Appl Water Sci (2017) 7:4785–4792
https://doi.org/10.1007/s13201-017-0599-0

SHORT RESEARCH COMMUNICATION

Assessment of river quality in a subtropical Austral river system: a combined approach using benthic diatoms and macroinvertebrates

Tamuka Nhiwatiwa[1] · **Tatenda Dalu**[2,3] · **Tatenda Sithole**[1]

Received: 10 May 2017 / Accepted: 19 July 2017 / Published online: 26 July 2017

Abstract River systems constitute areas of high human population densities owing to their favourable conditions for agriculture, water supply and transportation network. Despite human dependence on river systems, anthropogenic activities severely degrade water quality. The main aim of this study was to assess the river health of Ngamo River using diatom and macroinvertebrate community structure based on multivariate analyses and community metrics. Ammonia, pH, salinity, total phosphorus and temperature were found to be significantly different among the study seasons. The diatom and macroinvertebrate taxa richness increased downstream suggesting an improvement in water as we moved away from the pollution point sources. Canonical correspondence analyses identified nutrients (total nitrogen and reactive phosphorus) as important variables structuring diatom and macroinvertebrate community. The community metrics and diversity indices for both bioindicators highlighted that the water quality of the river system was very poor. These findings indicate that both methods can be used for water quality assessments, e.g. sewage and agricultural pollution, and they show high potential for use during water quality monitoring programmes in other regions.

Keywords Water quality · Bioindicators · Macroinvertebrates · Diatoms · Nutrients · Multivariate analysis

Introduction

Rapid industrialisation, urbanisation and population growth have resulted in an increased deterioration of water quality in river systems (Wong and Wong 2003; Dalu and Froneman 2016; Tudesque et al. 2014; Teittinen et al. 2015). River pollution is a result of several pollutant sources, which are linked to man-made discharges such as wastewater discharge and non-point sources, from diffuse sources such as land drainage and agricultural surface runoff (Tudesque et al. 2014; Bere et al. 2016a; Dalu et al. 2017a, b; Nhiwatiwa et al. 2017). Nutrient enrichment leading to eutrophication in streams greatly reduces habitat heterogeneity, therefore directly and indirectly impacting aquatic biota (Kelly and Whitton 1995; Bere 2007; Dalu and Froneman 2016). The water quality of these aquatic ecosystems has become a subject of ongoing concern worldwide and has resulted in the need for river water quality monitoring. Regular monitoring of aquatic water quality is therefore not only to predict the further deterioration in ecosystem health, but also provides a scope to assess current investments for pollution control (Soininen and Könönen 2004; Bellinger and Sigee 2010; Nhiwatiwa et al. 2017).

Studies have shown that diatoms are better related to water quality, while macroinvertebrates were better indicators of catchment disturbances (Sonneman et al. 2001).

Electronic supplementary material The online version of this article (doi:10.1007/s13201-017-0599-0) contains supplementary material, which is available to authorized users.

✉ Tatenda Dalu
dalutatenda@yahoo.co.uk

[1] Biological Sciences, University of Zimbabwe, P O Box MP167, Mt. Pleasant, Harare, Zimbabwe

[2] Zoology and Entomology, Rhodes University, P O Box 94, Grahamstown 6140, South Africa

[3] South African Institute for Aquatic Biodiversity, P Bag 1015, Grahamstown 6140, South Africa

However, a study by Belore et al. (2002) found that diatoms and macroinvertebrates were equally important in predicting water quality. As a result, some scholars (e.g. Resende et al. 2010; Mangadze et al. 2016) have advocated the use of both diatoms and macroinvertebrates for effective water quality monitoring. Therefore, the current study used a combined approach (i.e. diatoms and macroinvertebrates) to assess the impact on pollution on river water quality. Most studies in the region on water quality assessments tend to concentrate on a single parameter, either macroinvertebrates (Dallas 1997; Bere et al. 2016a, b) or diatoms (De la Rey et al. 2004; Bere and Mangadze 2014; Dalu et al. 2015, 2016). The study's main aim was to investigate the responses of benthic diatoms or macroinvertebrates to water quality changes along the Ngamo River which drains part of the urban and agricultural area in the Midlands Province of Zimbabwe. The study further assessed how the benthic diatom and macroinvertebrate fauna respond to changes in water quality.

Materials and methods

Study area

The study was carried out on Ngamo River, in the Midlands Province of Zimbabwe. The river is approximately 8 km in length and drains sections of a local town Gweru, flowing past farming areas and finally draining into the Anchor Reservoir (Fig. 1). The mean annual rainfall is 684 mm, with the least rainfall occurring during the cool-dry season (i.e. July and August—mean 1 mm) and high amount of rainfall occurring during the hot-wet season (i.e. December—159 mm). The mean temperature is 18.1 °C, with the highest average being observed in the hot-dry season (i.e. October ~ 21.5 °C) and the lowest mean temperatures in the year occurring in July (i.e. 12.8 °C). The continuous discharge of sewage effluent keeps the river flowing even during the dry season. Four sites sampled over three seasons in 2016, hot-wet (March), cool-dry (June) and hot-dry (September), were selected along the Ngamo River, with site 1 located about 100 m from below the sewage treatment works (WTW) discharge point, site 2 in the farmlands, site 3 approximately 1 km downstream of site 2 and site 4 above the reservoir mouth.

