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The Impact of pollution on the Riffle fauna of the Umwindisi and Mkuvisi Rivers. Harare, Zimbabwe

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Abstract

The impact of pollution on Umwindisi and Mukuvisi rivers was determined using Riffle fauna as biological indicators to monitor water quality and determine the level of pollution using micro-benthic organisms as indicators of pollution level. There is value addition to the existing methods of chemical analysis of water. The study is important in developing a sound management policy for water quality and effluent disposal.as well as research in aquatic environments. The abundance and diversity of the riffle fauna in the unpolluted Umwindisi river was compared with that of the polluted Mukuvisi from October 2001 to March 2002. The sampling sites on the two rivers were strategically located. Temperature, pH. Conductivity, dissolved oxygen, ammonia concentration and biological oxygen demand were determined. The abundance of collected riffle fauna was done by microscopy and classified. Data was analysed using MINITAB – and the Shannon Weiner diversity index. Riffle fauna abundance and diversity was high in Umwindisi than in Mukuvisi indicating high pollution impact in the later river.

Keywords: biological indicators, riffle fauna, water pollution, industrial discharge, species diversity and water quality

INTRODUCTION

With the growing urban and industrial use of water, greater amounts of the organic and inorganic wastes are spewed back into water sources so that less and less pure water becomes available at the quality required as a result of the self-destructive process of pollution (Shuval ,1972). The assessment of water quality in Zimbabwe has been biased towards the analysis of physico-chemical analysis while biological surveillance has been largely neglected (Phiri 2000). Animal and plant communities respond to intermittent pollution which may be missed in a chemical sampling programme, therefore biological surveillances have advantages that biotic communities may respond to new or unsuspected pollutants in the environment. The sources and concentrations of certain pollutants along the Mukuvisi River were determined by Zaranyika (1997) and Mathuthu (1993) who showed the impact of industrial discharge on the quality of the water in Mukuvisi River in the Msasa Industrial area. These studies focused on the sources and concentrations of pollution and did not include the impact of pollution on the biota.

Aquatic biological monitoring can provide a low-cost and moderately sensitive means of monitoring water quality (Gratwickle, 1998). The health of two rivers near Harare, Zimbabwe, was assessed using micro invertebrates community structure and selected physicochemical variables by Phiri (2000) but this study did not consider the impact of the effluent discharge from a phosphate industry on the riffle fauna with an acceptable control site. The ecology and sensitivity to pollution of many of the organisms used in water quality assessments are still very inadequately known, even in those countries with a long tradition of research in freshwater biology (Murphy, 1978).

Riffle fauna were chosen in this study as the most suitable organisms, for assessing water quality because the benthic macro invertebrates are relatively sessile and their low mobility makes them less capable of avoiding pollutants as evidenced by Ballock *et al* (1976). The Riffle fauna have a relatively long life history and their presence or absence helps in deducing environmental pollution factors over a long period of time as shown by Davies (1998). In addition there are good identification keys for most groups up to family level. The sampling procedures are also relatively well developed and can even be operated by someone working alone.

LIMITATIONS OF THE STUDY

The findings could have been more conclusive if the study period had been extended for a period of at least two years where more samples could have been collected. Since micro-benthic organisms are stationary, fast flowing waters may have limited the sampling procedures employed,. However this equally affected all stations

STUDY AREA

The study area included Mukuvisi and Umwindisi rivers. Mukuvisi is a polluted river which flows through the eastern industrial area of the City of Harare. Most of the effluent from these industries are discharged into this river, partially treated or untreated at all. The study area on this river covered the area form Cleveland dam downstream to about 5 kilometer distance after the last effluent discharge from Zimbabwe Phosphate Industries (ZIMPHOS) as shown in Fig. 1. Umwindisi is a relatively unpolluted river which flows through the low density surburbs of Harare about 25 kilometres north east of this city and there is no discharge of putrescible organic waste into this river which could lead to an increase in dissolved solids resulting in poor water quality. Therefore Umwindisi River has been used as an acceptable control site in this study. The assumption made was that the biological community was identical in the unpolluted control and the polluted site. One of the main criticisms of biological indices is that though they may be suitable for one area, they may not produce the desired results in different scenarios as shown by Armitage *et al* (1983). Also the key organisms in the ecology of one particular watershed may be insignificant in a neighbouring one of a different geology or flow regime. Pollutants affect organisms differently at different life stages or different times of year while natural changes in pollution size may underlie any of the effects of pollutions. Therefore although a comparative study of the water quality of two rivers within Harare was investigated on the basis of micro invertebrates, water quality assessment information on the basis of micro invertebrate community structure in Zimbabwean rivers is still very scanty.

