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Research paper

Responses of macroinvertebrate community metrics to urban pollution in semi-arid catchments around the city of Bulawayo, Zimbabwe

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River health monitoring is becoming increasingly important because of the anthropogenic activities that continue to impact on water quality and biodiversity of aquatic systems. This study aimed at identifying and evaluating macroinvertebrate community-based metrics that best respond to degradation due to urban pollution in riverine systems of Bulawayo, Zimbabwe. Data (physicochemical variables and macroinvertebrate specimens) were collected from 17 sites over 3 seasons. The sites were selected across an impairment gradient comprising less impacted, moderately impacted and heavily impacted sites. Heavily impacted sites had the highest levels of total dissolved solids, conductivity, salinity, turbidity, total phosphates, total nitrogen, chemical oxygen demand and sedimentary zinc. Dissolved oxygen was significantly highest in less impacted sites. Sensitivity of 24 macroinvertebrate metrics to this impairment gradient were assessed. A total of 5 metrics were identified as sensitive to modifications in water quality due to urban pollution. These metrics were taxon richness, South African Scoring System (SASS5) score, average score per taxon (ASPT), percentage collectors and percentage scrapers. The selected metrics will be useful for the monitoring and assessment of the studied riverine systems and can be further integrated into one multimetric index that combines a range of indices and allows the integration of ecological information for better management of aquatic ecosystems in this region.

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INTRODUCTION

The adverse impacts of human actions on aquatic ecosystems have provoked global calls for the better management of these ecosystems and development of monitoring techniques (Cao et al., 1996; Adams, 2002; Bere, 2016; Dolédec and Statzner, 2010; Hodkinson and Jackson, 2005). There are converging ideas on the utilization of inhabitant organisms in aquatic systems to monitor the ecological conditions of ecosystems (biomonitoring) (Siziba, 2017). While biomonitoring has become an international practice, some regions have made significant progress, e.g., Australia, the United States of America, and Europe (Suriano et al., 2011; Dahm et al., 2013; Lorenz et al., 2016). Tropical regions, which include most of the developing countries, have lagged behind in this regard and have often adopted indices developed in other regions (Suriano et al., 2011).

Several macroinvertebrate-based biomonitoring methods and indices have been developed, starting with the saprobic system (Kolkwitz and Marsson, 1909). Other biomonitoring techniques include the Biological Monitoring Working Party Score System – BMWP (Armitage et al., 1983), Family Biotic Index- FBI (Hilsenhoff, 1987), and South African Scoring System – SASS (Dickens and Graham, 2002; Chutter, 1994, 1998). These biomonitoring methods, e.g., the SASS and BMWP are based on presence and absence of aquatic macroinvertebrate families and the tolerance of these to pollution. However, the effectiveness of biotic indices is limited as a measure of overall ecological integrity as it reduces data into one index score. This is problematic as organisms respond differently to various types of degradation in the environment (Monaghan, 2016). Thus, ecological research is moving towards the use of multimetric indices to integrate information from multiple biological organisations to capture a wider variety of responses to various environmental stressors (Collier, 2008; Elliott et al., 2018; Singh and Saxena, 2018). In Europe, the multimetric system approach has been adopted as the main instrument for assessing the ecological quality of water, following proposals established by the European Commission Water Framework Directive (European Commission, 2000).

The multimetric approach consists of several metrics associated with biological attributes like functional feeding groups, species composition, pollution tolerance and trophic structure metrics. These metrics have to undergo rigorous evaluation before inclusion in a multimetric index (Hawkins et al., 2010; Feld et al., 2014; Gonçalves and Menezes, 2011; Suriano et al., 2011; Odume et al., 2012). Inclusion of individual metrics into a multimetric index is dependent on a range of considerations, including the metric sensitivity to the stressor being investigated, seasonal stability, the occurrence in the ecoregion of interest and predictable response to the stressor. The implication is that multimetric indices vary in sensitivity, complexity and region of implementation (Feld et al., 2014; Suriano et al., 2011). Selected metrics are those that show significant change that can be related to the disturbance in a predictable way. Thus, metrics are tested and validated for performance before they are included in the multimetric index for use in a targeted area (Klemm et al., 2002).

