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Diatoms as Indicators of Anthropogenic Changes in Water Quality in Mucheke and Shagashe Rivers, Masvingo, Zimbabwe

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Abstract

The most widely used method of water quality assessment, physical and chemical variables assessment is less reliable compared to the use of biological methods such as diatom assemblages. The objective of this study was to (1) assess response of diatom assemblages to anthropogenic changes in water quality in two rivers that drain an urban area in Masvingo, Zimbabwe, (2) test the applicability of the Trophic diatom index (TDI) and Pampean diatom index (PDI) in assessing water quality in the study area. Water quality sampling and benthic diatom community data were collected in May to July 2012 from nine sampling stations in the Mucheke and Shagashe Rivers, Zimbabwe.The data were subjected to canonical correspondence analysis (CCA) to determine environmental gradients along which the diatom species were distributed. Diatom-based biotic indices i.e. the TDI and PDI were used to determine the ecological status of study streams in relation to human-induced stressors. Pearson's correlation was used to determine the relationship between the calculated index scores and measured physical and chemical water quality data. Two-way ANOVA was used to compare these correlation values among sampling stations. The PDI and TDI scores on all the sampling sites showed significant correlations with physical and chemical variables. Thus, the indices proved useful in providing an indication of the quality of the investigated waters. No significant differences in physical and chemical variables were recorded between the three sampling periods. Diatom community structure closely reflected this gradient, with communities from polluted sampling stations (U1, U2, U3, U4 and U5) being different from other communities. Polluted sampling stations were associated with pollution tolerant species such as *Diatoma vulgaris, Nitzschia palea, Fragilaria biceps, Achnanthes exigua* and *Cymatopleura solea*. Diatoms communities demonstrated potential for acting as indicators of changes in water quality due to organic and industrial pollution and are therefore recommended for use in research and monitoring of water bodies by relevant governmental and non-governmental organizations in Zimbabwe.

Keywords: diatoms, biological monitoring, pollution, water quality, diatom indices.

Introduction

The success of human civilization is largely due to our skills as ecosystem engineers (KIM; WEAVER, 1994). Although these engineering activities are primarily directed towards achieving some specific purposes (e.g. industrial production), most have major indirect and unintended effects on ecosystems (TANNER, 2001). Freshwater ecosystems are among the most endangered ecosystems in the world and the decline in freshwater biodiversity is far greater than in most affected terrestrial ecosystems (DUDGEON *et al.*, 2006). Disposal of human waste has now become one of the greatest challenges of urbanization in both developed and developing countries (BERE, 2007; BEYENE *et al.*, 2010). This problem is more severe in developing countries like Zimbabwe where rapid urbanization, coupled with rapid population growth, is not matched by associated technical standards for systems such as sewage treatment, collection of garbage and urban drainage due to economic problems and socio-political bewilderments (DUBE; SWATUK, 2002; BERE; MANGADZE, 2014; MANGADZE *et al.*, 2016; MWEDZI *et al.*, 2016). In such instances, waterways are used for disposal of sewage and industrial effluent leading to problems such as the eutrophication and organic pollution (HARPER, 1992; BERE, 2007).

Two threads of basic approaches to the assessment of water quality deterioration in streams run through the literature; physical and chemical methods and biological methods (BERE; TUNDISI, 2010). Physical and chemical methods provide, at best, a fragmented overview of the state of aquatic systems, as sporadic or periodic sampling cannot reflect fluxes of effluent discharge (TAYLOR *et al.*, 2007b). The chemistry at any given time is a snapshot of the water quality at the time of sampling ignoring temporal variation of water quality variables that is usually high in streams (TAYLOR *et al.*, 2007b). In contrast, biological monitoring(the theory behind which decoding environmental change information enshrined in biota) gives a time-integrated indication of the water quality components because of the capacity of reflecting conditions that are not present at the time of sample collection and analysis (KARR, 1981; TAYLOR *et al.*, 2007b). Biological monitoring is a fast and cost effective approach for assessing the effects of environmental stressors, making it a particularly essential tool for the management of rivers in developing countries (ROUND, 1991).

Benthic diatoms are amongst the commonly used biological indicators because they offer several advantages compared to other potential biological indicators like fish, macro invertebrates and plants (HARDING *et al.*, 2005; BERE, TUNDISI, 2010; SMOL; STOERMER, 2010). Diatoms, a type of uni-cellular algae, have a short developmental cycle (a few hours to several days), depending on species and environmental conditions, a rich species composition and wide distribution thus making them ideal for bio-monitoring (RIMET, BOUCHEZ, 2011). Changes in water chemistry will inhibit the multiplication of some species, while supporting that of others (tolerant species), thus the percentage composition of certain species within a community will be changed (WERNER, 1977). Diatoms are sensitive to changes in nutrient concentrations i.e. growth response is directly affected by changes in prevailing nutrient concentrations and light availability (ROUND, 1991; SMOL, STOERMER, 2010; WOOD *et al.*, 2016). Each taxon has a specific optimum and tolerance for nutrients such as phosphate and nitrogen, and this is usually quantifiable. While diatoms collectively show a broad range of tolerance along a gradient of changes in water quality, individual species have specific water chemistry requirements (SMOL, STOERMER, 2010; HARDING, TAYLOR, 2011). Up to 70% of what happens to water quality can be reflected in diatom assemblages (TAYLOR *et al.*, 2007a). Although over the last few decades a number of biological monitoring methods have been developed for the assessment of water quality in streams, these have rarely been applied in Africa, especially in Zimbabwe (PHIRI *et al.*, 2007; BERE; MANGADZE, 2014; MANGADZE *et al.*, 2015, 2016). For instance, diatom-based water quality assessment protocols have been developed and used extensively elsewhere but with little use in Zimbabwe.

