possible effects on water quality. There is also need to assess the levels of nitrates which are a major pollutant from agricultural activities as well as pesticide levels that are a major threat to water quality and therefore aquatic life. There is need to maintain and protect Tokwe water from contamination in light of the envisioned use of Tokwe dam water for fish production, tourism, irrigation as well as for the well-being of aquatic macroinvertebrates. It is therefore important to continuously monitor the water in Tokwe river to maintain the good water quality so that it is maintained within acceptable levels for aquatic life.

ACKNOWLEDGEMENTS

We are grateful to the numerous villagers along Tokwe River who acted as guides and warned us of crocodile/hippopotamus infested areas and inaccessible muddy roads. To young Jose Makaure, we say thank you for the camping kit.

Funding

This study was supported by the Midlands State University, Zimbabwe, who, through the Research and Post Graduate Office, provided most of the funds to finance this research (Grant 26Ap2013). Dr. R.J. Mapaya also had the heart to spare some of her funds to finance the same. Personal funds from one of the authors (Caston Makaka) also contributed immensely to the success of the research.

REFERENCES

Allan, JD., Erickson, DL and Fay, J. (1997). The influence of catchment land use on stream integrity across multiple spatial scales. Freshwater Biology 37 149 - 161

Armengol, J., Garcia, J.C., Comerme, M., Romero, M., Dolz, J., Roura, M., Han, B.H., Vidal, A. and Simek, K. (1999). Longitudinal processes in Canyon type Reservoirs: The case of Sau (N.E. Spain). In: J.G. Tundisi and M. Straskraba (Eds.), Theoretical Reservoir Ecology and its Applications. IIE, Backhuys Publishers, Brazilian Academy of Science: 313-345

Barakata, A., Baghdadia, M.E., Raisa, J., Aghezzafb, B., Slassib, M. (2016). Assessment of spatial and seasonal water quality variation of Oum Er Rbia River (Morocco) using multivariate statistical techniques. International Soil and Water Conservation Research 4:284 -292.

Benjamin L. B., Popp, A., Lotze-Campen, H, Dietrich, J.P., Rolinski, S., Weindl, I ., Schmitz, C., Müller, C., Bonsch, M., Humpenöder, F., Biewald, A., Stevanovic, M. (2014). Reactive nitrogen requirements to feed the world in 2050 and potential to mitigate nitrogen pollution
Nature Communications volume 5, Article number: 3858

Bere T., Chiyangwa G, Mwedzi, T. (2016). Effects of land-use changes on benthic macroinvertebrate assemblages in the tropical Umfurudzi River Zimbabwe. Afr J Aquat Sci 41:353–357

Beurmann, Y., du Preez, H.H., Steyn, G.J., Hamse, J.T., and Deacon, A. (1995). Suspended silt concentrations in the lower Olifants River (Mpumalanga) impacts of silt releases from the Phalborwa Barage on water quality and fish survival. Koedoe 38, 11 -34

Boulton A. J., (2012) Temperature impacts on stream ecology, Water Encyclopedia, http://www.waterencyclopedia.com/Re-St/Stream-Ecology-Temperature-Impacts-on.html

Busulwa HS, Bailey RG. (2004). Aspects of the physicochemical environment of the Ruwenzori Rivers, Uganda. Afr. J. Ecol. 42 (1): 87-92.

Carignan C. (2000). Integrative studies in water management and Development; In Boreal shields watersheds (ed) Gunn, J.M, Steedman R.J. and Ryder R.A. Lewis publisher. Washington DC.

Canadian Council of Ministers of the Environment (*CCME*). (*2009)* .Whitehorse, Yukon - February 16-17.

Chakona, A and Marshall, B. (2008). A preliminary assessment of the impact of forest conversion from natural to pine plantation on macroinvertebrate communities in two mountain streams in Zimbabwe. African Journal of Aquatic Science 33, 115–124.

Clenaghan, C., P. S. Giller, J. O′Halloran and R. Hernan, (1998). Stream macroinvertebrate communities in a conifer-afforested catchment in Ireland: Relationships to physicochemical and biotic factors. – Freshwater. Biol. 40: 175–193

Deas M. L., and Lowney C. L., (2000). Water Temperature Modeling Review, California Water modeling forum

Dyson, M., Bergkamp, G., Scanlon, G. (Eds), (2003). Flow. The Essentials of Environmental Flows. IUCN, Gland, Switzerland and Cambridge, UK, p. 118.