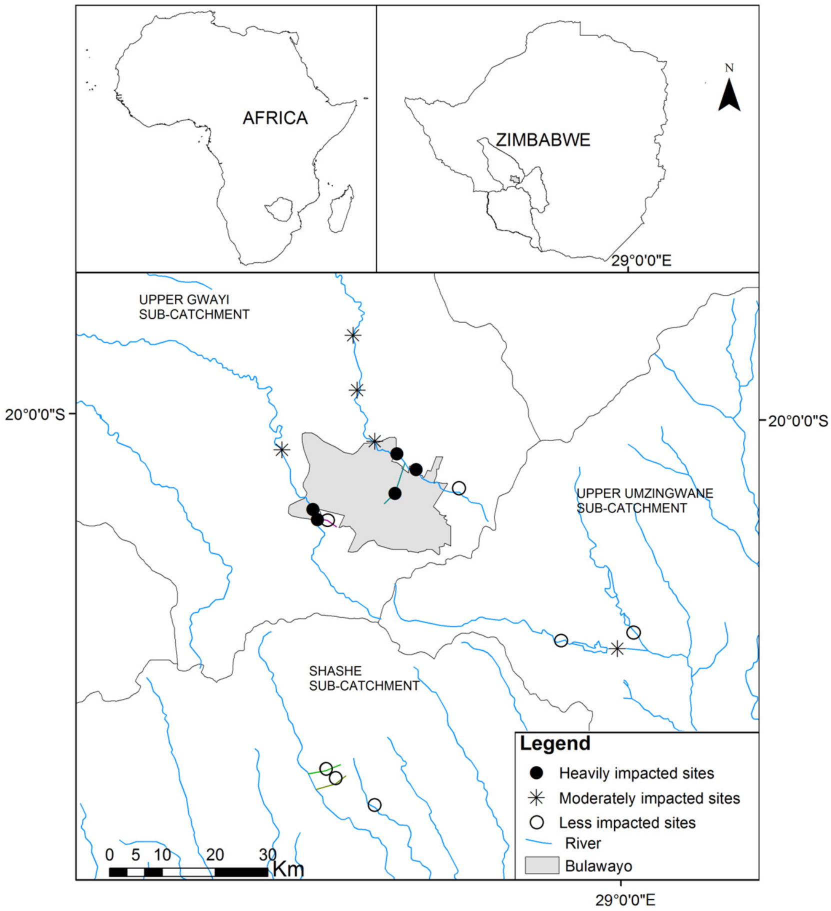

Figure 1. Map showing the study area and sampling sites for macroinvertebrate assemblages

In Zimbabwe, little work has been done on the testing and validation of macroinvertebrate-based metrics used to distinguish water quality between polluted sites and less impacted sites (Bere and Nyamupingidza, 2014). The current study focused on the responses of macroinvertebrate community metrics to urban-induced pollution of riverine systems in semi-arid catchments around Bulawayo, Zimbabwe. The City of Bulawayo is on a watershed of three sub-catchments; Upper Gwayi, Upper Umzingwane and Shashe, with one catchment (Upper Gwayi) being considerably urbanized and impacted. On the other hand, the Upper Umzingwane and Shashe sub-catchments constitute low-density agricultural and protected areas. The different activities within this study area provide a distinct opportunity to evaluate the response of macroinvertebrate metrics to water quality modifications in contrasting land-use settings (Siziba et al., 2017). The objective of this study was to identify and evaluate macroinvertebrate community-based metrics that best respond to degradation due to urban pollution in riverine systems of Bulawayo, Zimbabwe. It is anticipated that this study will be a fundamental step towards the development of a relevant multimetric index for the sustainable management of the riverine systems within this water-stressed region.

METHODS

Study area

The study was done in Bulawayo (Zimbabwe) (Fig. 1). The area is prone to droughts, with a mean annual rainfall of 550 mm and mean annual and minimum temperatures of 25.8°C and 12.7°C, respectively (Mugandani et al., 2013). The city is located on the watershed with most of the rivers in the region radiating from a close proximity to the city. In the upper Gwayi catchment, we sampled the Khami and Umguza Rivers. These rivers drain poorly treated wastewater from Bulawayo. Umzingwane and Ncema Rivers were sampled in the Upper Umzingwane catchment – a catchment that is not affected by wastewater from the City of Bulawayo. Maleme and Hovhi Rivers were sampled in the Shashe catchment – the rivers flow through the Matobo National Park and surrounding areas with very low population densities. A field reconnaissance survey was used for the selection of 17 sites (Fig. 1) that were sampled 3 times in 2015, i.e., hot wet season (February), hot dry season (October) and cold dry season (July).

Measurement of physicochemical variables

In the field, water samples (500 mL, n = 3) were collected at each site, using acid-cleaned polyethylene containers at a depth of 20–30 cm, and fixed with 3 drops of concentrated sulphuric acid. The samples were transported to the laboratory for analyses. The parameters measured on site include: (i) dissolved oxygen (DO) and temperature using a portable dissolved oxygen meter (AMI 605, Martini Instruments, USA); (ii) pH, electrical conductivity (EC) and total dissolved solids (TDS) using a portable pH/conductivity/TDS combination meter (MW801, Milwaukee, USA); (iii) water velocity using a flow velocity meter (FP 201 global flow probe, USA); and (iv) turbidity using a turbidity meter (MI415, Martini Instruments, USA). Sediment samples were also collected at each site using a sediment grab sampler (1.5 kg, n = 2, depth of ~5–10 cm) and transferred into polyethylene ziplock bags. These were oven-dried at 60°C in the laboratory until constant weight was attained.

In the laboratory, the nesslerization method (APHA, 1988) was used for determining total phosphates (TP) in water samples. The amount of total nitrogen (TN) in water was determined by oxidising nitrogenous compounds to nitrate following the method of Korroleff (1972). Biological oxygen demand (BOD) and chemical oxygen demand (COD) were determined by oxidation of potassium dichromate following Jirka and Carter (1975). The two-staged nitric acid, perchloric acid method (APHA, 1988) was used for digesting sediment samples. A flame atomic absorption spectrophotometer (Varian Australia Pty Ltd, Victoria Australia) was then used in determining total concentrations of copper (Cu), lead (Pb), cobalt (Co), chromium (Cr), zinc (Zn), nickel (Ni) and cadmium (Cd) in the sediment and water samples.

