Physics and Chemistry of the Earth 92 (2016) 14–19

Contents lists available at ScienceDirect

Physics and Chemistry of the Earth

journal homepage: www.elsevier.com/locate/pce

Impact of urbanization on the ecology of Mukuvisi River, Harare, Zimbabwe

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ARTICLE INFO

Article history:
Received 23 March 2015
Received in revised form
25 August 2015
Accepted 21 September 2015
Available online 31 October 2015

Keywords:
Pollution
Macroinvertebrates
Water quality
Diversity
Liver

ABSTRACT

The main objective in this study was to compare the physico-chemical characteristics and biota of a river (Mukuvisi) passing through an urban area to that of a non-urbanised river (Gwebi). Five sites in the Mukuvisi River and five sites in the Gwebi River were sampled for water physico-chemical parameters (pH, conductivity, DO, BOD, TDS, ammonia, Cl, SO_4^{2-}, PO_4^{2-}, NO_3^{3-}, F^-, Pb, Cu, Fe, Mn, Zn and Cr) once every month between August, 2012–August, 2013. Cluster analysis based on the physico-chemical parameters grouped the sites into two groups. Mukuvisi River sites formed their own grouping except for one site which was grouped with Gwebi River sites. Principal Component Analysis (PCA) was used to extract the physico-chemical parameters that account for most variations in water quality in the Mukuvisi and Gwebi Rivers. PCA identified sulphate, chloride, fluoride, iron, manganese and zinc as the major factors contributing to the variability of Mukuvisi River water quality. In the Gwebi river, sulphate, nitrate, fluoride and copper accounted for most of the variation in water quality. Canonical Correspondence Analysis (CCA) was used to explore the relationship between physico-chemical parameters and macro-invertebrate communities. CCA plots in both Mukuvisi and Gwebi Rivers showed significant relationships between macroinvertebrate communities and water quality variables. Phosphate, ammonia and nitrates were correlated with *Chironomidae* and *Simulidae*. Gwebi River had higher ($P < 0.05$, ANOVA) macro-invertebrates and fish diversity than Mukuvisi River. *Clarias gariepinus* from the Mukuvisi River had high liver histological lesions and low AChE activity and this led to lower growth rates in this river.

1. Introduction

Urbanization puts unprecedented pressure on lentic and lotic ecosystems. The susceptibility of lotic systems is made worse by their unidirectional nature. Any activity within a river catchment has the potential to cause environmental change and pollutants entering a river are likely to exert effects for a large distance downstream. There has been a substantial increase in nutrient concentrations throughout the world and, globally, fewer than 10% of the rivers can be classified as pristine in terms of their nitrate status as defined by World Health Organisation (i.e. <0.1 mg/l NO_3-N) (Malmqvist and Rundle, 2002).

Streams in urban areas are severely impaired by industrial and sewage effluent. Urban streams are functionally less diverse than undisturbed streams (Meyer et al., 2005). However, information on anthropogenic impacts on streams and rivers in developing countries is patchy. There is a great disparity between fundamental knowledge of riverine ecology in developed and developing countries with only 2% of papers published in international limnological journals between 1987 and 2013 originating from scientists in developing countries.

The city of Harare lies within its catchment area and the Mukuvisi River which passes through the city, is polluted from both point and non-point sources. The limited work done on the ecology of the Mukuvisi River focused on the analysis of physicochemical conditions of water (Zaranyika et al., 1993; Jawarazi, 1997; Mathuthu et al., 1997). The effect of pollution on the biota in Mukuvisi River has generally been ignored with the exception of Moyo and Phiri (2002). Nyamangara et al. (2008) investigated the effect of sewage and industrial effluent on zinc, copper, lead and cadmium concentrations in water and sediment of the Mukuvisi River. They concluded that accumulation of heavy metals is better monitored using sediments than water. The main problem with their approach is that, chemical analysis of water and sediment