Physico-chemical variables

Water conductivity, dissolved oxygen (DO), pH, salinity, total dissolved solids (TDS) and temperature were measured on-site using WTW 340i multiparameter meter (Xylem, Germany). Depth-integrated 1 L water samples were collected for the determination of turbidity, total nitrogen (TN), nitrates, ammonia, total phosphorus (TP) and reactive phosphates in the laboratory using the standard methods for the examination of water and wastewater (Clesceri et al. 1998). All samples were stored on ice in the field.

Sampling

Diatoms

Prior to sampling, all rock substrata were gently shaken in stream water to remove any loosely attached sediment. At least ten rocks and/or stones (~80–120 mm diameter) were randomly collected at each sampling site and the top surface brushed into a 500 mL polyethylene container with distilled water and preserved in 70% ethanol [see Taylor

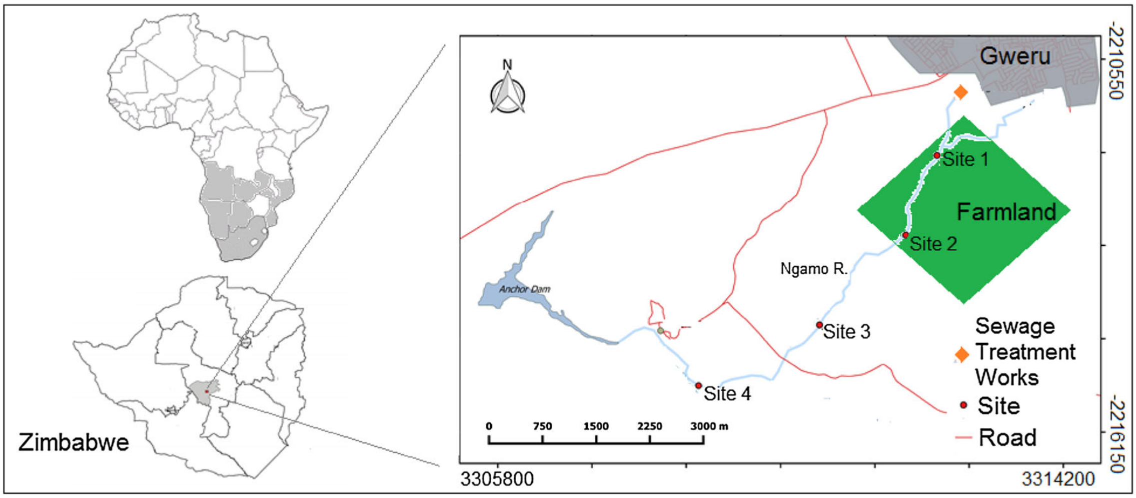

Fig. 1 Map showing study locations near Gweru urban area, Midlands Province, Zimbabwe

et al. (2005) for detailed sampling methodology]. In the laboratory, the diatom samples were set aside for 2 days to sediment before being processed using potassium permanganate method according to Taylor et al. (2005). Diatoms were identified to species level using a phase-contrast light microscope (Olympus CX) at 1000× according to Taylor et al. (2007). Species richness as the number of different species at a site was used as a measure of diatoms diversity. Diatom keys developed by Taylor et al. (2007) were used to classify diatoms into four classes: A (clean water, i.e. no pollution), B (moderately polluted), C (strongly polluted) and D (electrolyte rich).

Macroinvertebrates

Macroinvertebrates were collected by kicking benthic sediment and rocks with feet and sweeping through vegetation in a zigzag manner using a kick net (1.5 m handle, mesh size 500 µm, dimension 30 × 30 cm) to form an integrated sample and then preserved in 500 mL polyethylene container with 70% ethanol according to Dickens and Grahams (2002), Dalu et al. (2012) and Bere et al. (2016a) methods. At each site, ~6 min was spent sampling all available aquatic habitats (i.e. kicking substratum—rocks, sediment (5 m transect length) was 2 min; sweeping littoral macrophytes (2 m^2) and marginal vegetation (5 m transect length) was 2 min each, respectively). Macroinvertebrates were identified to family level using identification guides by Thirion et al. (1995) and Gerber and Gabriel (2002). Several macroinvertebrate community measures were computed to assess the ability of macroinvertebrates to respond to water quality changes: South African Scoring System version 5 (SASS5) scores (i.e. the sum of pre-determined taxa tolerance values of all macroinvertebrates within a particular sample), average score per taxa (ASPT; calculated by dividing the SASS5 score by the sample number of taxa; see Dickens and Grahams (2002) for detailed methodology), diversity indices (Shannon–Wiener, Simpsons, Margalef), %Ephemeroptera, Plecoptera and Trichoptera (EPT) abundance, %Ephemeroptera abundance, %Diptera abundance, %Trichoptera abundance and EPT/Chironomidae ratio. The SASS5 and ASPT scores used to determine the condition of a site were based on Thirion et al. (1995): excellent: SASS >100 and ASPT >7; good: 80–100 and 5–7; fair: 60–80 and 3–5; poor: 40–60 and 2–3 and very poor: <40 and <2, respectively.