Macroinvertebrate sampling

At each sampling site, macroinvertebrates were collected using a macroinvertebrate net (mesh size 1 000 µm) following the South African Scoring System Version 5 (SASS5) protocol (Dickens and Graham, 2002). The samples were pooled into one composite sample. Macroinvertebrates were identified in the field to family (in some cases class) level using keys by Barbour et al. (1999), Gerber and Gabriel (2002), De Moor et al. (2003a), and De Moor et al. (2003b). Those macroinvertebrates that could not be identified in the field were preserved in 70% alcohol and transported to the laboratory for identification. The number of taxa and abundance of each taxa present at each site were counted and recorded.

Data analysis

Data from the different seasons were combined following studies by Clarke et al. (2002) and Humphrey et al. (2000) and recommendations by Cao and Hawkins (2011) in developing indices. We used multidimensional scaling (MDS) based on environmental variable data to assess the similarity of sampled sites. Data was log transformed to improve normality before ordinations were done. Using this method, the sites were grouped into 3 clusters according to the level of pollution. Differences in the physicochemical characteristics of these sites were tested through one-way analysis of variance (ANOVA) with Tukey's post-hoc test after data were tested for normality and homogeneity of variance using Kolmogorov–Smirnov and Levene's tests, respectively.

Macroinvertebrate data were used in calculating a total of 24 metrics (commonly used in Zimbabwe) belonging to 4 metric categories (composition measures, diversity measures, functional measures and tolerance measures) for each site (Table 1). Metrics were assessed for their ability to discriminate between less impacted and heavily impacted sites, following Jun et al. (2012). Metrics with low values across sites were left out at this stage because they poorly discriminated between sites. Box and whisker plots were then used to assess metrics' potential to differentiate less impacted and heavily impacted sites. The assessment was based on the extent of median and inter-quartile range overlap of the less impacted and heavily impacted sites. Metrics that did not have overlaps in inter-quartile range and that showed gradual change through the moderately impacted category were regarded as having strong discriminatory power. A redundancy check (using Spearman's correlation analysis, $r > 0.80$, $p < 0.05$) within each metric category was conducted for metrics that met this criterion. The sensitivity of each of these metrics to environmental changes was then finally assessed using Spearman's correlation analysis (Cao et al., 1996, Baptista et al., 2013, Hering et al., 2006).

RESULTS

Site classification and environmental characteristics

Multidimensional scaling (MDS), based on environmental variable data (Fig. 2), grouped the sites into three groups. Group 1 consisted of heavily impacted sites and these sites were within the urban areas. Group 2 consisted of moderately impacted sites and these sites were generally further downstream of urban areas. Group 3 consisted of less impacted sites and consisted of rivers that were not impacted by wastewater from Bulawayo.

Of the 24 physicochemical variables that were assessed, 5 variables – Cu, Co, Cd, Zn and Ni – from the water column were not detectable by the atomic absorption spectrophotometer (<0.01 mg/L). These variables were therefore left out of the subsequent analyses. Significant differences among site categories were observed in DO, water velocity, conductivity, TDS, salinity, turbidity, TN, TP, COD, BOD and sediment Zn, le Ni, Cr, Ni and Pb (ANOVA, $p < 0.05$, Table 2). DO and sediment Zn and Ni differed significantly among all the site categories (Tukey's, p <0.05). Dissolved oxygen was highest for less impacted sites and lowest for heavily impacted sites, while sediment Zn and sediment Ni were lowest at less impacted sites and highest at the heavily impacted sites. Water velocity, conductivity, TDS, salinity and sediment Cr and Ni were significantly lower at the less impacted sites (Tukey's, $p < 0.05$), relative to the other two site categories which did not vary. Heavily impacted sites had significantly higher turbidity, TN, TP, COD and BOD (Tukey's, $p < 0.05$) relative to the other two site categories which did not vary. Sediment Pb was significantly higher at the moderately impacted sites (Tukey's, $p < 0.05$) relative to the other two site categories which did not vary.

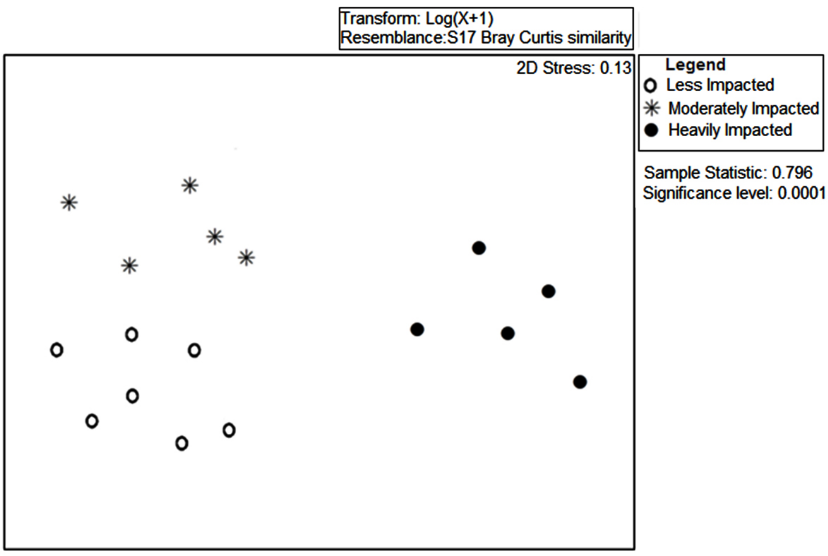

Figure 2. Multi-dimensional scaling of sampled sites based on environmental variables

Table 1. Metrics used in this study and studies that have applied them in Zimbabwe