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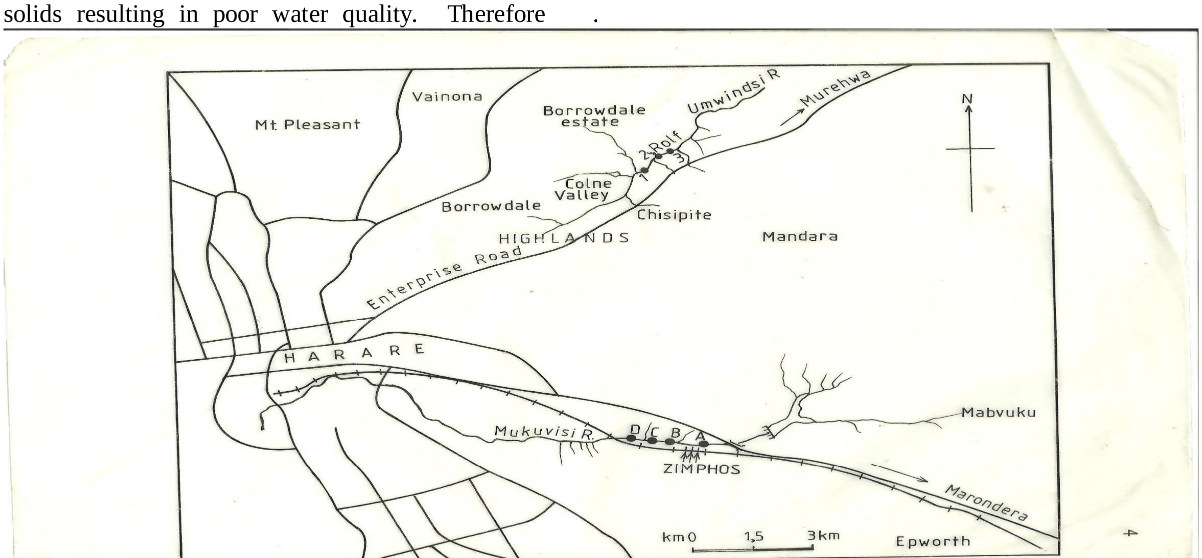

Fig 1: Map of Mukuvisi and Umwindisi Rivers showing the sampling points.

The aim of this investigation was to use the riffle fauna to compare the water quality of the Mukuvisi and Umwindisi rivers and assess the impact of pollution on their abundance and diversity.

MATERIALS AND METHODS

Sampling sites on the Mukuvisi River were strategically located to assess the impact on water quality of the effluent discharge from the Zimbabwe Phosphate Industries. The sampling site that extended from Cleveland dam to just before the first effluent canal from ZIMPHOS which discharges into the Mukuvisi River was designated A. Sampling site B, C and D were then located downstream of the effluent discharge and were located about one kilometer apart. Sampling stations along the Umwindisi River were also located about one kilometer apart and were designated as 1, 2 and 3 (Table 1).