Data analysis

The data collected did not meet the assumptions of parametric tests such as normality and homogeneity of variance. Hence, the data were not normal as confirmed by the Shapiro–Wilk normality test. Therefore, a non-parametric test, Kruskal–Wallis, was used to test for differences in physico-chemical variables and community metrics among sites and seasons. Pairwise comparisons using the Kruskal–Wallis multiple comparisons of *p* values for physico-chemical variables among sites and seasons was carried out to assess the significant differences indicated by the Kruskal–Wallis test in STATISTICA version 12.0 (StataCorp 2011). Spearman rank correlations were carried out to determine the relationships that existed between the physico-chemical variables vs community metrics and diversity indices.

A detrended canonical correspondence analysis (DCCA) was used to examine whether linear or unimodal analysis ordination methods should be employed. The DCCA gradient lengths were examined, and, since the longest gradient was greater than 3, a unimodal canonical correspondence analysis (CCA) model was used (ter Braak and Verdonschot 1995; Lepš and Šmilauer 2003) to study diatom and macroinvertebrate communities and their relation with physico-chemical variables. CCA was carried out to assess the relationships between water quality parameters (i.e. physico-chemical variables) and diatom and macroinvertebrate community data. All data was log $(x + 1)$ transformed prior to analysis. The down-weighting option and the automatic stepwise forward selection procedure, with Monte Carlo significance test (permutation: $n = 9999$, $p < 0.05$), were selected to examine the direct effects of physico-chemical variables on the variation of diatoms and macroinvertebrates community composition. All statistical analysis was carried out in CANOCO version 4.5 (ter Braak and Šmilauer 2002).

Results

Physico-chemical variables

Conductivity, salinity, turbidity and total dissolved solids (TDS) showed a decreasing trend from site 1 to 4 (Table 1). High total nitrogen (TN; 2.42 mg L^{-1}) and phosphorus (TP; 1.85 mg L^{-1}) were observed at site 1. The water quality at site 4 was relatively good compared to other sites based on the physico-chemical variables (Table 1). Very low dissolved oxygen concentrations were recorded throughout the duration of the study (mean range 0.95–3.5 mg L^{-1}) due to sewage discharge (Table 1). For all measured physico-chemical variables, no significant site variation was observed ($p > 0.05$). Conductivity, salinity, turbidity and total dissolved solids (TDS) showed an increasing trend across seasons, similar to all nutrient variables measured. Water quality was low during the hot-dry season in comparison to the rest of the seasons. Ammonium, pH, salinity, total phosphorus and temperature

Table 1 Mean (±SD) summary of physical and chemical variables in the Ngamo River

Variable	Site				Kruskal–Wallis	
	1	2	3	4	Site	Season
Cond (μS cm^{-1})	1129 ± 225.23	1013.33 ± 83.97	953.33 ± 112.34	793.67 ± 288.92	4.128 (0.248)	5.692 (0.058)
DO (mg L^{-1})	2.69 ± 0.87	1.73 ± 0.71	1.52 ± 0.47	2.21 ± 0.27	4.590 (0.204)	4.192 (0.123)
pH	7.63 ± 0.54	7.68 ± 0.46	7.74 ± 0.38	7.46 ± 0.44	0.744 (0.863)	**7.223 (0.027)**
Salinity (ppm)	0.33 ± 0.15	0.27 ± 0.06	0.27 ± 0.06	0.17 ± 0.15	1.963 (0.580)	5.692 (0.058)
TDS (mg L^{-1})	700.33 ± 139.03	628.33 ± 52.65	591 ± 70.15	492 ± 180.36	4.128 (0.248)	**7.446 (0.024)**
Temperature (°C)	11.3 ± 4.5	12.83 ± 4.07	12.6 ± 3.82	12.47 ± 3.93	2.104 (0.551)	1.404 (0.496)
Turbidity (NTU)	20 ± 7.8	12 ± 1	10.67 ± 7.51	3.67 ± 2.25	6.163 (0.104)	**9.846 (0.007)**
Ammonia (mg L^{-1})	0.04 ± 0.02	0.05 ± 0.04	0.05 ± 0.04	0.05 ± 0.04	0.538 (0.910)	**7.538 (0.023)**
TN (mg L^{-1})	2.38 ± 0.04	2.28 ± 0.15	2.37 ± 0.02	1.93 ± 0.07	6.590 (0.086)	1.038 (0.595)
Nitrates (mg L^{-1})	0.04 ± 0.02	0.14 ± 0.12	0.17 ± 0.08	0.22 ± 0.04	5.359 (0.147)	2.808 (0.246)
TP (mg L^{-1})	1.65 ± 0.20	1.42 ± 0.3	1.51 ± 0.22	1.35 ± 0.44	1.513 (0.679)	**6.038 (0.049)**
RP (mg L^{-1})	1.13 ± 0.16	1 ± 0.02	0.94 ± 0.07	0.80 ± 0.24	6.795 (0.079)	3.115 (0.211)