Isolated cases where attempts have been made to assess water quality using diatoms rely heavily on information from other countries. However, there is evidence that this information is less successful when applied in other areas (PIPP, 2002). This is due not only to the floristic differences and occurrence of endemics among regions, but also to the environmental differences that modify species responses to water-quality characteristics (POTAPOVA, CHARLES, 2002; TAYLOR *et al.*, 2007b). The first objective of the present study was to assess response of diatom assemblages to anthropogenic changes in water quality in two rivers that drain an urban area in south-eastern Zimbabwe. The second objective was to test the applicability of PDI and TDI in assessing water quality in the study area. In particular, we asked: (1) to what extent observed changes in water quality reflect themselves in diatom communities in the study streams and (2) to what extend PDI and TDI metrics detect changes in water quality in the study streams. We hypothesised that diatom communities are capable of reflecting changes in water quality, with PDI and TDI metrics being sensitive to water quality changes in the study region because of occurrence of ubiquitous taxa that probably have similar environmental tolerances to those recorded for these two indices.

Materials and Methods

Study area

The area under study is located in the southern parts of Zimbabwe (Figure 1) in the Runde catchment area. The two study rivers, Mucheke and Shagashe, fall in a subtropical steppe/low-latitude semi-arid climatic region were the average temperature and rainfall patterns are 19.4°C and 623 mm per annum. Headwaters of the study rivers fall mainly within an agricultural area where crop production and animal husbandry is practiced. From the agricultural area, the streams pass through urban area of the city of Masvingo, a medium-sized city with a population of 88 554 (Zimbabwe National Statistics Agency – ZNSA) located at the confluence of these rivers. Due to rapid population growth, that is not matched by upgrading of systems such as sewage treatment, collection of garbage and urban drainage due to economic problems and socio-political bewilderments, the capacity of municipal sewage treatment facilities has been exceeded. Poor maintenance and breakdowns of these facilities is also very common because of the financial constrains currently facing the municipality. Options that are available for sewage treatment such as biological nutrient removal plants, conventional stabilization ponds, septic tanks and blair latrines are not being exploited to combat eutrophication because of the nation's economic and social problems (MAPIRA, 2011). Therefore, the study streams receive untreated or semi-treated effluent from sewage treatment plants and bust sewage pipes as well as other diffuse sources as they pass thorough the city.

Nine sampling sites were established along the two rivers: two sites (R1 and R2) in the relatively less impacted agricultural and forested headwaters to act as reference sites; five sites (U1, U2, U3, U4 and U5) in the polluted urban area; and two sites (D1 and D2) in downstream area after the urban area where water quality is expected to improve due to river self-purification capacity (BERE, 2007). The rational for choosing the sampling sites was to obtain a pollution gradient of all the stream systems from relatively unpolluted agricultural headwaters to highly polluted urban downstream sites. Monthly samplings of diatom and water quality were conducted from may to july

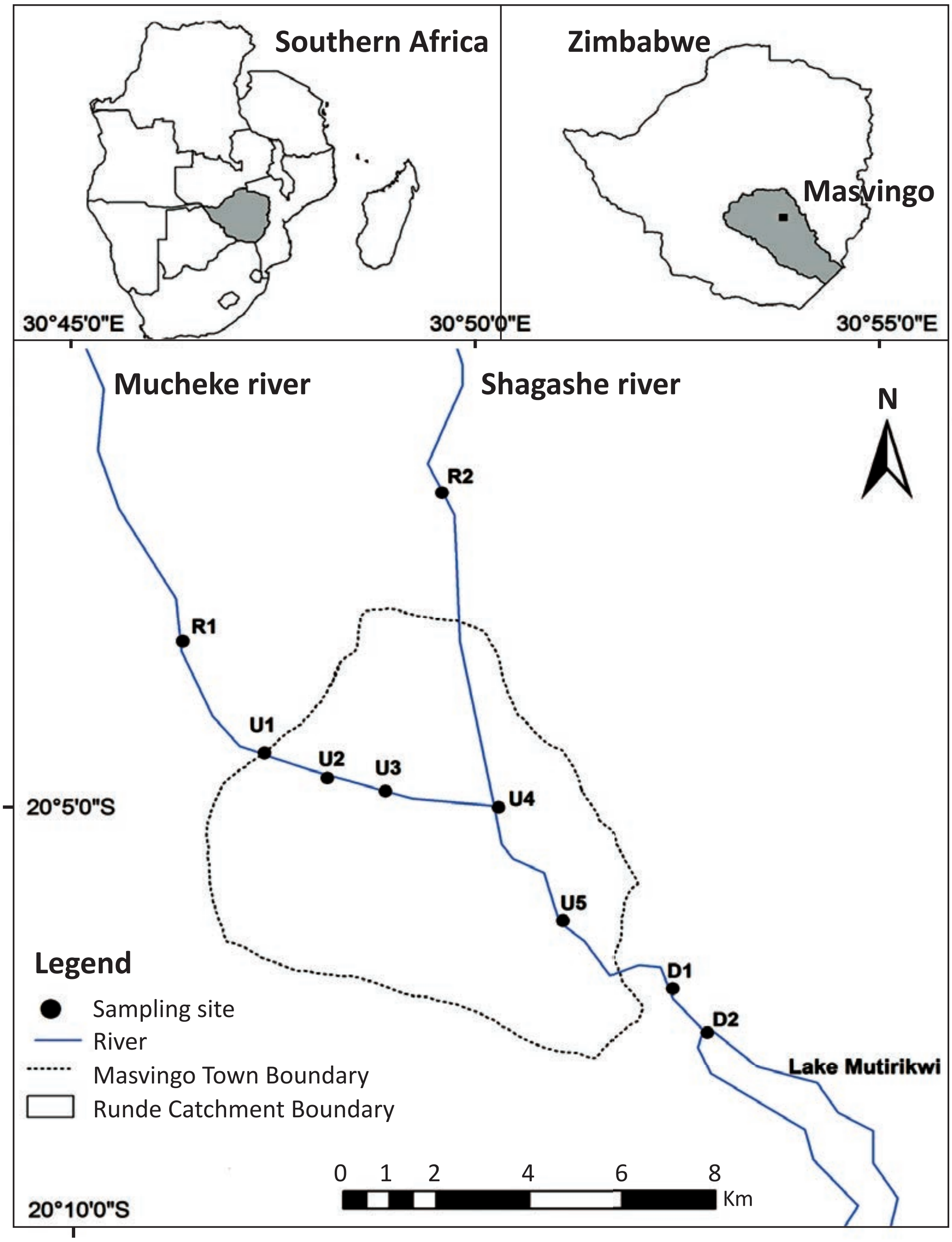

Figure 1 – The location of the Mucheke and Shagashe rivers showing the location of the sampling stations (R1 and R2 = reference sites; U1-U5 = urban sites; D1 and D2 = downstream sites).