Metric	Description	Studies that have used the metric in Zimbabwe
	Composition measures	
Diptera family	Number of families belonging to the order Diptera	Nhiwatiwa et al. (2009); Anusa et al. (2012); Moyo and Phiri (2002); Mwedzi et al. (2017)
Plecoptera family	Number of families belonging to the order Plecoptera	Nhiwatiwa et al. (2009)
Trichoptera family	Number of families belonging to the order Trichoptera	Chakona et al. (2008); Chakona et al. (2009); Moyo and Phiri (2002); Mwedzi et al. (2017); Nhiwatiwa et al. (2009)
Ephemeroptera family	Number of families belonging to the order Ephemeroptera	Anusa et al. (2012); Chakona et al. (2008); Moyo and Phiri (2002); Mwedzi et al. (2017); Nhiwatiwa et al. (2009)
% Coleoptera	Proportion of beetles present in an ecosystem	Moyo and Phiri (2002); Mwedzi et al. (2017); Nhiwatiwa et al. (2009); Siziba et al. (2017)
% Diptera	Proportion of dipterans present in the ecosystem	Phiri (2000); Siziba et al. (2017); Bere et al. (2016b)
% EPT	Proportion of mayflies, stoneflies and caddisflies families present in the ecosystem	Siziba et al. (2017)
% Ephemeroptera	Proportion of mayflies present in the ecosystem	Nhiwatiwa et al. (2009); Phiri (2000); Siziba et al. (2017); Bere et al. (2016b)
% Odonata	Proportion of dragonflies and damselflies present in the ecosystem	Moyo and Phiri (2002); Siziba et al. (2017)
% Plecoptera	Proportion of stoneflies present in the ecosystem	
% Trichoptera	Proportion of caddisflies present in the ecosystem	Mhlanga and Siziba (2006); Bere et al. (2016b); Phiri (2000)
EPT Taxa	Total number of families belonging to the orders Ephemeroptera, Plecoptera, or Trichoptera	Chakona and Marshall (2008)
Baetidae/ Ephemeroptera ratio	A measure of the ratio of the abundance of the family Baetidae to the entire Ephemeroptera order	Bere et al. (2016b)
	Diversity measures	
Taxon richness	Number of different species represented in an ecological community	Mwedzi et al. (2016b), Mwedzi et al. (2017); Mwedzi et al. (2016a); Chakona and Marshall (2008); Chakona et al. (2008); Chakona et al. (2009); Dalu et al. (2012); Dube et al. (2010); Mudyazhezha and Kanhukamwe (2014); Bere and Nyamupingidza (2014); Phiri (2000); Bere et al. (2016a); Nhiwatiwa et al. (2017b); Nhiwatiwa et al. (2017a); Siziba (2017)
Evenness	A measure of how equal the community is i.e. the similarity of frequencies of the different units making up a popoulation	Bere et al. (2016b); Chakona et al. (2009); Mwedzi et al. (2017); Bere et al. (2016a); Dalu et al. (2012); Utete and Kunhe (2013); Chakona and Marshall (2008); Mudyazhezha and Kanhukamwe (2014); Nhiwatiwa et al. (2017b); Dube et al. (2010)
Shannon-Wiener index	A mathematical measure of species diversity in a community accounting for both abundance and evenness	Anusa et al. (2012); Mwedzi et al. (2016b); Mwedzi et al. (2016a); Chakona et al. (2009); Dalu et al. (2012); Mwedzi et al. (2017); Bere et al. (2016b); Mudyazhezha and Kanhukamwe (2014); Utete and Kunhe (2013); Chakona et al. (2008); Chakona and Marshall (2008); Bere et al. (2016a); Dube et al. (2010); Phiri (2000); Nhiwatiwa et al. (2017b); Moyo and Rapatsa (2016)
Simpson	A mathematical measure of species diversity in a community accounting for the number of species present, as well as the abundance of each species.	Chakona and Marshall (2008); Dalu et al. (2012); Moyo and Phiri (2002); Phiri (2000)
	Functional measures	
% Collectors	Proportion of organisms that physically gather food, or construct netlike structures to catch food present in the ecosystem	Phiri et al. (2011); Chakona and Marshall (2008); Mwedzi et al. (2016b); Nhiwatiwa et al. (2017a)
% Filters	Proportion of organisms that consume very small pieces of detritus (<1 mm) present in the ecosystem	Nhiwatiwa et al. (2017a); Chakona and Marshall (2008); Phiri et al. (2011)
% Shredders	Proportion of organisms that chew on intact or large pieces (>1 mm) of plant material present in the ecosystem	Mwedzi et al. (2016b); Nhiwatiwa et al. (2017a)
% Scrapers	Proportion of organisms that scrape off and consume thin layer of algae growing on solid substrates in shallower waters present in the ecosystem	Mwedzi et al. (2016b); Chakona and Marshall (2008); Nhiwatiwa et al. (2017a)
% Predators	Proportion of organisms that feed on living animals present in the ecosystem	Chakona and Marshall (2008); Nhiwatiwa et al. (2017a); Phiri et al. (2011); Mwedzi et al. (2016b)
Tolerance measures		
ASPT value	Equals the average sensitivity of the families of the organisms' present ranges from 0 to 10.	Anusa et al. (2012); Mwedzi et al. (2016b); Mwedzi et al. (2017); Gratwicke (1998); Mudyazhezha and Kanhukamwe (2014); Utete and Kunhe (2013); Bere et al. (2016b); Bere and Nyamupingidza (2014); Dube et al. (2010); Nhiwatiwa et al. (2017b); Phiri (2000)
SASS score	Total score for each taxon after the summations of assigned tolerance /sensitivity scores	Anusa et al. (2012); Gratwicke (1998); Mwedzi et al. (2016a, b); Mwedzi et al. (2017); Bere et al. 2016; Bere and Nyamupingidza (2014); Chikodzi et al. (2017); Dube et al. 2010; Mangadze et al. (2017); Nhiwatiwa et al. (2017); Phiri (2000); Utete and Kunhe (2013); Ndebele-Murisa Mzime (2012)