H-values with significance levels in parentheses; Significant differences at $p < 0.05$ are indicated in bold

DO dissolved oxygen, *Cond* conductivity, *RP* reactive phosphorus, *TDS* total dissolved solids, *TN* total nitrogen

were significantly different ($p < 0.05$) within seasons (Table 1). Using multiple comparisons, significant differences for ammonia ($z' = 2.550$, $p = 0.032$), pH ($z' = 3.138$, $p = 0.005$), total phosphorus ($z' = 2.451$, $p = 0.043$) and temperature ($z' = 2.402$, $p = 0.049$) were observed between the hot-wet and hot-dry seasons.

Community structure and metric responsiveness

Macroinvertebrates

A total of 30 macroinvertebrates families belonging to eight orders were recorded during the study period (Table S1). Chironomidae, Culicidae and Hydroptilidae were the most dominant macroinvertebrate families forming >60% abundance. Macroinvertebrate taxa richness increased in a downstream trend. The %EPT, %Trichoptera, %Ephemeroptera and EPT/Chironomidae ratio were zero at site 1 and high at sites 3 and 4 (Table 2). The diversity indices (Margalef, Shannon–Wiener, Simpsons), SASS5 and ASPT scores all increased at downstream sites, whereas, %Diptera decreased (Table 2). Based on the SASS5 and ASPT scores, the water quality ranged from very poor to fair. Significant differences were observed for %Trichoptera ($H = 8.303$, $p = 0.040$) across the study sites, whereas significant seasonal differences were observed for taxa richness ($H = 6.598$, $p = 0.037$) and the Margalef diversity index ($H = 6.038$, $p = 0.049$) (Table 2).

Diatoms

Eighty-four diatom taxa belonging to 35 genera were recorded across four study sites and seasons, with *Nitzschia*, *Navicula*, *Gomphonema* and *Craticula* being the most dominant groups (Table S2). Diatom species richness per sites ranged from 11 to 27 taxa, with the species richness increasing at downstream sites. The most frequently occurring species were *Tryblionella fasciculata* Agardh (100%), *Gomphonema pumilum* Reichardt (83%), *Sellaphora pupula* Kützing (75%), *Gomphonema parvulum* Kützing (75%) and *Craticula accomoda* Hustedt (67%) (Table S2).

Spearman rank correlation showed that most physico-chemical variables were strongly related ($p < 0.05$) to macroinvertebrate and diatom community metrics and diversity indices (Table 3). Strongly pollutant-tolerant species dominated sites 1 and 2. Most class A species (e.g. *Achnanthes standeri* Cholnoky, *Eunotia* spp. and *Pinnularia divergens* Smith) which prefer clean waters were dominant at the downstream sites 3 and 4 during the hot-wet and cool-dry seasons. Species belonging to three diatoms classes, A, B and D, increased in frequency of occurrence from sites 1 to 4, while species belonging to class C species declined downstream. All sites and seasons were found to be very similar ($p > 0.05$) in terms of diatom classes (Table 2) and were very poor in terms of water quality.

Table 2 Macroinvertebrates and diatom community metrics (mean ± standard deviation) for the four study sites recorded on the Ngamo River