Table 1: Description of the sampling sites during the six-month study period (October 2001 to March 2002)

	Site	Width of bed(m)	Characteristic features of the Study sites
	A	4.0	Phragmites, slow flowing
Mukuvisi River	B	3.5	Discharge point, warm water
	C	3.0	Water nearly stagnant, lots of pollutants
	D	3.4	Fast flowing water agitated by rocks
	1	4.6	Fast flowing water, algae mats present at the bottom of the bed.
Umwindisi River	2	5.5	Slow flowing water trees make a canopy leaves fall into this water
	3	6.0	River meandering. Slow flowing. Open water

Sampling was done once at approximately three-week intervals which gave six sampling occasions at each of these stations of these two rivers, from

October 2001 to March 2002. Temperature and pH were determined at each site using a WTW L330 meter while conductivity was measured with a WPCM35 conductivity meter. Dissolved oxygen concentrations were determined with a WTW Oxi 330 oxygen meter and the biological oxygen demand (BOD) was determined by incubating a water sample from each site for five days in tightly stoppered bottles in the dark at 20^0C, measuring the oxygen consumed in the 5 days. Dissolved oxygen had previously been determined in samples collected separately in 300ml glass and chemically fixed on site by the Winkler method (Golterman and Clymo, 1971).The continuous measurements of these selected physicochemical factors were done throughout the study period. The ammonia concentration was determined calometrically using phenate method by measuring the intensity of the blue colour developed by the reaction of ammonia in the water sample from each station with alkaline hypochlorite in the presence of phenol. The intensity of the blue colour was measured using a UNICAM 8625 UV/VIS spectrometer at 630nm. A calibration graph in the ammonia nitrogen range of 0.2 – $10mgl^{-1}$ was prepared (Fig.2) treating the standards exactly as the sample throughout the procedure. The absorbances of the ammonia from each of the sampling sites were converted into concentration of ammonia by reading off the concentrations from the calibration graph (Fig 2).

The riffle fauna were collected from the sampling sites with a hand net 30cm diameter and 50cm deep with a 0.05mm gauge mesh. Five rocks per sampling station were being washed in the hand net and the samples were combined into one sample from each station. In the laboratory the animals were sieved through a 1mm gauge sieve and then spread into manageable portions in a white tray with clear water 1-2cm deep (Chutter, 1998). Sand, algae and the remaining debris in the tray were agitated often to remove any animals hiding (Thirion, et al., 1995). Some samples were preserved in 70% ethanol while others were mounted on microscope slides in Canada Balsam for identification. Animals were identified to family level using a dichotomous key to the common micro in vertebrate taxa of South African inland waters (Davies, 1998). The MINITAB statistical package was used to test for correlation between the riffle fauna and chemical variables.

The South African Scoring System (SASS) which is a biotic index for the rapid assessment of water quality using benthic microinvertebrates, was used to assess the condition of the two rivers. It was calculated by assigning a score to each of the families present, based on their sensitivity to organic pollution (Thirion, *et al* 1995) and(Chutter, 1998).This score is then multiplied by the sum of another score based on the abundance of the family (in four categories 1:1-10:2:11-100: 3: 101 – 1000: 4: > 1000) in each sample. The results were interpreted according to the guidelines proposed for non-Cape streams. (Table 2).

Table 2: Categories used to classify Habitat, SASS and ASPT values

Habitat	**SASS**	**ASPT**	**Condition**
>100	>140	>7	Excellent
80-100	100-140	5-7	Good
60-80	60-100	3-5	Fair
40-60	30-60	2-3	Poor
<40	<30	<2	Very poor

(source: Thirion et.al 1995)

Diversity indices have been used to assess water quality (Murphy 1978). The Shannon – Weiner index of species is:

$$H^1 = -\sum \frac{Ni}{N} \log \frac{Ni}{N}$$

Where N = the total number of individuals in the sample, and Ni = number of individuals of species in the sample. Ni i.e. the number of individuals in a given taxon is divided by the total number of organisms in the collection (Murphy, 1978).

RESULTS AND DISCUSSION

Table 3: The mean with standard deviation in brackets parameters determined at each of the sampling station. (October 2001 to March 2002).