2012. The dry season was chosen to avoid variable effects of the rainy season such as great variations in water level and velocity, floods and inundations. These variations affect the growth, development of diatoms and the relative abundance of different species (ROUND, 1991).

Water quality sampling and analysis

At each site, dissolved oxygen (DO), electrical conductivity, specific conductivity, nitrate (NO_3), ammonium, ammonia, chloride, total dissolved solids (TDS), salinity and pH were measured using a portable meter (YSI professional plus, Yellowstone. USA).

Epilithic diatom sampling

At each site, epilithic diatoms were sampled by brushing stones with a tooth brush following (HARDING *et al.*, 2005). Prior to sampling of epilithic surfaces, all substrata were gently shaken in the stream water to remove any loosely attached sediments and non-epilithic diatoms. At least five pebble-to-cobble (5-15 cm), sized stones were randomly collected along each sampling stretch, brushed and the resulting diatom suspensions were pooled to form a single sample which was then put in a labeled plastic container. The dislodged material was decanted into a sample bottle and preserved using formalin to be identified in the laboratory.

In the laboratory, sub-samples of the diatom suspensions were cleaned of organic material using wet combustion with concentrated sulphuric acid and hydrogen peroxide and mounted in Naphrax (Northern Biological supplies Ltd., UK, R1 = 1.74) following Biggs and Kilroy (2000). Three replicate slides were prepared for each sample. A total of 300-650 valves per sample (based on counting efficiency determination method by Pappas and Stoermer (1996) were identified and counted using a compound microscope (× 1000; Nilcon, Alphaphot 2, Type YS2-H, China). The diatoms were identified to species level based mainly on studies from South Africa (TAYLOR *et al.*, 2007a); studies from other tropical regions were consulted when necessary e.g. (METZELTIN, LANGE-BERTALOT, 1998).

Indices calculation

The PDI and TDI were calculated following Gómez and Licursi (2001) and Kelly *et al.* (2001) respectively. The PDI values range from 0 to 4 as follows: 0–0.5 (very good), > 0.5-1.5 (good), > 1.5–2 (acceptable); > 2–3 = bad and > 3–4 (very bad) water quality.Values for the TDI range from 1 (very low nutrient concentrations) to 5 (very high nutrient concentrations). The percentage pollution tolerance taxa is then calculated as a measure of the reliability of the trophic diatom index. Different categories are drawn out from the percentage values to come up with an interpretation of the proportion of count composed of taxa tolerant to organic pollution.

Statistical analysis

A two-way analysis of variance (Two-Way ANOVA) with Tukey's post hoc HSD tests was used to compare means of physical and chemical variables among the three sampling station categories and between the three sampling periods. Pearson's correlation was used to determine the relationship between the calculated index scores (TDI and PDI) and measured physical and chemical water quality data. One-way ANOVA was used to compare the PDI and TDI scores among sampling stations.

Multivariate data analyses were performed on the diatom community data to explore the main gradients of floristic variation and to detect and visualize similarities in diatom samples. Preliminary detrended correspondence analysis (DCA) was applied on diatom data set to determine the length of the gradient. The DCA revealed that the gradient was greater than three standard deviation units, justifying the use of unimodal ordination techniques (ter Braak and Verdonschot, 1995). Thus, canonical correspondence analysis (CCA) was performed to relate diatom community structure to simultaneous effects of predictor environmental variables, and to explore the relationship amongst and between species and predictor variables. Preliminary CCA identified collinear variables and selected a subset on inspection of variance inflation factors (VIF < 20); (Ter Braak and Smilauer, 2002). Monte Carlo permutation tests (999 unrestricted permutations, $p \leq 0.05$) were used to test the significance of the axis and determine if the selected environmental variables could explain nearly as much variation in the diatom community structure as all the environmental variables combined. DCA and CCAs were performed using CANOCO version 4.5 (TER BRAAK; SMILAUER, 2002). All other statistical tests were performed with Palaeontological Statistics Software (PAST) Version 2.16 (Hammer *et al.*, 2001).

Physical and chemical variables

The values of the physiochemical variables recorded in the Mucheke and Shagashe River during this study are summarized in Table 1. A total of 10 environmental variables were analyzed. Generally, water quality deteriorated at sites that were at or near discharge points along the two rivers (Table 1). Conductivity and TDS were significantly high in U2, U5 and D1 compared to.R1, R2 and D2 (ANOVA, $P < 0.05$). There were no significant differences in pH and salinity among sampling stations (ANOVA, $P > 0.05$). Ammonia, ammonium, NO_3 specific conductance and Cl were significantly high in urban sampling stations (U1-U5) (ANOVA, $P < 0.05$), while DO was significantly low in the same (ANOVA, $P > 0.05$) compared to the reference and downstream sites.

Diatom indices

The PDI and TDI scores based on all the site categories showed significant correlations ($P < 0.05$) with physical and chemical variables (Table 2). Significant differences (ANOVA, $P < 0.05$) in the PDI scores based on different site categories were recorded, with reference sites R1 and R2 classified as good. Downstream sites D1 and D2 were generally classified as acceptable and good respectively, while urban sites U1, U2, U3, U4 and U5 were classified as bad.

Similarly, significant differences (ANOVA, $P < 0.05$) in the TDI scores

Table 1 – Means (± SD) (n = 3) of physical and chemical variables recorded during the three sampling trips (May to July 2012) for all the sites (R1-D2).