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http://dx.doi.org/10.1016/j.pce.2015.09.007
1474-7065/

cannot provide direct indications of the effect of contaminants on the biota. Macroinvertabrates have been widely used in Southern Africa to monitor organic pollution (Chutter, 1994; Dickens and Graham, 2002). Moyo and Phiri (2002) looked at the effect of sewage effluent on macroinvertebrates in the Mukuvisis River. Although this approach focuses on biota, it has been criticized for only indicating severe stress that has already occurred (Adams et al., 2005). Biomarkers have been proposed as a way of detecting stress in biota before community level (e.g. macroinvertebrates) responses (Adams et al., 2005). In this study, the use of liver histopathology and the acetylcholinesterase assay as a biomarker is used for the first time in assessing pollution of the Mukuvisi River. The scarcity of information on a river that is being seriously degraded prompted this study. This study compares the water quality, macroinvertebrate fauna and fish species of two rivers, one heavily polluted (Mukuvisi River) and the other relatively unpolluted (Gwebi River). The Gwebi River has not been affected by industrial activities as it flows along the northern boundaries of the city mainly through commercial agricultural land.

2. Materials and methods

The Gwebi and Mukuvisi originate close to the city of Harare. The Gwebi River rises from the northern boundary of the city while the Mukuvisi rises to the east of the city. Five sampling sites were chosen along both rivers (Fig. 1). Seventeen physicochemical parameters were determined at each of the sites. Temperature, pH, conductivity and total dissolved solids (TDS) were measured on site with a conductivity meter (TSI Model 33). The Winkler method was used to determine dissolved oxygen, iron (Fe), manganese (Mn), Chromium (Cr), lead (Pb), copper (Cu) and zinc (Zn) were determined by atomic absorption spectrophotometry (AAS). Chloride (Cl^-) was determined by a precipitation titrimetric procedure using 0.01 M silver nitrate with a potassium chromate indicator. An ion selective electrode using a total ionic strength-adjusting buffer was used to determine fluoride (F^-). A turbidimetric procedure, using a conditioning reagent and barium chloride dehydrate to precipitate the sulphate from the water was used to measure the concentration of sulphate (SO_4^{-2}). The methods used to determine nitrate (NO_3), ammonia (NH_4) and phosphate (PO_4) are explained in Madera et al. (1982). A hierarchical method, average linkage cluster analysis, was applied to the mean values of the physical and chemical variables for each site using the IBM SPSS version 20.0 statistical package.

Principal component analysis (PCA) was used to determine the water quality parameters that contribute to the water quality variation between the two rivers. Canonical correspondence analysis (CCA) was used to explore the relationship between macroinvertebrates and water quality parameters. Both PCA and CCA were run using the statistical package CANOCO 5. Shannon–Wiener diversity was used to determine the diversity of macroinvertebrates between the two rivers.

Invertebrates were sampled using a hand net, with a mesh size of 2 mm, secured to a 30 cm square frame. A maximum stretch of 20 m was sampled at each site. Most of the macroinvertebrates were identified to the family level using keys from Thirion et al. (1995).

A South Rot VI-A electrofisher powered by a Honda EZ 4500 generator was used to capture fish along the two streams. Each station was fished for 10 min and relative abundance was expressed as catch per effort (no. min^{-1}). Liver tissues from 22 *Clarias gariepinus* individuals caught in the Mukuvisi River and 22 from Gwebi River were embedded in paraffin wax. The liver tissues were then sectioned into 5 μm slices before staining with haematoxylin and eosin. Each slide was scored between 0 and 4 according to methods adapted from Van Dyk et al. (2003). AChE activity was determined in the brain tissue of *C. gariepinus* from the two rivers, following the methods of McLoughlin et al. (2000).

The aticular otoliths were embedded in clear polyester casting resin and then sectioned (0.4 mm). The sections were used to determine the age of *C. gariepinus* from the two river systems. The von Bertallanffy model was used to describe the growth of *C. gariepinus* in the Mukuvisi and Gwebi rivers:

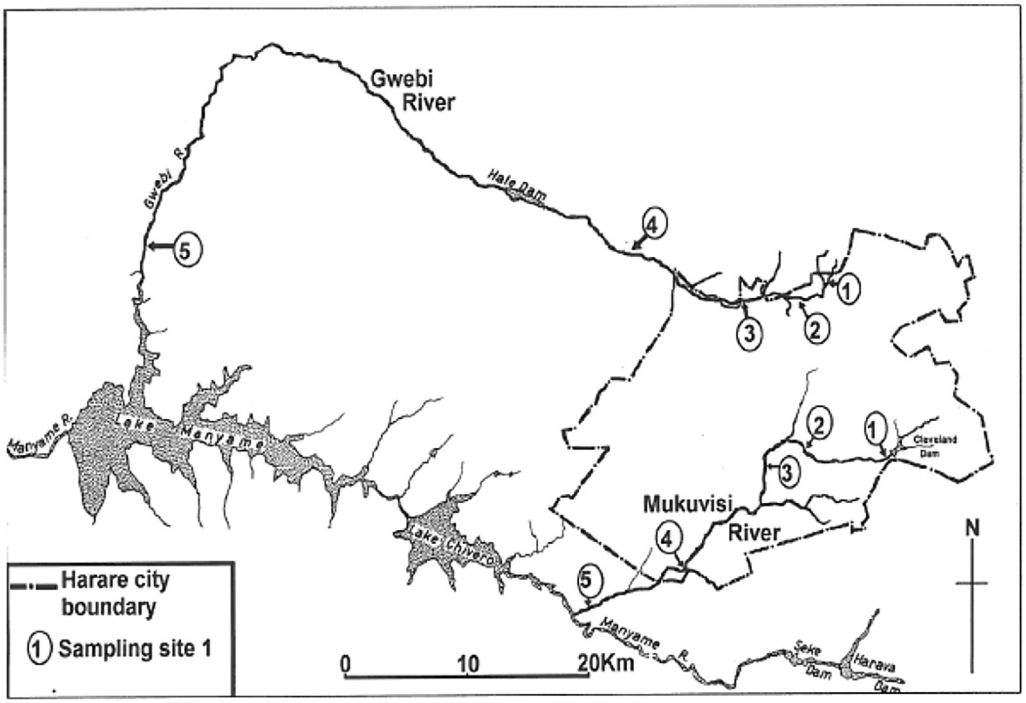

Fig. 1. Study area showing the sampling sites on the Gwebi and Mukuvisi Rivers.

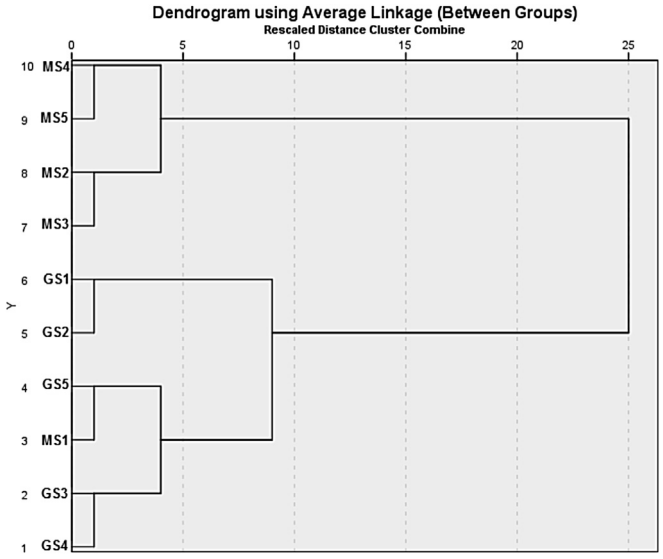

Fig. 2. Dendrogram of the sampling sites clusters along the Mukuvisi and Gwebi Rivers.

$$L_t = L_\infty\left\{1 - \exp^{[-k(t-t0)]}\right\}$$

Where L_t is length at time t
K is growth coefficient
L_∞ is the asymptotic length
t_0 is the hypothetical age at zero length

3. Results

The application of the average linkage cluster analysis on the water quality variables produced two major clusters (Fig. 2). Cluster 1, consisted of MS_2, MS_3, MS_4 and MS_5. Cluster 2 consisted of all the Gwebi River sites (G_1, G_2, G_3, G_4 and G_5) and the MS_1. The two rivers are different with respect to water quality parameters.

PCA showed that the first two components accounted for 92% of the total variation in water quality. PC1 accounted for 87% of the variation (Table 1) and was associated with SO_4^{-2}, Cr, F^-, Zn, Cl, TDS, conductivity, ammonia-N and NO_3^{-2}, representing the Mukuvisi River (Table 2; Fig. 3). PC2 accounted for 5% of the variation and was not highly correlated with any of the physico-chemical parameters. This represented the Gwebi River and MS1 site of the Mukuvisi River.