Table 2. Physicochemical characteristics of the different sampling categories (mean ± std. error of mean)

Variable	Less impacted sites	Moderately impacted sites	Heavily impacted sites
Water velocity (m^3/s)	0.50 ± 0.15[a]	1.16 ± 0.17	0.96 ± 0.10
Temperature (°C)	21.78 ± 1.41	23.20 ± 1.25	21.58 ± 1.25
Dissolved oxygen (% saturation)	127.98 ± 12.84[a]	67.72 ± 9.00[b]	29.09 ± 8.63[c]
pH	7.48 ± 0.17	7.85 ± 0.13	8.47 ± 0.09
Turbidity (NTU)	26.14 ± 9.23	23.41 ± 6.78	88.50 ± 16.52[a]
Conductivity (µS/cm)	259.35 ± 46.89[a]	824.38 ± 109.76	993.08 ± 62.91
Total dissolved solids (mg/L)	158.14 ± 32.48[a]	574.78 ± 83.84	712.00 ± 55.27
Salinity (mg/L)	0.13 ± 0.03[a]	0.48 ± 0.06	0.58 ± 0.03
Total nitrogen (mg/L)	0.42 ± 0.06	1.16 ± 0.23	5.25 ± 2.28[a]
Total phosphates (mg/L)	0.39 ± 0.18	0.68 ± 0.15	1.52 ± 0.22[a]
COD (mg/L)	48.38 ± 16.45	54.00 ± 9.61	157.33 ± 24.87[a]
BOD (mg/L)	1.28 ± 0.48	2.31 ± 0.70	5.49 ± 1.85[a]
Water lead	0.38 ± 0.02	0.25 ± 0.06	0.19 ± 0.07
Sediment zinc	26.18 ± 8.66[a]	56.65 ± 14.91[b]	70.24 ± 20.36[c]
Sediment copper	6.78 ± 2.07[a]	21.03 ± 6.87	23.44 ± 4.96
Sediment lead	31.86 ± 17.17	186.30 ± 102.86[a]	36.87 ± 11.26
Sediment chromium	11.23 ± 3.03[a]	25.10 ± 5.22.	29.14 ± 5.32
Sediment cadmium	0.67 ± 0.37	1.67 ± 0.98	0.78 ± 0.36
Sediment nickel	11.67 ± 3.12[a]	22.50 ± 3.97[c]	27.82 ± 6.95[b]

Different superscript letters (a, b and c) indicate values that differ significantly from others in the same row (Tukey's HSD, $p < 0.05$*).*

Table 3. Spearman correlation coefficients of measured physicochemical parameters and macroinvertebrate metrics

Variable	Taxon richness	% Collectors	% Scrapers	ASPT	SASS
Water velocity	0.15	0.25	−0.28	−0.05	0.11
Temperature	0.01	−0.29	0.00	0.08	0.06
Dissolved oxygen %	0.32*	−0.51**	−0.03	0.40**	0.32*
pH	−0.06	−0.14	−0.32*	−0.11	−0.13
Turbidity	−0.46**	0.40**	−0.31*	−0.54**	−0.51**
Conductivity	−0.48**	0.29	−0.35*	−0.45**	−0.52**
Total dissolved solids	−0.46**	0.30*	−0.37*	−0.45**	−0.51**
Salinity	−0.42**	0.33*	−0.41**	−0.48**	−0.50**
Total nitrogen	−0.58**	0.52**	−0.38*	−0.61**	−0.66**
Total phosphates	−0.18	0.48**	−0.15	−0.30*	−0.21
Chemical oxygen demand	−0.30*	0.46**	−0.27	−0.36*	−0.30*
Biological oxygen demand	−0.40**	0.19	−0.26	−0.09	−0.35*
Water lead	0.28	−0.06	0.23	0.03	0.20
Sediment zinc	−0.24	0.22	−0.14	−0.20	−0.23
Sediment copper	−0.41**	0.38**	−0.12	−0.30*	−0.42**
Sediment lead	−0.42	0.00	−0.28	−0.01	−0.34*
Sediment chromium	−0.38**	0.38**	−0.20	−0.50**	−0.45**
Sediment cadmium	−0.30*	−0.20	−0.18	0.13	−0.23
Sediment nickel	−0.39**	0.33*	−0.19	−0.38**	−0.44**

**indicates* $p < 0.05$ *and **indicates* $p < 0.01$*; ASPT = average score per taxon; SASS = South African Scoring System score.*