Variables	Site								
	R1	R2	U1	U2	U3	U4	U5	D1	D2
Ammonia (mg/l)	0.01 ± 0.01^a	0.02 ± 0.2^a	0.2 ± 0.02^b	0.5 ± 0.01^c	0.1 ± 0.04^b	0.2 ± 0.03^b	0.04 ± 0.01^a	0.01 ± 0.1^a	0.01 ± 0.01^a
Ammonium (mg/l)	0.7 ± 0.2^b	0.4 ± 0.4^a	0.6 ± 0.7^b	1.6 ± 0.5^c	0.9 ± 0.4^b	2.3 ± 2.1^c	0.7 ± 0.6^b	0.4 ± 0.2^a	0.2 ± 0.2^a
Cl (mg/l)	1.4 ± 1.3^a	1.4 ± 1.2^a	5.9 ± 2.6^b	24.5 ± 4.8^c	21.8 ± 1.4^c	23.5 ± 1.4^c	10.6 ± 2.6^b	11.9 ± 5.2^b	10.2 ± 5.9^b
Conductivity(µS.cm)	111.9 ± 18.1^a	174.3 ± 133.5^a	355.3 ± 34.3^b	552 ± 126.7^b	238.2 ± 93.1^c	258.4 ± 126.5^c	348.9 ± 83.1^b	401.9 ± 127.3^b	116.8 ± 11.9^a
Dissolved oxygen (mg/l)	6.8 ± 1.3^c	6.4 ± 2.2^c	4.7 ± 0.7^b	2.8 ± 1.9^a	3.4 ± 2.2^a	3.6 ± 2.4^b	4.8 ± 1.9^b	5.6 ± 0.3^b	6.1 ± 0.7^c
NO_3 (mg/l)	0.2 ± 0.1^a	0.5 ± 0.2^a	0.9 ± 0.2^b	1.3 ± 0.1^b	2.5 ± 1.4^c	0.9 ± 0.2^b	0.7 ± 0.4^b	0.8 ± 0.4^b	0.1 ± 0.1^a
pH	8.2 ± 0.2	7.5 ± 0.1	7.7 ± 0.1	8.4 ± 0.1	7.7 ± 0.2	7.8 ± 0.3	8 ± 0.7	7.7 ± 0.2	7.7 ± 0.1
Salinity (ppt)	0.1 ± 0.01	0.3 ± 0.4	0.3 ± 0.03	0.3 ± 0.1	0.5 ± 0.5	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.1 ± 0.01
Specific conductance (µS.cm)	123.2 ± 20.8^a	189.8 ± 150.9^b	564.1 ± 11.7^c	626.6 ± 132.9^c	319.6 ± 52.1^c	356.4 ± 132.6^c	510.1 ± 164.2^c	548.1 ± 148.2^c	134.7 ± 5.5^a
Total dissolved solfids (mg/l)	80 ± 13.5^a	123.3 ± 98.1^b	340.4 ± 39.2^c	407.2 ± 86.5^c	210.7 ± 31.5^b	231.4 ± 86.7^b	332 ± 106.4^c	346.2 ± 87.8^c	88.8 ± 1.6^a

Different letters denote significant differences obtained through Tukey's post hoc comparison test.

based on different site categories were recorded (Figure 3). Reference sites (R1 and R2) as well as downstream sites (D1 and D2) had low percentage pollution tolerant taxa (below 20 %), which means they were free from significant organic pollution (Figure 3). Urban sites generally had high percentage pollution tolerant taxa (above 20 %; Figure 3) indicating some evidence of organic pollution and in some cases (sites U3, U4 and U5) organic pollution was likely to be contributing significantly to eutrophication. Correlations between the PDI scores and physical and chemical variables were also generally lower compared to those between the TDI scores and physical and chemical variables.

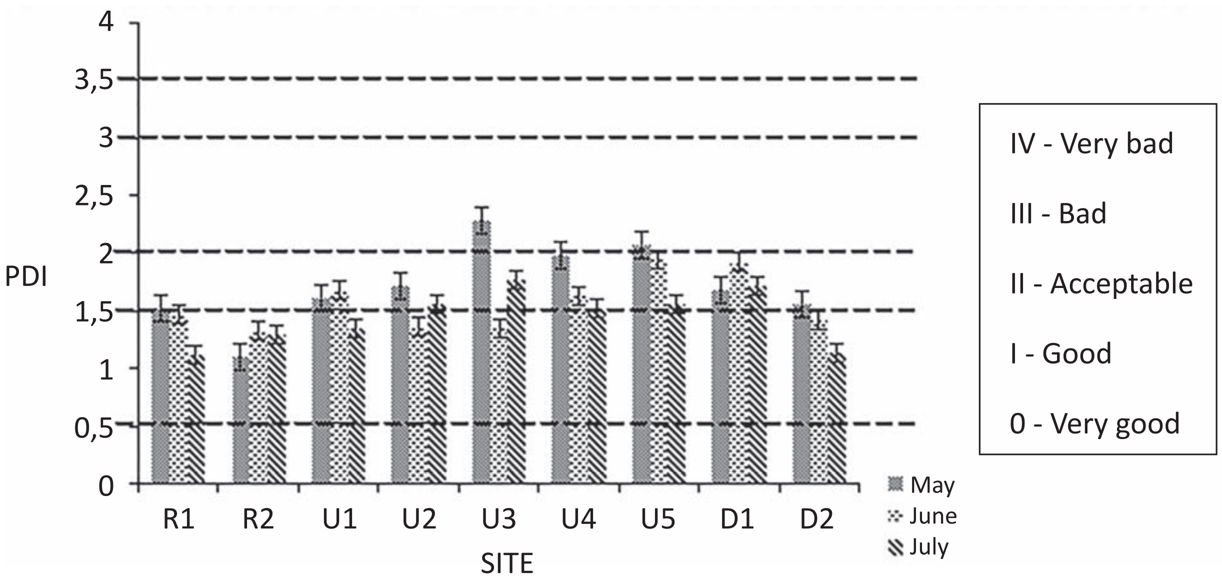

Figure 2 – The Pampean diatom index (PDI) scores recorded at sites along the Mucheke and Shagashe rivers for the study period (may to june).