Abundance and diversity of macroinvertebrates were higher in the Gwebi River than the Mukuvisi River (Table 3; Fig. 4).

CCA was used to determine the relationship between macroinvertebrates and water quality variables. CCA axis 1 and axis 2 explained 67% and 19% of the total variation respectively (Table 4). CCA ordination plot showed that simulidae and chironomidae were positively correlated to NO_3^{-2}, PO_4 and ammonia-N (Fig. 5). These conditions prevailed at MS5 (Fig. 5). Most of the macroinvertebrates were associated with low nutrient levels and these conditions were characteristic of all the Gwebi River sites and MS5.

Table 1
Eigenvalues of the correlation matrix of the water quality parameters of the Gwerbi and Mukuvisi Rivers.

Water quality	PC 1	PC 2	PC 3	PC 4
Eigenvalues	0.8701	0.0498	0.0378	0.0229
Explained Variation (cumulative)	87.01	91.99	95.76	98.06
Total variation				**23.15**

Table 2
Water quality eigenvectors of the correlation matrix.

Variable	PC 1	PC 2	PC 3	PC 4
Cl	0.9525	−0.1480	−0.1615	0.2049
SO_4^{2-}	0.9862	−0.1062	0.0122	−0.1166
PO_4^{2-}	0.6358	0.6422	−0.2295	−0.3013
NO_3^{2-}	0.7006	0.4705	−0.3836	0.0657
F^-	0.9545	−0.1772	−0.0327	−0.2289
Pb	0.4608	−0.1859	0.0992	−0.0355
Cu	0.2908	0.3957	−0.0805	0.1984
Fe	0.2959	0.1489	−0.2922	0.0370
Mn	0.0733	0.2605	−0.2779	0.0994
Zn	0.9535	0.0776	−0.1304	−0.1930
Cr	0.9652	−0.1132	−0.1716	−0.1564
pH	0.2025	0.6465	−0.1906	0.5763
Conductivity	0.9058	0.2260	0.3355	0.1213
DO	0.2807	−0.2960	0.3665	−0.0233
TDS	0.9587	0.1664	0.0920	−0.0638
Ammonia-N	0.7017	0.5624	−0.3359	−0.1662

Fourteen fish species were recorded along the Gwebi River compared to only two species along the Mukuvisi River (Table 5). The growth of *C. gariepinus* in the Mukuvisi River was described by the von Bertalanffy equation $L_t = 710.2\ (1 - {}^{-0.21(t-0.33)})$. In the Gwebi River, the *C. gariepinus* grew faster and attained a larger size as described by the von Bertalanffy growth model $L_t = 1300.2\ (1 - e^{-1.4(t+0.16)})$. A comparison of the k and L_∞ of the von Bertalanffy using likelihood ratio methods showed that there were significant differences in the k and L_∞ from the two rivers.

Most of the fish caught along the Mukuvisi River showed pathological changes with the most common lesions being melanomacrophage centres, cellular swelling and vacuolation (Table 6). There were significant differences in the mean liver histological alteration grade between the rivers (Mann–Whitney U test, $P < 0.01$). Significant differences in the AChE were measured (Mann–Whitney U test, $P < 0.01$). The mean AChE activity was 22.54 ± 5.6 nmol min^{-1} mg $protein^{-1}$ along the Mukuvisi River compared to 58 nmol min^{-1} mg $protein^{-1}$ along the Gwebi River.