Fafioye O. O., Olurin K. B., and Sowunmi A. A., (2005). Studies on the physicochemical parameters of Omi water body of Ago-Iwoye, Nigeria, African Journal of Biotechnology, 4 (9):1022-1024

Farwell, J.K. (1993). "The impact of inorganic chemicals on water quality and health," *Annali dell'Istituto Superiore di Sanita*, vol. 29, no. 2, pp. 293–303, 1993.

Gliwicz Z.M. and Warsar A. (1992). Diel migrations of juvenile fish: a ghost of predation past or present? Archiv für Hydrobiologie, 124, 385–430.

Gombiro, P.E, Mukaro, J. Mugadza K., Ashley. Faranyika M, and Benhura C. (2014). Drinking Water Quality Assessment in Zimbabwe: A Case Study of Bottled Drinking Water from Selected Retail Outlets in Harare. Available from: https://www.researchgate.net/publication/262495258_Drinking_Water_Quality_Assessment_in_ZimbabweA_Case_Study_of_Bottled_Drinking_Water_from_Selected_Retail_Outlets_in_Harare [accessed Feb 02 2018].

Gordon, N.D., McMahon, T.A., Finlayson, B.L., Gippel, C.J., Nathan, R.J., (2004). Stream Hydrology: an Introduction for Ecologists. John Wiley & Sons, p. 429.

Hanson, *M.A. and.* Butler *M.G*. (2012). Responses to food web manipulation in a shallow waterfowl lake. Hydrobiologia 279–280: 457–466.

International Rivers: Africa Dams Briefing (IRADB). (2010).

Kelly Addy M. S., Linda Green M. S., Elizabeth Herron M. A., (2004). pH and Alkalinity, URI Watershed Watch program; Department of Natural Resources Science, College of the Environment and Life Sciences, University of Rhode Island; http://www.uri.edu/ce/wq/ww/Publications/pH%26alkalinity.pdf

Makaka C, Muteveri T., Makoni P. Phiri C, Dube T. (2018). Longitudinal distribution of the functional feeding groups (FFGs) of aquatic macroinvertebrates and ecosystem integrity of
Tokwe River, Zimbabwe. Journal of Biodiversity and Environmental Sciences (JBES) Vol. 13, No. 1, p. 16-33, 2018

Manora C. (2012). Electrical Conductivity: Kerala Result 15; (www.manoraonline.com) Retrieved 16th June, 2012

Manora.C (2012). Total Dissolved Solids: Kerala Result 13; (www.manoraonline.com) Retrieved 16th June, 2012

Manjonjo, J.M. (1999). Impact of sewage and Sludge effluent on surface Water: A case study of the Impact of Crowborough Farm on Marimba River in Harare, Zimbabwe. MSC WREM Thesis, University of Zimbabwe.

Marshall, B.E. (1997). Lake Chivero after forty years: The impact of eutrophication. In N.A.G. Moyo (eds) Lake Chivero: A polluted lake. University of Zimbabwe Publications. Harare. 134 p
Moreno et al., 2014

. Moreno V,. Bach J,. Baixeras C, Font, L. (2014). Radon levels in groundwaters and natural radioactivity in soils of the volcanic region of La GarrotxaSpain. J. Environ. Radioact., 128 pp. 1-8

Murwira A, Masocha M, Magadza HCD, Owen, R, Nhiwatiwa, T., Barson, M., Makurira H. (2014). Zimbabwe-Strategy for Managing Water Quality and Protecting Water Sources Final Report Phase *1*: Rapid Assessment – Identification and Characterization of Hotspots of Water Pollution and Source Degradation. Prepared for Ministry of Environment, climate and Water.

Mathuthu, A.S., Mwanga, E and Simoro, A. (1997). Impact assessment of industrial and sewage effluent on water quality of the receiving Marimba River in Harare. In: Moyo NAG (ed) Lake Chivero: a polluted Lake. University of Zimbabwe Publications, Harare, Zimbabwe. 43-52

Mhere G, Jonnalagadda SB, (2001). Water quality of the Odzi river in the Eastern Highlands of Zimbabwe. Water Res. 35(10):2371-6.