	Umwindisi River			Mukuvisi River			
Station/Parameter	**1**	**2**	**3**	**A**	**B**	**C**	**D**
PH	6.58(-+0.15)	7.41(-+0.24	6.76(-+0.24)	6.80(-+0.11)	3.35(-+0.30	4.05(-+0.32)	5.30(-+0.62)
Temperature (^{0}C)	18.2(-+0.42)	18.7(-+0.27)	18.0(-+0.61)	22.4(-+0.34)	24.6(-+0.70)	23.6(-+0.68)	23.4(-+0.59)
Conductivity ($uScm^{-1}$)	320(-+9.39	323(-+1.5)	330(-+3.30)	1200(+170.78)	2100(+0.81.6)	1800(-+81.65)	1500(+81.65)
DO ($mg1^{-1}$)	6.84(-+0.12)	6.58(-+0.31)	7.11(-+0.11)	6.88(+-0.16)	4.51 (-+0.41)	5.38(-+0.04)	6.36(-+0.03)
BOD ($mg1^{-1}$)	-867(-+28.96	-661(-+6.95)	-811(-+5.32)	6.98(-+4.32)	787(-+10.98)	780(-+5.07)	705(-+6.99)
Ammonia ($mg1^{-1}$)	0	0	0	0.5(-+0.14)	4.3(-+0.22)	2.4(-+0.43)	1.8(-+0.22)

In Umwindisi river conductivity ranged from 320-330 $uScm^{-1}$ at all stations (Table 3). In Mukuvisi river at site A, it was much higher 1 200 $uScm^{-1}$ and at sites B, C and D below the effluent discharged it ranged from 1500-2100 $uScm^{-1}$. For Mukuvisi below the effluent discharge conductivity was very high, this is likely as a result of increased temperature of the water, waste products from ZIMPHOS such as those of Ammonium Nitrate and Phosphates ions. In Mukuvisi, the Pearson Correlation of riffle fauna family diversity and conductivity was found to be -0.822 and P value of 0,023. Therefore, $P<0.05$, showing that there is a strong relationship between conductivity and riffle fauna species diversity and abundance as well as their distribution. However, in Umwindisi river conductivity was found to be very low, the sites in this river were used as minimally impacted sites and were used to define the best attainable reference condition and the riffle fauna diversity and abundance was high with low conductivity.

The conductivity results obtained from Umwindisi and Mukuvisi rivers are also in agreement with the conductivity of most fresh waters which are said to range from 10-1000 $uScm^{-1}$ but may exceed 1000 $uScm^{-1}$ especially in polluted waters and those receiving large quantities of land run-off (Chapman,1996). In this study conductivity in addition to being a rough indicator of mineral content, it was also measured to establish a pollution zone in Mukuvisi river around an effluent discharge point. Low conductivity recorded at sites C and D downstream after effluent discharge can perhaps be associated with self-purification of the Mukuvisi river as most of the mineral ions will be absorbed by the plants growing in the river and riverbanks and riffle fauna diversity started to improve as the distance from the discharge point downstream increases. In Mukuvisi, the pH for the three study sites B, C and D were very low as compared to the pH at site A on the same river which was relatively higher (Table 3). In Mukuvisi the Pearson correlation of riffle fauna species diversity and pH was found to be 0.899 and P value was 0.006. Therefore $P<0.05$, showing a strong relationship between pH and riffle fauna species diversity and abundance. The pH recorded from Umwindisi falls within the range of 6.0 and 8.5 which is the pH of most natural waters and also falls within the recommended standard of 1977 water and waste water regulations (Gratwicke 1998). However, as most natural waters contain weak acids these perhaps are responsible for slight fluctuations in pH recorded at stations 1 and 3 in this river (Table 3).The reduction in the measured BOD on samples on sites B, C and D is likely a result of the presence of organic and toxic substances in these samples. The toxic substances in a sample may affect microbial activity leading to a reduction in the measured BOD. The riffle fauna families were not recorded at sites B and C in Mukuvisi but very low taxa were recorded at study site D. This perhaps is also because of the interactive nature of conductivity, temperature, pH, Ammonia and dissolved oxygen, all these contributing to the reduction of the diversity and abundance of riffle fauna. Pearson correlation of riffle fauna species diversity and BOD (mgl^{-1}) was found to be – 0.663 in Mukuvisi river and the P value of 0.105 was obtained. Therefore $P>0.05$ showing no relationship between riffle fauna species diversity and the BOD, (Table 3). The BOD recorded in Umwindisi river was found to be very low in all stations as compared to those from Mukuvisi, showing low levels of water pollution and high diversity index of riffle fauna families diversity and abundance. Slightly lower BOD recorded at site 2 of Umwindisi might be a result of humus formed by the chemical and biochemical decomposition of vegetative residues and from the synthetic activity of micro-organisms.