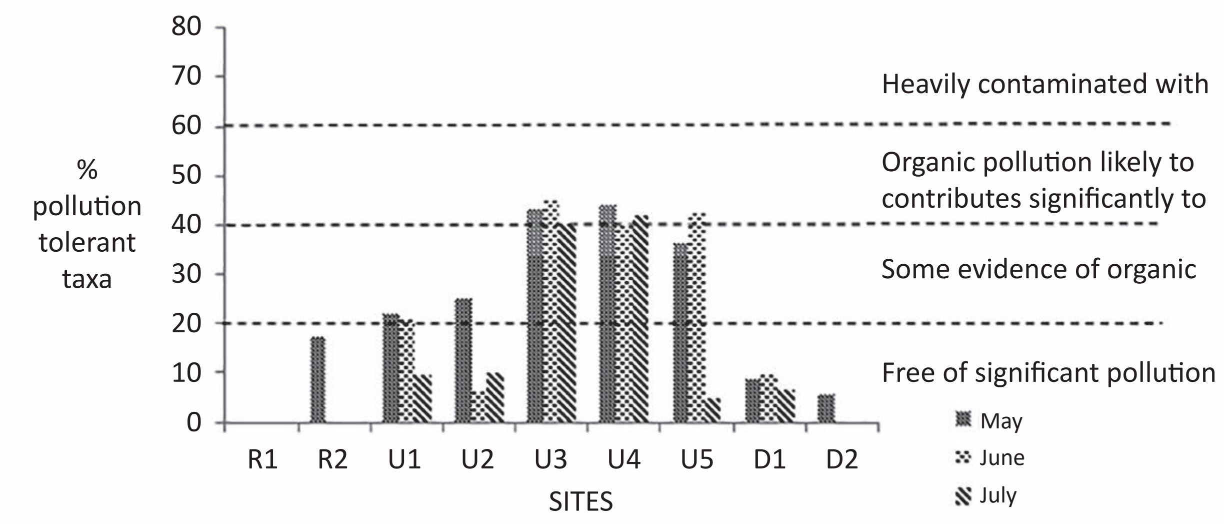

Figure 3 – Percentage pollution tolerant taxa from the nine sampling sites.

Table 2 – Pearson`s correlation between diatom indices and environmental variables.

Parameter	Metric	
	TDI	PDI
Ammonia (mg/l)	0.34	-0.16
Ammonium (mg/l)	0.48	0.2
Cl (mg/l)	0.16	0.07
Conductivity (µS.cm)	0.31	0.29
Dissolved oxygen (mg/l)	-0.18	-0.03
NO3 (mg/l)	-0.09	-0.2
pH	-0.2	0.07
Salinity (ppt)	0.48	-0.1
Total dissolved solids (mg/l)	0.41	0.38

Community composition

A total of 39 diatom species belonging to 25 genera were identified in all nine sampling sites (Table 3). Species composition in terms of species richness, species diversity, dominance and evenness is in the same range for reference and downstream sites compared to urban sites.

The results of CCA are presented in Figure 4. The first four axes of the selected exploratory variables accounted for 79.9% of the total variance in the community data (Table 2). Axis 1 and 2 significantly explained 26.4 % and 16.3%, respectively, of the diatom species variance (Table 2; Monte Carlo unrestricted permutation, $P < 0.05$). CCA Axes 1 and 2 separated the sites into 3 groups. The first group consisted of less polluted sites R1 and R2 that were positively associated with the first axis. Diatom species characterising these sites include species such as *Achnanthidium minutissimum, Aulacoseira distans, Encyonema silesiacum, Encyonopsis minuta, Cymatopleura solea, Eunotia flexuosa Diploneis subovalis, Cymbella kappii, Eunotia flexuosa, Fragilaria nanana, Rhopalodia gibba, Diadesmis confervacea, Brachysira neoexilis, Gomphonema laticollum,Cymatopleura solea,Pinnularia acrosphaeria, Gomphonema minitum, Pinnularia subcapitata* and *Staurosirella pinnata.* The second group consisted of highly polluted sites (U1-U5) that were negatively associated with the first and positively associated with the second axis, respectively (Figure 4). These sites were associated with high ammonium, ammonia and nitrate levels. Diatom species characterising these sites include species such as *Fragilaria biceps, Fragilaria ulna, Rhoicosphenia abbreviate, Cyclotella meneghiniana, Nitzschia palea, Gomphonema parvulum, Cyclotella spp, Pinnularia confirma, Pinnularia viridiformis.* This group of species was associated with high levels of ammonia, ammonium and nitrate as compared to the rest of the species. The third group consisted of medium polluted sites D1 and D2 that were negatively associated with the first and second axis. These sites were associated with high salinity and pH levels. Nutrient levels were generally low compared to those of sites U1-U5. Sites D1and D2 wereassociated *Pleurosigma* *elongatum*, *Tabellaria flocculosa*, *Sellaphora stroemii*, *Sellaphora seminulum*, *Planothidium frequentissimum*, *Nitzschia frustulum*, *Gomphonema insigne*, *Fallacia monoculata*, *Achnanthes exigua* and *Diatoma vulgaris.*

Table 3 – Mean values of species richness, diversity, dominance and evenness.