Mustapha, M.K. (2008). Assessment of the Water Quality of Oyun Reservoir, Offa, Nigeria, Using selected Physicochemical Parameters. Turkish Journal of Fisheries and aquatic sciences 8: 309-310

Ndebele-Murisa M.R. (2012). Biological monitoring and pollution assessment of the Mukuvisi River, Harare, Zimbabwe. Lakes & Reservoirs: Research and Management. 17: 73–80.

Ngodhe,O.S., Raburu A, Alfred A, (2013). The impact of water quality on species diversity and richness of macroinvertebrates in small water bodies in Lake Victoria Basin, Kenya
Journal of Ecology and the Natural Environment Vol. 6(1), pp. 32-41

Nhapi I. and Tirivarombo S. (2004). Sewage discharges and nutrient levels in Marimba River, Zimbabwe. Water SA Vol. 30: 107-114

Protection Agency (EPA). (*2006).* EPA's *2008* Report on the Environment. National Center for Environmental. Assessment, Washington, DC; EPA/600/R-07/045F. Available from the National Technical Information Service, Springfield, VA, and online at
http://www.epa.gov/roe. EPA

US Environmental Protection Agency, Office of Water, (2012)

Nhiwatiwa T, Marshall BE. (2006). Seasonal and diurnal stratification in two small Zimbabwean reservoirs. Afr J Aquat Sci 31:185–196

Nhiwatiwa, T. Dalu, T. Sithole, T. (2017). Assessment of river quality in a subtropical Austral river system: a combined approach using benthic diatoms and macroinvertebrates Appl Water Sci (2017) 7:4785–4792

Novotny, V. (2005). Diffuse pollution from agricultural- a worldwide outlook. Water Science technology. 39, 1-13

Onozeyi B.D, (2013). Assessment of Some Physicochemical Parameters of River Ogun (Abeokuta, Ogun State, Southwestern Nigeria) in Comparison With National and International Standards. International Journal of Aquaculture, Vol.3, No.15, 79-84

Qader M. (1998). Diversion of the Ganges water at Farakka and its effects on salinity in Bangladesh. Environ. Manage. 22 711-722.

Stark JR, Hanson PE, Goldstein RM, Fallon JD, Fong AL, Kroening SE, Andrews WJ. (2000). Water quality in the Upper Mississippi River Basin, Minnesota, Wisconsin, and South Dakota. United States Geological Survey, Circular. 1211:1995–1998.

US Environmental Protection Agency, Office of Water, (1986)

U.S. Environmental

Tchobanoglous, G. and E. D. Schroeder. (1985). Water Quality. Boston, MA: Addison-Wesley

Tafangenyasha C. and Dube L. T. (2005). The effect of season on a Lowveld Tropical

Tafangenyasha C. and Dzinomwa T. (2005). Land-use impacts on river water quality in lowveld sand river systems in south-east

Zimbabwe. Land Use and Water Resources Research 5: 3.1–3.10

Tharme, R.E., King, J.M., (1998). Development of the building block methodology for in-stream flow assessments and supporting research on the effects of different magnitude flows on riverine ecosystems. Water Research Commission Report No 576/1/98, Pretoria, South Africa, p. 452.

Turner D. (2012), Phosphate: Trilogy Laboratory Fluorometer, (www.turnerdesigns.com) Retrieved 16th July 2012.

Rahmanian, N. Siti Hajar Bt Ali. Homayoonfard, M. Ali, N. J. Rehan, M. Sadef, Y and. Nizami A. S (2014). Analysis of Physiochemical Parameters to Evaluate the Drinking Water Quality in the State of Perak, Malaysia. Journal of Chemistry

Scatena, F. N. (2000). “Drinking water quality,” in *Drinking Water from Forests and Grasslands: A Synthesis of the Scientific Literature*, G. E. Dissmeyer, Ed., General Technical Report SRS-39, p. 246, Department of Agriculture, Southern Research Station, Asheville, NC, USA, 2000

Wepener, V and Walsh G. (2009). The influence of land use on water quality and diatom community structures in urban and agriculturally stressed rivers Water SA Vol. 35

Wetzel, R.G. (2001).Limnology, Third Edition. Academic Press, USA.

Zimbabwe National Water Authority (ZINWA). (1995)