Metric	Site				Kruskal–Wallis	
	1	2	3	4	Site	Season
Macroinvertebrates						
Taxa richness	5.3 ± 4.2	7.7 ± 3.8	6.7 ± 3.5	11.7 ± 4.5	3.770 (0.287)	**6.598 (0.037)**
%EPT	0	40.1 ± 20.9	53.2 ± 18.6	22.2 ± 19.4	7.533 (0.057)	0.389 (0.823)
%Trichoptera	0	40.1 ± 20.9	51.6 ± 17.5	14.7 ± 12.7	**8.303 (0.040)**	0.389 (0.823)
%Ephemeroptera	0	0	1.6 ± 2.8	7.5 ± 6.9	4.992 (0.172)	2.054 (0.358)
%Diptera	95.6 ± 5.6	49.4 ± 27.7	36.7 ± 16.5	58.0 ± 29.1	5.974 (0.113)	2.000 (0.368)
EPT/Chironomidae ratio	0	3.8 ± 5.4	2.2 ± 1.2	0.9 ± 0.9	4.935 (0.177)	1.530 (0.465)
SASS5 score	18.7 ± 25.5	33 ± 24.2	24 ± 18.7	54.0 ± 28.6	4.863 (0.182)	5.239 (0.073)
ASPT score	2.4 ± 2.1	4.0 ± 1	3.7 ± 1	4.3 ± 1.0	3.487 (0.323)	5.133 (0.077)
Shannon–Wiener index	0.7 ± 0.2	1.1 ± 0.2	1.2 ± 0.3	1.6 ± 0.5	7.205 (0.066)	2.000 (0.368)
Simpson index	0.4 ± 0.1	0.6 ± 0.1	0.6 ± 0.1	0.7 ± 0.1	7.308 (0.063)	1.500 (0.472)
Margalef	0.9 ± 0.7	1.3 ± 0.5	1.1 ± 0.6	2.1 ± 0.9	4.231 (0.238)	**6.038 (0.049)**
Diatoms						
Class A (%)	6.8 ± 9.6	3.2 ± 2.6	11.1 ± 3.1	14.2 ± 8.6	4.471 (0.230)	4.501 (0.093)
Class B (%)	17.2 ± 4.1	35.4 ± 8.4	33.3 ± 7.2	34.6 ± 9.4	4.183 (0.105)	2.436 (0.130)
Class C (%)	65.5 ± 1.7	41.9 ± 3.5	33.3 ± 5.8	30.6 ± 1.2	3.250 (0.221)	1.422 (0.257)
Class D (%)	10.3 ± 4.5	19.3 ± 5.5	22.2 ± 8.1	20.4 ± 0.8	1.019 (0.391)	2.501 (0.513)

H-values with significance levels in parentheses; significant differences at $p < 0.05$ are indicated in bold

Diatom classes: *A* clean water i.e. no pollution, *B* moderately polluted, *C* strongly polluted, *D* electrolyte rich

Relationship between water quality and biological indicator

Macroinvertebrates

The CCA analysis identified two variables, reactive phosphorus (RP) and TN concentrations, as significantly important ($p < 0.01$) in explaining macroinvertebrate community structure accounting for 43.9% of species variance. CCA axes 1 and 2 accounted for 24.7 and 19.2% variance, respectively. Reactive P and TN were positively associated with the second axis. The CCA axes 1 and 2 separated the sites into roughly four groups based on season, location and pollution levels. Hot-wet (sites 1, 2) and cool-dry (sites 2, 3) seasons were associated with Elmidae, Pyralidae and Hydroptilidae, and were positively associated with axis 1 and 2 being characterised by high TP and RP (Fig. 2a). Cool-dry (sites 1, 2, 3) and hot-dry (sites 1, 4) were associated with pollution-tolerant Oligochaetae, Syrphidae and Culicidae. On the other hand, hot-wet (site 4) and cool-dry (site 3) seasons were associated with pollution-sensitive taxa such as Notonectidae, Caenidae, Pleidae, Coenagrionidae and Veliidae (Fig. 2a).

Diatoms

CCA analysis of the first two axes explained 31.3%, with axes 1 and 2 explaining 16.7 and 14.6%, respectively, of the total diatom community. The RP concentration was highly negatively associated with the first axis. Similar to macroinvertebrate community analysis, the CCA axes 1 and 2 separated the sites into roughly four groups based on season, location and pollution levels. Site 4 during the hot-dry season was generally characterised by low RP (Fig. 2b) and was associated with species such as *Encyonopsis subminuta, Navicula arvensis* var. *maios, Nitzschia communis* and *Placoneis dicephala.* Cool-dry season, sites 2, 3 and 4, were associated with diatom species such as *Nitzschia pura, Pseudostaurosira brevistriata* and *Rhoicosphenia abbreviata.* Most of the study sites were associated with pollution-tolerant taxa *Gomphonema*, *Navicula* and *Nitzschia* (Fig. 2b).