4. Discussion

Cluster analysis grouped all the Gwebi sites and MS_1 site

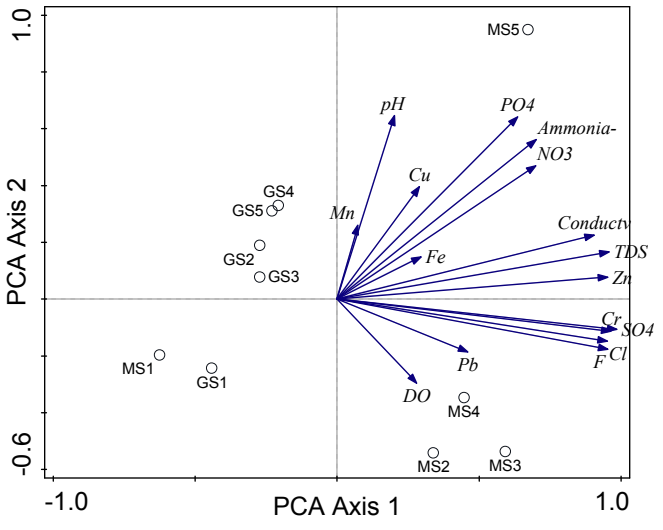

Fig. 3. PCA biplot of water quality parameters in the Gwebi and Mukuvisi Rivers.

Table 3
The number of macroinvertebrates obtained from sites on the Gwebi and Mukuvisi Rivers.

Family	GS1	GS2	GS3	GS4	GS5	MS1	MS2	MS3	MS4	MS5
Aeshnidae	0	0	3	1	3	0	0	0	0	0
Anthomycidae	0	0	0	0	0	0	0	0	57	0
Baetidae	8	0	19	23	0	0	1	0	0	0
Belostomatidae	2	0	0	8	0	0	0	0	0	15
Caenidae	19	51	66	126	37	13	0	0	0	0
Ceratopogonidae	0	0	0	24	3	0	0	0	0	0
Chironomidae	1	83	21	127	21	49	118	647	111	3811
Coenagriidae	0	30	27	162	7	27	19	48	33	12
Corixidae	0	0	0	15	3	0	2	0	0	0
Crab	0	2	5	8	0	1	3	2	1	0
Culicidae	1	59	19	74	4	7	1	59	36	0
Dytiscidae	10	99	28	33	16	46	2	1	9	7
Elmidae	4	7	0	5	3	6	7	0	0	0
Ephemerelidae	8	0	0	0	0	0	0	0	0	0
Gerridae	0	0	7	18	6	0	0	0	0	0
Glossiphonidae	0	13	20	38	55	0	0	171	0	0
Gomphidae	8	0	0	0	16	4	0	4	0	0
Gyrinidae	8	0	1	12	9	27	5	0	5	0
Haliplidae	4	0	2	0	2	3	0	0	0	0
Heleidae	0	0	12	1	3	0	0	0	0	0
Helmidae	0	0	0	0	2	0	0	0	0	0
Helolidae	0	0	0	0	0	0	2	0	0	0
Hydrobiidae	23	0	0	0	825	0	0	0	0	0
Hydrophilidae	0	11	0	0	0	48	13	0	0	18
Hydropsychidae	1	0	0	4	0	0	50	0	0	0
Lepidoptera	0	0	0	0	0	3	0	0	0	7
Leptoceridae	0	0	0	3	0	0	0	0	0	0
Lestidae	0	3	3	24	10	0	0	0	0	0
Libelludidae	0	87	49	10	3	115	156	1	10	6
Limnophilidae	0	1	0	0	0	0	0	0	0	0
Lymnaeidae	0	5	0	11	782	24	0	1	3	0
Macroveliidae	0	0	0	0	0	1	0	0	0	0
Mellanidae	0	0	0	0	704	0	0	0	0	0
Masorellidae	1	0	0	0	0	0	0	0	0	0
Muscidae	0	0	0	0	0	0	0	1	0	0
Naucoridae	6	0	4	3	0	0	0	0	0	2
Nematode	0	0	0	0	0	0	0	0	23	0
Nepidae	0	0	5	0	0	0	0	0	0	1
Notonectidae	0	1	12	2	2	0	0	0	0	0
Oligochaeta	8	203	52	238	129	70	17	697	739	143
Ostrachods	0	0	0	0	0	0	0	0	0	9
Physidae	27	30	4	0	139	26	2	9	7	0
Piscicolidae	0	0	0	0	5	0	0	0	0	0
Plamodidae	12	29	22	65	335	34	0	0	0	0
Pleide	0	0	17	13	2	20	0	0	0	0
Simulidae	0	0	0	1	0	3	0	39	0	108
Sphaeridae	0	0	12	17	114	0	0	0	0	0
Tetanoceridae	0	0	0	24	0	0	0	0	0	0
Tipulidae	0	3	0	0	1	0	0	0	0	0
Trichopteraen larva	1	0	0	11	47	0	0	0	0	20
Unionidae	1	0	0	0	0	0	0	0	0	0
Water mites	0	0	0	0	0	0	0	0	0	11
Water spiders	0	0	0	0	0	7	0	0	7	0