	Site								
	R1	**R2**	**U1**	**U2**	**U3**	**U4**	**U5**	**D1**	**D2**
Speciesrichness	8 ± 1	10 ± 2	8 ± 1	10 ± 0	7 ± 1	5 ± 1	6 ± 2	10 ± 2	9 ± 2
Shannondiversity	1.6 ± 1.8	2.1 ± 0.1	1.9 ± 0.3	2.1 ± 0.04	1.8 ± 0.2	1.5 ± 0.1	1.5 ± 0.4	1.8 ± 0.3	1.8 ± 0.2
Dominance	0.3 ± 0.1	0.1 ± 0.02	0.2 ± 0.1	0.1 ± 0.01	0.2 ± 0.03	0.2 ± 0.03	0.3 ± 0.1	0.3 ± 0.1	0.2 ± 0.04
Evenness	0.6 ± 0.1	0.8 ± 0.05	0.8 ± 0.1	0.8 ± 0.03	0.9 ± 0.05	0.8 ± 0.05	0.7 ± 0.1	0.6 ± 0.2	0.7 ± 0.02

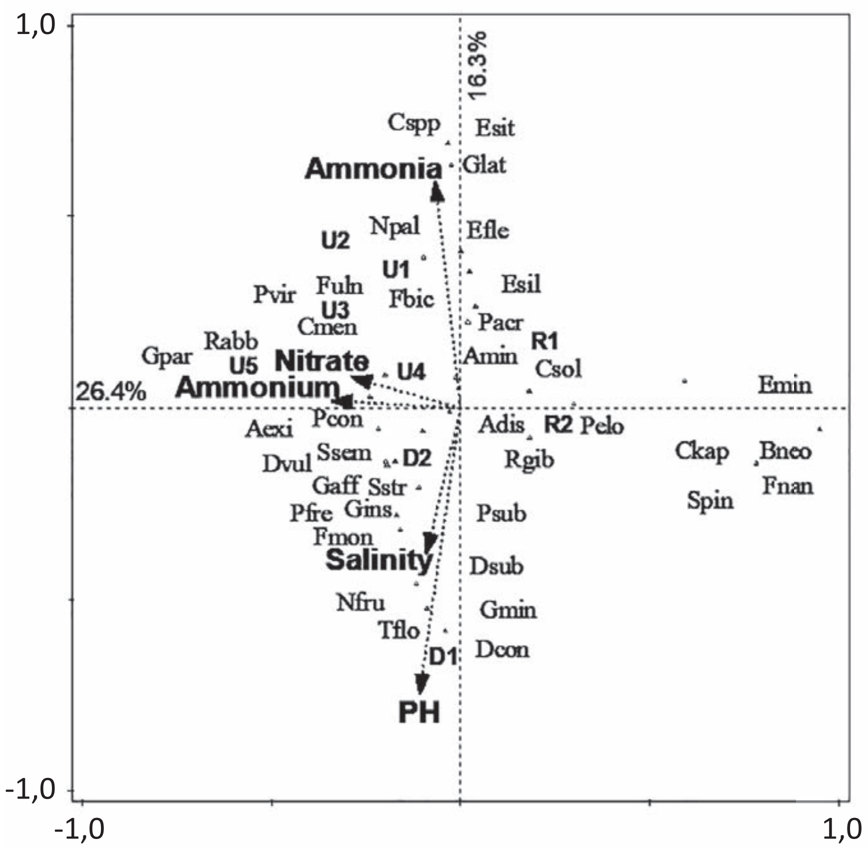

Figure 7 – Ordination diagram based on canonical correspondence analysis (CCA) of diatom species composition in nine sampling sites in respect with six environmental variables.

Table 4 – Diatom species codes used in the canonical correspondence analysis.

Species	Code	Species	Code
Achnanthes exigua	Aexi	*Gomphonema insigne*	Gins
Achnanthidium minutissimum	Amin	*Gomphonema laticollum*	Glat
Aulacoseira distans	Adis	*Gomphonema minutum*	Gmin
Brachysira neoexilis	Bneo	*Gomphonema parvulum*	Gpar
Cyclotella meneghiniana	Cmen	*Nitzschia frustulum*	Nfru
Cyclotella species	Cspp	*Nitzschia palea*	Npal
Cymatopleura solea	Csol	*Nitzschia reversa*	Nrev
Cymbella kappii	Ckap	*Pinnularia acrosphaeria*	Pacr
Diadesmis confervacea	Dcon	*Pinnularia confirma*	Pcon
Diatoma vulgaris	Dvul	*Pinnularia subcapitata*	Psub
Diploneis subovalis	Dsub	*Pinnularia viridiformis*	Pvir
Encyonopsis minuta	Emin	*Planothidium frequentissimum*	Pfre
Encyonema silesiacum	Esil	*Pleurosigma elongatum*	Pelo
Encyonema sitesiam	Esit	*Rhoicosphenia abbreviata*	Rabb
Eunotia flexuosa	Efle	*Rhopalodia gibba*	Rgib
Fallacia monoculata	Fmon	*Sellaphora seminulum*	Ssem
Fragilaria biceps	Fbic	*Sellaphora stroemii*	Sstr
Fragilaria nanana	Fnan	*Staurosirella pinnata*	Spin
Fragilaria ulna	Fuln	*Tabellaria flocculosa*	Tflo
Gomphonema affine	Gaff		

Discussion

Water quality

The results of the physical and chemical variables in the study showed that pollution levels, especially organic pollution and eutrophication, differed among the sites sampled (Table 1). Conductivity, ammonium, ammonia, chloride and nitrate were significantly higher in sites that were near or at a pollution point in the urban areas.Industrial, domestic and sewage effluent disposals are the main causes of decrease in the water quality along the Mucheke and Shagashe River system. These high levels of nutrients are associated with deterioration of water quality and eventually lead to eutrophication and changes in diatom species composition (BERE, 2010).