Discussion

The current study managed to highlight that the Ngamo River was in a very poor state using a combined approach of nutrients, diatom and macroinvertebrate community

Table 3 Spearman correlation coefficient between physico-chemical variables vs community metrics and diversity indices along the Ngamo River

	Temperature	Turbidity	Ammonia	TN	Nitrate	TP	RP	PH	DO	TDS	Conductivity	Salinity
Macroinvertebrates												
Taxa richness	0.66**	−0.74**	−0.57*			−0.69**	−0.62*	0.63*		−0.75**	−0.75**	−0.77**
%EPT					0.56*				−0.59*			
%Trichoptera					0.53*				−0.64*			
%Ephemeroptera		−0.76**		−0.57*			−0.67**					
%Diptera	−0.53*	0.51*			−0.55*		0.61*					
EPT/Chironomidae ratio	0.51*											
SASS5 score	0.66**	−0.76**	−0.50*			−0.70**	−0.70**	0.52*		−0.71**	−0.71**	−0.77**
ASPT score	0.67**	−0.60*	−0.578*			−0.60*	−0.55*	0.57*		−0.55*	−0.55*	−0.64*
Shannon–Wiener index		−0.74**					−0.58*			−0.59*	−0.59*	
Simpson Index		−0.69**					−0.57*			−0.57*	−0.57*	
Margalef	0.63*	−0.75**	−0.57*			−0.69**	−0.64*	0.59*		−0.73**	−0.73**	−0.77**
Diatoms												
Class A		−0.79**	−0.52*	0.73**					0.68**			
Class B			−0.58*	0.68**		0.77**				0.51*	0.66**	0.63*
Class C				0.66**			0.80**			0.73**	0.66*	0.54*
Class D		0.73**						0.63*	0.54*			

TN total nitrogen, *RP* reactive phosphorus, *DO* dissolved oxygen, *TDS* total dissolved solids

* Significance levels at $p < 0.05$

** Significance levels at $p < 0.01$

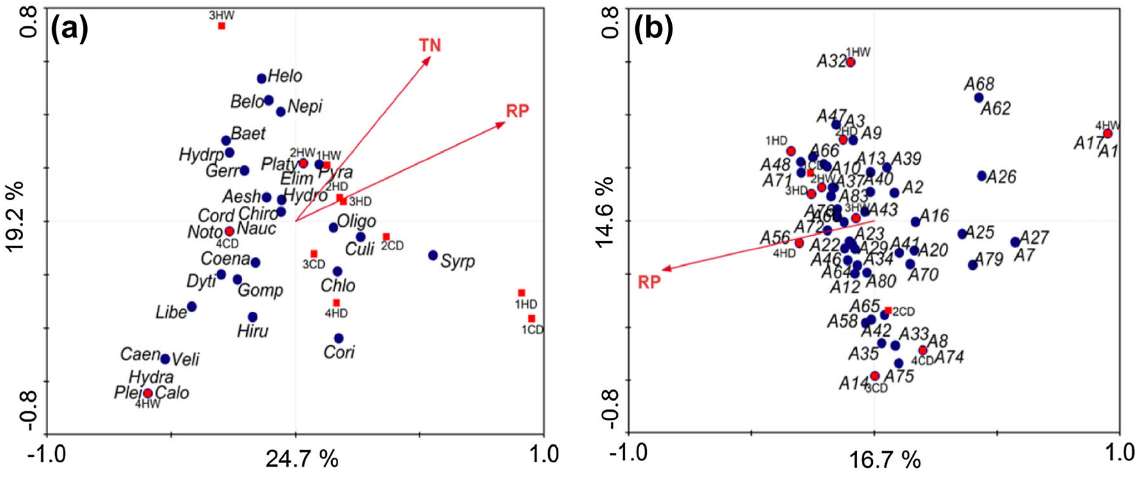

Fig. 2 CCA triplot showing the effects of environmental variables on: **a** macroinvertebrates and **b** diatom community structure in the Ngamo River. *CD* cool-dry, *HW* hot-wet, *HD* hot-dry. The numbers next to the seasons are site numbers. Abbreviations are further highlighted in Tables 1, S1 and S2

assessments and metrics across all study sites and seasons. The use of a combined approach provides important and better information of the river state (Mangadze et al. 2016). Overall, the macroinvertebrate and diatom community metrics were almost similar in their abilities to predict river quality, with macroinvertebrate communities being driven by TP and RP, while diatom communities were driven by RP concentrations. In areas with high RP or TP due to organic pollution, i.e. sewage spillages, only pollution-tolerant taxa, e.g. Diptera, *Gomphonema*, *Navicula, Nitzschia*, were found and sensitive disappeared, e.g. Trichoptera, Ephemeroptera, *Diplonies*, *Sellaphora*. The current results are in agreement with other studies (e.g. Ometo et al. 2000; Tudesque et al. 2014; Teittinen et al. 2015; Bere et al. 2016a, b; Dalu et al. 2016, 2017a, b) that predict catchment activities greatly impacts on river state.

Nutrients were significantly high across the study sites, which could be attributed to raw sewage discharge and agriculture. These findings are similar to those observed by Bere and Nyamupingidza (2014) and Teittinen et al. (2015) who found that urban streams generally had high nutrients due to sewage pollution. There were differences with regard to levels of nutrient enrichment depending on seasonal variation that causes dilution of the raw sewage from burst pipes or partially treated sewage discharged from treatment works by the rain water. The continuous sewage input into the river resulted in a marked increase in ammonia and nitrates in hot-dry season as there was also no dilution (Nhiwatiwa et al. 2017; Dalu et al. 2017a).