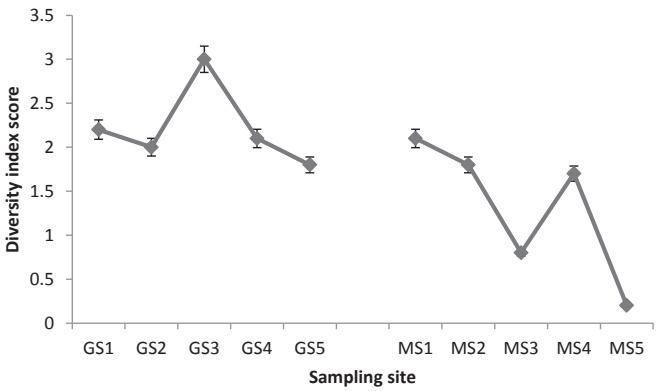

Fig. 4. The diversity of macroinvertebrates at Gwebi and Mukuvisi Rivers.

together. MS_1 is the Mukuvisi River site before the river enters the industrial zone. All the other Mukuvisi River sites formed a separate cluster. The Mukuvisi River passes through an urbanized, industrialized and densely populated area, and this explains the high water physico-chemical parameters recorded along this river. Furthermore, sewage effluent is discharged into this Mukuvisi River at MS_5. PCA showed that most of the variation in the water quality

Table 4
Eigenvalues of the correlation matrix of the species–environment relation.

Macroinvertebrates and water quality parameters	Axis 1	Axis 2	Axis 3
Eigenvalues	0.0285	0.082	0.0034
Explained variation (Cumulative)	67.16	86.50	94.56
Total variation			**0.0424**

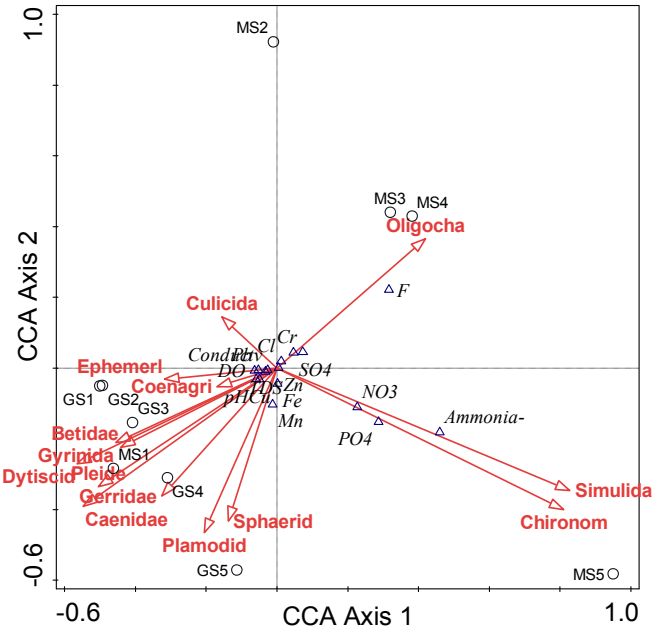

Fig. 5. CCA plot of the relationship between water quality parameters and macroinvertebrates in the Gwebi and Mukuviksi Rivers.

Table 5
Relative abundance (no.min^{-1}) of fish sampled in the Gwebi and Mukuvisi Rivers.