Macroinvertebrate metrics' sensitivity to urban pollution

The first criterion was not met by 11 of the original 24 metrics due to the fact that they had low values that did not enable identification of deterioration in environmental quality. Thus Plecoptera family, Trichoptera family, Ephemeroptera family, % EPT, % Ephemeroptera, % Plecoptera, % Trichoptera, EPT Taxa, Baetidae/Ephemeroptera ratio, % filters and % shredders were dropped at this stage. Of the 13 metrics that were evaluated through the box and whisker criterion, % Coleoptera and evenness showed overlap in interquartile ranges between less impacted and heavily impacted sites (Fig. 3b, e). These metrics were therefore dropped at this stage. Six metrics (Diptera family, % Diptera, % Odonata, Shannon-Wiener index, Simpson's index and % predators) revealed differences between heavily impacted and less impacted sites but failed to show a gradual change in the moderately impacted category (Fig. 3a, d, e, g, h and k, respectively). Diptera family and % Diptera metrics increased in heavily impacted sites while % Odonata, Shannon-Wiener index, Simpson's index and % predators metrics decreased in heavily impacted sites. Only 5 metrics (taxon richness, % collectors, % scrapers, ASPT and SASS score) clearly discriminated less impacted, moderately impacted and heavily impacted sites (Fig. 3c, i, j, l and m, respectively). Percentage collectors showed a gradual increase following degradation in habitat quality due to urban pollution while % scrapers, ASPT, SASS score and taxon richness metrics showed a gradual decrease with increase in habitat degradation due to urban pollution. These metrics were tested for redundancy and none were redundant. They were therefore considered to be potentially suitable for assessing degradation in habitat quality due to urban pollution.

Metrics response to physicochemical variables

The correlations between the selected metrics and physicochemical variables are given in Table 3. All of the 5 remaining metrics correlated with 6 to 12 physico-chemical parameters ($p < 0.05$, Table 3). Percentage collectors increased with corresponding increases in pollution, as shown by increases in turbidity, total dissolved solids, salinity, total phosphates, total nitrogen, chemical oxygen demand and heavy metals (chromium, copper and nickel) (Table 3). These metrics decreased in conditions with less pollution, e.g., with an increase in dissolved oxygen. On the other hand, taxon richness, % scrapers, ASPT and SASS metrics decreased with corresponding increases in physicochemical parameters that indicate pollution (Table 3), e.g., increased turbidity, conductivity, TDS, salinity, TN, TP, COD, BOD and heavy metals (copper, lead, chromium, cadmium and nickel).