Diatom community structure in relation to environmental variables

Diatom community structure and composition closely followed the observed changes in pollution levels, with less polluted sites R1 and R2 being associated with diatom communities that were different from highly polluted sites U1, U2, U3, U4 and U5. Cluster analysis of sampling stations based on epilithic diatom communities in streams of the Mucheke and Shagashe river clearly reflected the effects of pollution (Figure 2). The epilithic algal communities in this study were primarily affected by organic pollution and nutrient concentrations in the streams resulting from urban runoff as confirmed by the findings of Beyene *et al.* (2010). Diatoms have an important role in biological monitoring of lotic systems as they have shown capacity to respond to changes in water quality. Ammonia, Ammonium, salinity, pH and nitrate were found to be important in structuring benthic diatom communities in the study area (Figure 4). Other studies have also shown that nutrients (ammonia, ammonium and nitrate)are the primary drivers of periphyton community structure and biomass (BIGGS, THOMSEN, 1995; JOWETT, BIGGS, 1997). Nonetheless, a review of literature carried out by (SAROS, FRITZ, 2000) showed that salinity may influence nutrient availability to primary producers, as well as nutrient requirements and uptake by diatoms. pH exerts a direct physiological stress on diatoms (GENSEMER, 1991), and also strongly influences other water chemistry variables (SIGG, STUMM, 1981). Based on the CCA (Figure 4), sites that were relatively more polluted had pollution tolerant species such as *Nitzschia palea*, *Gomphonema parvulum*, *Cyclotella spp*, *Pinnularia confirma* and *Pinnularia viridiformis*. These species are known to be resistant to heavy metal and organic pollution (ROUND, 1991; BERE, TUNDISI, 2010). Whereas, reference sites R1 and R2 were characterized by low pollution tolerant species such as *Fragilaria nanana*, *Rhopalodia gibba*, *Diadesmis confervacea*, *Brachysira neoexilis*, *Gomphonema laticollum*,*Cymatopleura solea*,*Pinnularia acrosphaeria*, *Gomphonema minitum*, *Pinnularia subcapitata* and *Staurosirella pinnata*.These species are mainly found in oligo- to mesotrophic water with moderate conductivity (VAN DAM *et al.*, 1994; BERE, TUNDISI, 2011).

Applicability of TDI and PDI to the study area

The significant correlations between TDI and PDI index values and physical and chemical characteristics of streams recorded in this study indicate that these indices may be used to reflect general changes in water quality of rivers and streams of Zimbabwe (Table 2). Values of the TDI and PDI indices showed significant differences between reference sites R1 and R2 and heavily polluted urban sites U1-U5 (Figures 2 and 3). This is supported by (Bate *et al.*, 2004) who found that most dominant diatom species found in South African rivers were already recorded in international studies. Thus, most foreign diatom indices may be used in the study area as they are based on the ecology of widely distributed or cosmopolitan taxa. In conclusion, it can be said that the PDI and TDI are applicable to the study area. Diatoms have an important role in biological monitoring of lotic systems as they have shown capacity to respond to changes in water quality.

Conclusion

In conclusion, organic and industrial effluent has a great effect on the water quality of Mucheke and Shagashe Rivers as shown by the physical and chemical variables of the two rivers. Changes in the assemblages of diatom species are also evident of changes in water quality along the rivers, thus a relationship between diatoms and water quality. Diatoms have an important role in biological monitoring of lotic systems as they has shown capacity to respond to changes in water quality. Biological monitoring of water quality using diatoms is a reliable method for water quality assessment and should therefore be adapted in research and by relevant government organizations.

References

BATE, G., SMAILES, P. and ADAMS, J., 2004. A water quality index for use with diatoms in the assessment of rivers. ***Water SA,*** vol. 30, no. 4, pp. 493-498.

BERE, T., 2007. The assessment of nutrient loading and retention in the upper segment of the Chinyika River, Harare: Implications for eutrophication control. ***Water SA,*** vol. 33, no. 2.

BERE, T., 2010. Benthic diatom community structure and habitat preferences along an urban pollution gradient in the Monjolinho River, São Carlos, SP, Brazil. ***Acta Limnologica Brasiliensia***, vol. 22, no. 1, pp. 80-92.

BERE, T. and MANGADZE, T., 2014. Diatom communities in streams draining urban areas: community structure in relation to environmental variables. ***Tropical Ecology,*** vol. 55, no. 2, pp. 271-281.

BERE, T. and TUNDISI, J., 2010. Biological monitoring of lotic ecosystems: the role of diatoms. ***Brazilian Journal of Biology,*** vol. 70, no. 3, pp. 493-502.

BERE, T. and TUNDISI, J., 2011. Influence of ionic strength and conductivity on benthic diatom communities in a tropical river (Monjolinho), São Carlos-SP, Brazil. ***Hydrobiologia***, vol. 661, no. 1, pp. 261-276.

BEYENE, T., LETTENMAIER, D.P. and KABAT, P., 2010. Hydrologic impacts of climate change on the Nile River Basin: implications of the 2007 IPCC scenarios. ***Climatic change,*** no. 100, vol. 3-4, pp. 433-461.

BIGGS, B. and KILROY, C., 2000. ***Stream periphyton monitoring manual***: Niwa.

BIGGS, B.J. and THOMSEN, H.A., 1995. Disturbance of stream periphyton by perturbations in shear stress: time to structural failure and differences in community resistance. ***Journal of Phycology,*** vol. 1, no. 2, pp. 233-241.

DUBE, D. and SWATUK, L.A., 2002. Stakeholder participation in the new water management approach: a case study of the Save catchment, Zimbabwe. ***Physics and Chemistry of the Earth, Parts A/B/C,*** vol. 27, no. 11, pp. 867-874.

DUDGEON, D., ARTHINGTON, A.H., GESSNER, M.O., KAWABATA, Z.-I., KNOWLER, D.J., LÉVÊQUE, C., NAIMAN, R.J., PRIEUR-RICHARD, A.-H., SOTO, D. and STIASSNY, M.L., 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. ***Biological reviews,*** vol. 81, no. 2, pp. 163-182.

GENSEMER, R.W., 1991. The effects of pH and aluminum on the growth of the acidophilic diatom Asterionella ralfsii var. americana. ***Limnology and Oceanography,*** vol. 36, no. 1, pp. 123-131.

GÓMEZ, N. and LICURSI, M., 2001. The Pampean Diatom Index (IDP) for assessment of rivers and streams in Argentina. ***Aquatic Ecology,*** vol. 35, no. 2, pp. 173-181.

HAMMER, O., HARPER, D. and RYAN, P., 2001. PAST (Paleontological Statistics) version 3.14. Software package for education and data analysis. ***Paleontología Electrónica,*** vol. 4, no. 1, p. 9.

HARDING, W., ARCHIBALD, C. and TAYLOR, J., 2005. The relevance of diatoms for water quality assessment in South Africa: A position paper. ***Water SA,*** vol. 31, no. 1, pp. 41-46.