Species	Relative abundance (no.min^{-1})	
	Gwebi	Mukuvisi
Clarias gariepinus	0.8	0.4
Barbus trimaculatus	1.5	0
Barbus lineomaculatus	3.0	0
Barbus paludinosus	4.2	0
Barbus radiates	0.1	0
Oreochromis mossambicus	0.3	0.1
Oreochromis macrochir	0.1	0
Tilapia rendalli	0.5	0
Tilapia sparrmanii	1.0	0
Serranochromis robustus	0.2	0
Marcusenius macrolepidotus	0.3	0
Chiloglanis neumanni	0.1	0
Micralestes acutidens	0.1	0
Micropterus salmoides	0.2	0

variables was accounted for by SO_4^{-2}, Cr, F^-, Zn, Cl, TDS, conductivity, ammonia-N and NO_3^{-2}. All these water quality variables were higher along the Mukuvisi River because different industries discharge industrial effluent into it. The food and beverage manufacturing industries discharge effluent from their factories without any pre-treatment and this probably explains the high TDS, conductivity and ammonia-N. CCA showed that MS_5, which is a site after sewage effluent was discharged, was associated with NO_3^{-2}, PO_4 and ammonia-N. The two macroinvertebrate families found at this site were Simulidae and Chironomidae. These families are tolerant of high pollution conditions. The results from this study are consistent with previous studies (Mathuthu et al., 1997; Moyo and Phiri, 2002). The high pollution levels in the Mukuvisi River have led to a decrease in macroinvertebrate and fish diversity. The effect of pollution on macroinvertebrates is well documented (Seanego and Moyo, 2013). However, there is very little information on the effect of pollution on fish in rivers.

A comparison of the fish fauna between the two rivers further shows the negative impact of urbanization on the ecology of the Mukuvisi. Fish diversity and abundance was reduced in the Mukuvisi River because of widespread pollution. Little is known in Zimbabwe about the impact of pollution on fish. However, one species which is typically found in running water, *Opsaridium peringueyi* may now be extinct in the country since no specimens have been collected in forty years (Gratwicke et al., 2003). No *Barbus* species were found in the Mukuvisi yet *Barbus palundinosus* is a hardy species that occurs in most aquatic habitats including polluted waters (Gratwicke et al., 2003). Its absence from the Mukuvisi probably indicates that the Mukuvisi has been severely polluted. The Mukuvisi is only able to support fish species that are highly tolerant to pollution such as *C. gariepinus*. This fish is able to survive in places like sewage ponds where the concentration of dissolved oxygen is very low (<0.5 mg/l).

More than 95% of the *C. gariepinus* from the Mukuvisi River showed lesions on the liver. This probably indicates the effect of the pollution stressors. However, it must be pointed out that an increase in melanomacrophage centres can be indicative of parasitic infection (Hinton and Lauren, 1990; Dezfuli et al., 2007). The increase in the connective tissue in the parenchyma in *C. gariepinus* from the Mukuvisi River is probably a result of phagocyte infiltration to a focal area of necrosis as suggested by Hibiya (1982). Van Dyk (2003) also found an increase in the connective tissue of *C. gariepinus* from a polluted site. This observation suggests that this type of lesion may be a useful biomarker. Vacuolation has been shown to occur in fish exposed to stressful conditions (Rapatsa and Moyo, 2013, 2014).

The *C. gariepinus* from the Mukuvisi River had much lower AChE levels. This indicates that the chemical pollutants in the Mukuvisi River inteferred with AChE activity. It was initially thought that AChE activity was indicative of exposure to pesticides and insecticides. However, it has now been established that AChE activity is also inhibited by metals and herbicides (Roy et al., 2006; Modesto and Martinez, 2010). The poor water quality of the Mukuvisi River affected the growth of *C. gariepinus*. Differences in fish growth rate are probably due to prey availability and health status of the fish. *C. gariepinus* is a benthic feeder and there was more fish prey in the Gwebi River than the Mukuvisi River. Bosclair and Legget (1989) attributed differences in growth rates of yellow perch (*Perca flavencens*) to activity costs associated with feeding and not the composition of the diet. In this study, both food consumption and activity costs probably explain the differences in growth rates.

5. Conclusion

The Mukuvisi River is severely polluted and can no longer support high diversity of aquatic life. *C. gariepinus* is tolerant of high pollution levels but it is also now negatively affected by the high pollution levels in this river. It is recommended that rehabilitation

Table 6
Liver histological alterations along the Gwebi and Mukuvisi Rivers.

	Increase in melanomacrophage	Increase in perivascular connective tissue	Vacuolation of hepatocytes	Liver average grade
Mukuvisi River	20/22	21/22	20/22	3.8
Gwebi River	3/22	3/22	4/22	1.2

measures be instituted along the Mukuvisi River.

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