The fact that one or more sites had high catchment impact suggests that local river conditions may exert an important influence on biotic richness (Ometo et al. 2000). High Diptera larvae abundance within the study sites was probably due to organic pollution and this was coupled by high relative abundance of Oligochaetes (Ndebele-Murisa 2012). These taxa are highly adapted to organic pollution, and hence they can survive in highly polluted waters (Brinkhurst and Kennedy 1965; Kazanci and Girgin 1998). The CCA analysis highlighted that many of these physico-chemical variables (e.g. TN, RP) were found to impact significantly on the benthic macroinvertebrate community. However, the unexplained variation might be a result of other unmeasured physico-chemical variables, e.g. substratum embeddedness, water velocity and heavy metals.

The diatom assemblages within the Ngamo River were dominated by a few genera such as *Navicula*, *Nitzschia* and *Gomphonema*, which agrees with observations similar to other studies (Kelly and Whitton 1995; Teittinen et al. 2015). The fact that the river system was dominated by strong pollution-tolerant species reflects that the river quality was in very poor state. Diatom species richness was low at the first two sites as there were closer to catchment impacts i.e. agriculture and urban area. These sites were strongly polluted and only few diatom genera such as *Gomphonema*, *Navicula* and *Nitzschia* could tolerate these extremes of pollution.

In conclusion, using a multivariate combined approach of nutrients and diatom and macroinvertebrate community metrics and biological indices allowed going further in the river ecological diagnostic of the Ngamo River and facilitated the consideration of the biological communities compartment into decision-making processes related to river conservation and restoration. The different catchment activities, e.g. agriculture and sewage spillages, had a significant implication to the river state and had a huge impact on the river water quality, benthic diatom and macroinvertebrate communities. Therefore, it is of paramount importance to understand the catchment processes that cause changes in river ecosystems as a result of land use. This relatively pilot study in an understudied region of the world highlighted that the river state of the Ngamo River was very poor. We advocate for further studies to quantify the impact of the urban area and agriculture on the entire river system catchment through increased sampling sites and assessing nutrient loading over time and space.

Acknowledgements The study was funded by the Aquatic Ecology Laboratory, University of Zimbabwe. Tatenda Dalu is a Claude Leon Post-Doctoral Research Fellow. We would like to thank the technical staff of the Department of Biological Sciences, University of Zimbabwe, for assisting with all logistical and technical support. Special thanks go to Antelope park manager G Jones and the staff for their full support in data collection.

Compliance with ethical standards

Conflict of interest All authors declare that no conflict of interests exists.

References

Bellinger EG, Sigee DC (2010) Freshwater algae identification and use as bioindicators. Wiley, Chichester

Belore ML, Winter JG, Duthie HC (2002) Use of diatoms and macroinvertebrates as bioindicators of water quality in southern Ontario Rivers. Can Water Resour J 27:457–484

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 33(2):279–284

Bere T, Mangadze T (2014) Diatom communities in streams draining urban areas: community structure in relation to environmental variables. Trop Ecol 55:271–281

Bere T, Nyamupingidza B (2014) Use of biological monitoring tools beyond their country of origin: a case study of the South African Scoring System Version 5 (SASS5). Hydrobiologia 722:223–232

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

Bere T, Dalu T, Mwedzi T (2016b) Detecting the impact of heavy metal contaminated sediment on benthic macroinvertebrate communities in tropical streams. Sci Total Environ 572:147–156

Brinkhurst RO, Kennedy CR (1965) Studies on the biology of the Tubificidae (Annelida, Oligochaeta) in a polluted stream. J. Anim Ecol. 34:429–443

Clesceri LS, Greenberg AE, Eaton AD (1998) Standard Methods for the Examination of Water and Wastewater, 20th edn. American Public Health Association, American Water Works Association and Water Environment Federation, Washington

Dallas HF (1997) A preliminary evaluation of aspects of SASS (South African Scoring System) for the rapid bioassessment of water quality in rivers, with particular reference to the incorporation of SASS in a national biomonitoring programme. South Afr J Aquat Sci 23:79–94

Dalu T, Froneman PW (2016) Diatom based water quality monitoring in Africa: challenges and future prospects. Water SA 42:551–559

Dalu T, Clegg B, Nhiwatiwa T (2012) The macroinvertebrate communities associated with littoral zone habitats and the influence of environmental factors in Malilangwe Reservoir, Zimbabwe. Knowl Manag Aquat Ecosyst 406:6

Dalu T, Bere T, Richoux NB, Froneman PW (2015) Assessment of the spatial and temporal variation in periphyton communities along a small temperate river system: a multimetric and stable isotope analysis approach. S Afr J Bot 100:203–212