HARDING, W. and TAYLOR, J., 2011. ***The South African Diatom Index (SADI)***: A Preliminary Index for Indicating Water Quality in Rivers and Streams in Southern Africa. Report to the Water Research Commission, Water Research Commission.

HARPER, D.M., 1992. ***Eutrophication of freshwaters***: Springer.

JOWETT, I.G. and BIGGS, B.J., 1997. Flood and velocity effects on periphyton and silt accumulation in two New Zealand rivers. ***New Zealand Journal of Marine and Freshwater Research,*** vol. 31, no. 3, pp. 287-300.

KARR, J.R., 1981. Assessment of Biotic Integrity Using Fish Communities. ***Fisheries,*** vol. 6, no. 6, pp. 21-27. http://dx.doi.org/10.1577/1548-8446(1981)006<0021:AOBIUF>2.0.CO,2

KELLY, M., ADAMS, C. and GRAVES, A., 2001. ***The Trophic Diatom Index:*** A User's Manual, Revised Edition, Environment Agency.

KIM, K.C. and WEAVER, R.D., 1994. ***Biodiversity and landscapes: a paradox of humanity***: Cambridge University Press.

MANGADZE, T., BERE, T. and MWEDZI, T., 2015. Epilithic diatom flora in contrasting land-use settings in tropical streams, Manyame Catchment, Zimbabwe. ***Hydrobiologia,*** vol. 753, no. 1, pp. 163-173.

MANGADZE, T., BERE, T. and MWEDZI, T., 2016. Choice of biota in stream assessment and monitoring programs in tropical streams: A comparison of diatoms, macroinvertebrates and fish. ***Ecological Indicators,*** vol. 63, pp. 128-143.

MAPIRA, J., 2011. Sewage treatment, disposal and management problems, and the quest for a cleaner environment in Masvingo city (Zimbabwe). ***Journal of Sustainable Development in Africa,*** vol. 13, no. 4.

METZELTIN, D. and LANGE-BERTALOT, H., 1988. ***Tropische Diatomeen in Südamerika, I***: Koeltz Scientific Books, vol. 1.

MWEDZI, T., BERE, T. and MANGADZE, T., 2016. Macroinvertebrate assemblages in agricultural, mining, and urban tropical streams: implications for conservation and management. ***Environmental Science and Pollution Research***, vol. 1-12.

PAPPAS, J.L. and STOERMER, E.F., 1996. Quantitative method for determining a representative algalsample count 1. ***Journal of Phycology,*** vol. 32, no. 4, pp. 693-696.

PHIRI, C., DAY, J., CHIMBARI, M. and DHLOMO, E., 2007. Epiphytic diatoms associated with a submerged macrophyte, Vallisneria aethiopica, in the shallow marginal areas of Sanyati Basin (Lake Kariba): a preliminary assessment of their use as biomonitoring tools. ***Aquatic Ecology,*** vol. 41, no. 2, pp. 169-181.

PIPP, E., 2002. ***A regional diatom-based trophic state indication system for running water sites in Upper Austria and its overregional applicability.*** Paper presented at the Verh. Int. Ver. Theor. Angew. Limnol./Proc. Int. Assoc. Theor. Appl. Limnol./Trav. Assoc. Int. Limnol. Theor. Appl.

POTAPOVA, M.G. and CHARLES, D.F., 2002. Benthic diatoms in USA rivers: distributions along spatial and environmental gradients. ***Journal of biogeography,*** vol. 29, no. 2, pp. 167-187.

RIMET, F. and BOUCHEZ, A., 2011. Use of diatom life-forms and ecological guilds to assess pesticide contamination in rivers: lotic mesocosm approaches. ***Ecological Indicators,*** vol. 11, no. 2, pp. 489-499.

ROUND, F., 1991. Diatoms in river water-monitoring studies. ***Journal of Applied Phycology,*** vol. 3, no. 2, pp. 129-145.

SAROS, J. and FRITZ, S.C., 2000. Nutrients as a link between ionic concentration/composition and diatom distributions in saline lakes. ***Journal of Paleolimnology,*** vol. 23, no. 4, pp. 449-453.

SIGG, L. and STUMM, W., 1981. The interaction of anions and weak acids with the hydrous goethite (α-FeOOH) surface. ***Colloids and surfaces,*** vol. 2, no. 2, 101-117.

SMOL, J.P. and STOERMER, E.F., 2010. The diatoms: applications for the environmental and earth sciences. ***Cambridge University Press***.

TAYLOR, J., VAN VUUREN, M.J. and PIETERSE, A., 2007a. The application and testing of diatom-based indices in the Vaal and Wilge Rivers, South Africa. ***Water SA,*** vol. 33, no. 1.

TAYLOR, J.C., PRYGIEL, J., VOSLOO, A., PIETER, A. and VAN RENSBURG, L., 2007b. Can diatom-based pollution indices be used for biomonitoring in South Africa? A case study of the Crocodile West and Marico water management area. ***Hydrobiologia,*** vol. 592, no. 1, pp. 455-464.

TER BRAAK, C. and SMILAUER, P., 2002. Canoco for Windows version 4.5. ***Biometris–Plant Research International, Wageningen***.

TER BRAAK, C.J. and VERDONSCHOT, P.F., 1995. Canonical correspondence analysis and related multivariate methods in aquatic ecology. ***Aquatic Sciences,*** vol. 57, no. 3, pp. 255-289.

VAN DAM, H., MERTENS, A. and SINKELDAM, J. A, 1994. coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. ***Aquatic Ecology,*** vol. 28, no. 1, pp. 117-133, 1994.

WERNER, D., 1977. ***The biology of diatoms***. Univ of California Press, vol. 13.

WOOD, R.J., MITROVIC, S.M., LIM, R.P. and KEFFORD, B.J., 2016. The influence of reduced light intensity on the response of benthic diatoms to herbicide exposure. ***Environmental Toxicology and Chemistry,*** vol. 35, no. 9, pp. 2252-2260. http://dx.doi.org/10.1002/etc.3379