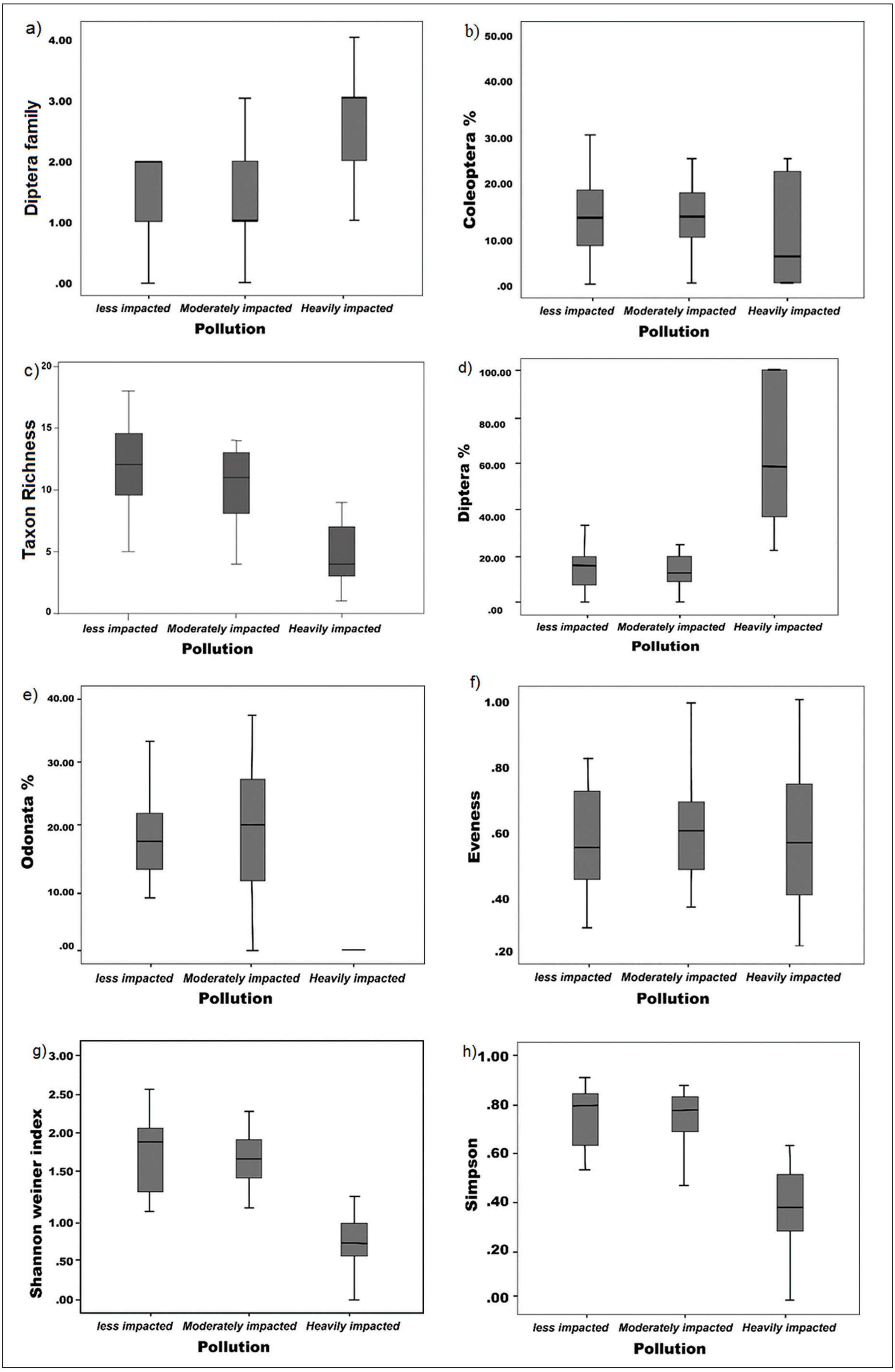

Figure 3. Comparison of selected metric values between the less impacted, moderately impacted and heavily impacted sites. Boxes represent interquartile ranges (25th–75th percentiles), the horizontal solid line represent the median and the error bars represent the standard deviation. Metrics which show interquartile range overlaps for less and heavily impacted sites have poor discriminatory power

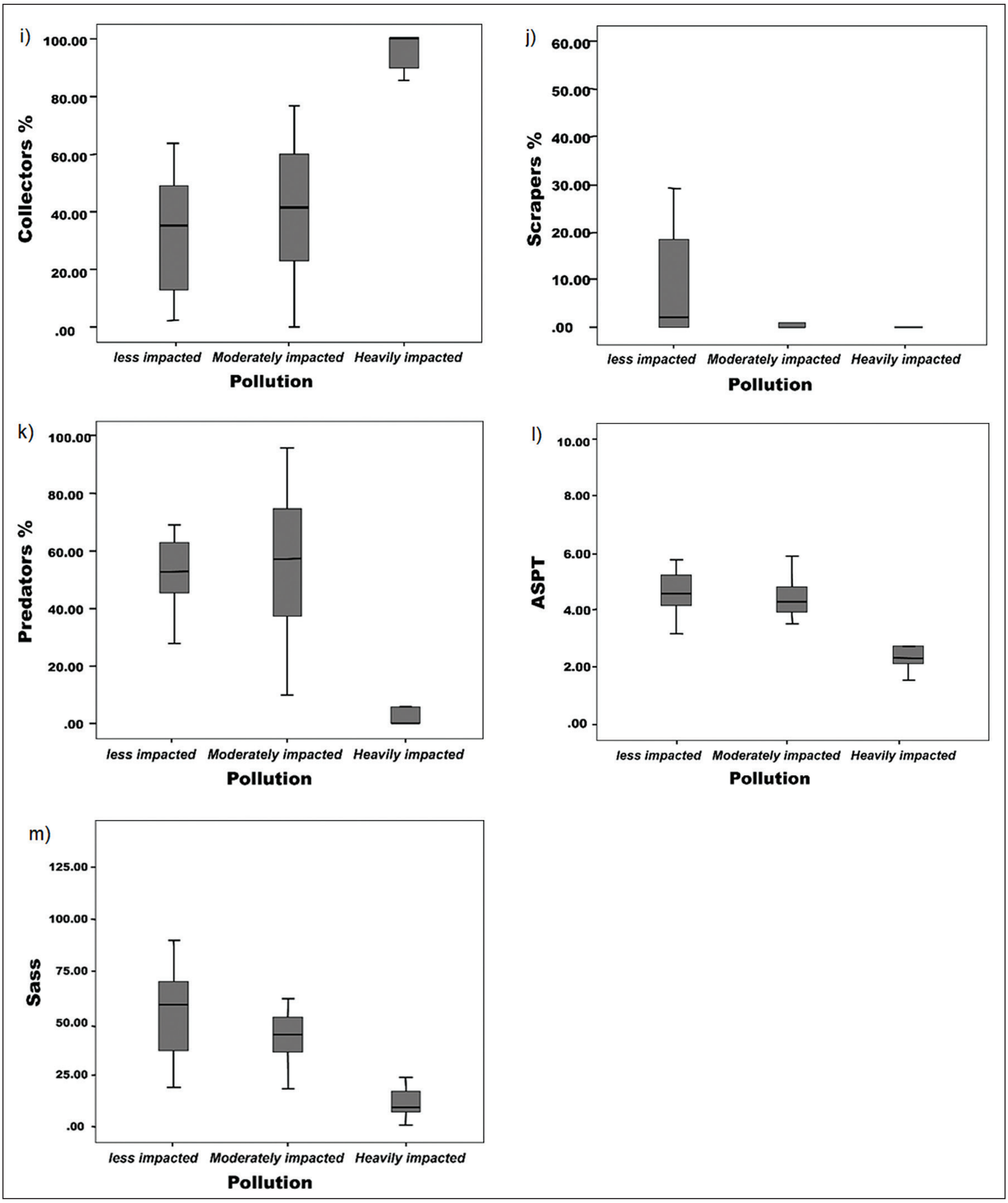

Figure 3 Continued. Comparison of selected metric values between the less impacted, moderately impacted and heavily impacted sites. Boxes represent interquartile ranges (25th–75th percentiles), the horizontal solid line represent the median and the error bars represent the standard deviation. Metrics which show interquartile range overlaps for less and heavily impacted sites have poor discriminatory power