Dalu T, Bere T, Froneman PW (2016) Assessment of water quality based on diatom indices in a small temperate river system: a case of the Kowie River, South Africa. Water SA 42:183–193

Dalu T, Wasserman RJ, Magoro ML, Mwedzi T, Froneman PW, Weyl OLF (2017a) Variation partitioning of benthic diatom community matrices: effects of multiple variables on benthic diatom communities in an Austral temperate river system. Sci Total Environ 601:73–82

Dalu T, Wasserman RJ, Tonkin JD, Alexander ME, Dalu MTB, Motitsoe SN, Manungo KI, Bepe O, Dube T (2017b) Assessing drivers of benthic macroinvertebrate community structure in African highland streams: an exploration using multivariate analysis. Sci Total Environ 601:1340–1348

De la Rey PA, Taylor JC, Laas A, Van Rensburg L, Vosloo A (2004) Determining the possible application value of diatoms as indicators of general water quality: a comparison with SASS 5. Water SA 30:325–332

Dickens CWS, Graham PM (2002) The South African Scoring System (SASS) version 5 rapid bioassessment method for rivers. Afr J Aquat Sci 27:1–10

Gerber A, Gabriel MJM (2002) Aquatic invertebrates of South African rivers field guide. Institute of Water Quality Studies, Pretoria

Kazanci N, Girgin S (1998) Distribution of Oligochaeta species as bioindicators of organic pollution in Ankara Stream and their use in biomonitoring. Turk J Zool 22:83–88

Kelly MG, Whitton BA (1995) The trophic diatom index: a new index for monitoring eutrophication in rivers. J Appl Phycol 7:433–444

Lepš J, Šmilauer P (2003) Multivariate Analysis of ecological data using CANOCO. Cambridge University Press, Cambridge

Mangadze T, Bere T, Mwedzi T (2016) Choice of biota in stream assessment and monitoring programs in tropical streams: a comparison of diatoms, macroinvertebrates and fish. Ecol Indic 63:128–143

Ndebele-Murisa RM (2012) Biological monitoring and pollution assessment of the Mukuvisi River, Harare, Zimbabwe. Lakes Reserv Res Manag 17:73–80

Nhiwatiwa T, Dalu T, Brendonck L (2017) Impact of irrigation based sugarcane cultivation on the Chiredzi and Runde Rivers quality, Zimbabwe. Sci Total Environ 587–588:316–325

Ometo JPHB, Martinelli LA, Ballester MV, Gessner A, Krusche AV, Victoria RL, Williams M (2000) Effects of land use on water chemistry and macroinvertebrates in two streams of the Piracicaba river basin, south-east Brazil. Freshw Biol 44:327–337

Resende PC, Resende P, Pardal M, Almenda S, Azeiteiro U (2010) Use of biological indicators to assess water quality of the UI River (Portugal). Environ Monit Assess 170:535–544

Soininen J, Könönen K (2004) Comparative study of monitoring South-Finnish Rivers and streams using macroinvertebrates and benthic diatom community structure. Aquat Ecol 38:63–75

Sonneman JA, Walsh CJ, Breen PF, Sharpe AK (2001) Effects of urbanization on streams of the Melbourne region, Victoria, Australia. II. Benthic diatom communities. Freshw Biol 46:553–565

StataCorp (2011) Stata statistical software. Release 12. StataCorp LP, College station

Taylor JC, De La Rey PA, Van Rensburg L (2005) Recommendations for the collection, preparation and enumeration of diatoms from riverine habitats for water quality monitoring in South Africa. Afr J Aquat Sci 30:65–75

Taylor JC, Harding WR, Archibald CGM (2007) An illustrated guide to some common diatom species from South Africa. Report TT 282/07. Water Research Commission, Pretoria

Teittinen A, Taka M, Ruth O, Soininen J (2015) Variation in stream diatom communities in relation to water quality and catchment variables in a boreal, urbanized region. Sci Total Environ 530:279–289

ter Braak CJF, Šmilauer P (2002) CANOCO reference manual and CanoDraw for Windows user's guide: Software for Canonical Community Ordination (version 4.5). Microcomputer Power, Ithaca

ter Braak CJF, Verdonschot PFM (1995) Canonical correspondence analysis and related multivariate methods in aquatic ecology. Aquat Sci 37:130–137

Thirion C, Mocke A, Woest R (1995) Biological monitoring of streams and rivers using SASS4: a user manual. Institute for Water Quality Studies, Department of Water Affairs and Forestry, Pretoria

Tudesque L, Tisseuil C, Lek S (2014) Scale-dependent effects of land cover on water physico-chemistry and diatom-based metrics in a major river system, the Adour-Garonne basin (South Western France). Sci Total Environ 466:47–55

Wong AWM, Wong MH (2003) Recent socio-economic changes in relation to environmental quality of the Pearl River delta. Reg Environ Change 4:28–38