DISCUSSION

The results indicate that urbanization has impacted on the ecological health of the riverine systems receiving the wastewater of Bulawayo. Multidimensional scaling (MDS) based on environmental variable data (Fig. 2) grouped the sampled sites into 3 clusters clearly distinguishing polluted urban sites from the less polluted sites. The relatively higher concentrations of pollutants in Bulawayo's city areas could be due to a high sewage influx and industrial effluents which have become prominent problems in the area (Siziba, 2017). This corroborates other studies that have shown that urban streams countrywide are polluted (Dube et al., 2010; Bere, 2016; Mwedzi et al., 2016b). However, these urban streams often demonstrate some self-purification capacity as the water quality improves along the river course further downstream (Ndebele-Murisa Mzime, 2012). Recovery is mainly attributed to the vegetation along the river course that acts as a sponge, and sediment that acts as a sink for nutrients and pollutants, cleaning up and revitalising the stream (Ndebele-Murisa Mzime, 2012). As a result, the water quality observed further downstream in this study (some kilometres away from the city) had greatly improved and formed another category, i.e., of moderately impacted sites.

The metrics of number of EPT, Baetidae/Ephemeroptera ratio and % EPT taxa were dropped early in the data analysis because their values were too low. Other studies have reported that metrics such as EPT taxa are excellent indicators of habitat quality and environmental degradation as their tolerance levels differ along pollution gradients (Klemm et al., 2002; Weigel et al., 2002; Whittier et al., 2007). However, Bressler et al. (2006) argue that regions have different assemblage characteristics and EPT metrics are only useful when EPT fauna naturally make up large proportions of the fauna. This is not the case in our study area and in tropical Africa in general, e.g., Plecoptera has low taxon richness (Masese and Raburu, 2017; Minaya et al., 2013). Furthermore, studies which have used EPT taxa in tropical Africa have provided mixed results, as a number of Ephemeroptera, Plecoptera and Trichoptera taxa (e.g., Caenidae, Baetidae, Hydropsychidae) can withstand a wide range of environmental deterioration (Minaya et al., 2013; Kasangaki et al., 2008; Kilonzo et al., 2014; Kaboré et al., 2016; Lakew and Moog, 2015). Hence EPT taxa has been reported with high abundances in polluted areas (Masese et al., 2014). It is therefore imperative that the EPT taxa metrics are evaluated and modified to suit local conditions before they can be applied in this region.

Functional metrics are said to be sensitive to changes in the environment, with each feeding group predicted to respond to accumulation of a particular food source (Ramírez and Gutiérrez-Fonseca, 2014; Jun et al., 2012; Merritt et al., 1996). Amongst the selected functional metrics in this study, % collectors and % scrapers were good indicators of urban pollution. Greater abundances of collectors were found at heavily impacted sites (Fig. 3i). This is because of the existence of large amounts of organic matter at such sites. We recorded low values of % shredders and % filters at all sites. Other studies in the tropics have also reported low numbers of shredders (Hyslop and Hunte-Brown, 2012; Mwedzi et al., 2016b). This is attributed to fast decomposition rates owing to the higher temperatures of water in the tropics (Hyslop and Hunte-Brown, 2012; Mwedzi et al., 2016b). Microbial action therefore takes the place of shredders in tropical streams. Consequently, input into tropical streams is usually in the form of fine particulate organic matter (FPOM), that collectors ingest directly. Furthermore, some leaves of tropical trees contain secondary compounds that make them unpalatable for shredders (Jun et al., 2012). Shredders are therefore localised specialists in the tropics, and are therefore not suitable as indicators of degradation in habitat quality (Mwedzi et al., 2016b).

Five metrics (taxon richness, % collectors, % scrapers, SASS5 and ASPT) clearly discriminated between less impacted and heavily impacted sites and did not show any overlap in interquartile ranges. Collectors which feed on fine particulate matter typically increased at highly polluted sites that had large quantities of organic material. This makes the % collectors metric a good indicator of organic pollution, as observed by Weigel et al. (2002).

Taxon richness decreased markedly along the pollution gradient (i.e., from less impacted sites to heavily impacted sites (Fig. 3c). This is in line with the universal paradigm that under environmental degradation aquatic biodiversity declines (Bunn and Arthington, 2002; Gallardo et al., 2011). Given that only a few specialized families can adapt to polluted environments, other metrics like % scrapers, ASPT and SASS5 also decreased at heavily impacted sites (Fig. 3j, l and m, respectively). ASPT and SASS5 are sensitivity metrics that have been shown to respond to habitat degradation, and especially organic pollution, in various studies in southern Africa (Bere and Nyamupingidza, 2014; Mwedzi et al., 2016b; Gratwicke, 1998; Gordon et al., 2015)

Metrics that correlate with at least one environmental variable are usually considered acceptable as they effectively reflect human influence (Jun et al., 2012). The correlation of the 8 metrics with 6 to 12 physicochemical parameters (Table 3) in this study indicates that they are powerful predictors of habitat quality and can easily detect degradation in habitat quality due to urban pollution. The final set of metrics chosen in this study therefore forms a stepping-stone for the development of future multimetric indices relevant to the region. Furthermore, our study shows that only a subset of the metrics used in the region are excellent discriminators of heavily polluted sites and less polluted sites. Metric selection is therefore of paramount importance in assessing pollution in the region as not all metrics are good discriminators of heavily polluted and unpolluted sites.

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