From all the three study sites of Umwindisi river, ammonia was not recorded although it can also occur naturally in water bodies arising from the breakdown of nitrogenous organic and inorganic matter in soil and water, excretion by biota and even reduction of the nitrogen gas in water by microorganisms. Its level in these three sites of the control river was too low to be peaked. In Mukuvisi river site A recorded the lowest concentration of ammonia.This perhaps, is mainly as a result of nitrogenous fertilizers and organic manure used in the small cultivated fields close to the river by residents close fromTafara and Mabvuku high density surbubs. At site B on Mukuvisi, the ammonia concentration was very high and started to fall as the water passes through site C, and D (Table 3). The high ammonia concentration in Mukuvisi coincide with findings of Gratwicke(1998) which showed that as pollutants became more concentrated the diversity of invertebrates and the SASS score decline. The Pearson Correlation of riffle fauna diversity and ammonia concentration was found to be -0.880 and P value of 0.009.

Therefore, $P<0.05$, showing that there was a strong relationship between ammonia concentration and species diversity, abundance and distribution. At study site D of Mukuvisi, the pollutant tolerant riffle fauna families such as the *Sciomyzidae* were collected. This is likely because the ammonia concentration in the river might have fallen as a result of self-purification of the river when most organic pollutants would have been absorbed by plants growing in the river and river banks such as the phragmites.

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Table 4: The principal animal taxa collected from the study areas in the two rivers, the SASS value and the pollution sensitivity score for each taxa.

Families	Pollution sensitivity score for each taxa	Mukuvisi Sampling Sites				Umwindisi Sampling Sites		
		A	B	C	D	1	2	3
Turbellaria	1	2					2	1
Notonemouridae	12	1				3	1	
Oligoneuridae	15	1				3	2	1
Gomphidae	6							1
Psephenidae	10						1	3
Hydropsychidae	4	1						4
Polycentropodidae	12					3	3	1
Hydraenidae	8					1		2
Chironimidae	2				2	2		
Athericidae	13						1	
Planorbidae	3	5						1
Hydrobiidae	3	5						2
Sciomyzidae	3	4			1	3		
SASS		75	0	0	7	138	103	93

The principal animal taxa collected from the study areas in the two rivers, the SASS value and the pollution sensitivity score for each taxa.The relative abundance of riffle fauna at each sampling site was recorded using the South African Scoring System (SASS) (Table 4). High SASS scores were recorded at all three sampling sites in the Umwindisi River but low scores, which reflect poor water quality, were recorded at sites B., C and D on the Mukuvisi River. The SASS score at site A was relatively high (75) but downstream along this river to sites B and C the SASS score was zero showing that these two stations were likely to be of very poor water quality. At site D which is further downstream on Mukuvisi River the SASS score had fairly improved (7) showing a fair improvement in the water quality compared to sites B and C. Along the Umwindisi River, the SASS scores were fairly high at sites 1 and 2 which recorded scores of 138 and 103 respectively (Table 4). At site 3 further down along this river, the SASS score had dropped to 93: this may be due to changes in the habitat which may be responsible in changes in biotic scores.

Table 5: The Shannon's diversity indices for the 7 sampling sites in the two rivers measuring stress in these environments

	Sampling Site	Diversity Indices (H^1)
Mukuvisi River	A	0.72
	B	0
	C	0
	D	0.29
Umwindisi River	1	0.66
	2	0.67
	3	0.82

The Shannon's diversity index in Mukuvisi River was highest at Site A (0.72),decreasing to zero at sites B and C and rising relatively at site D (0.29). In the Umwindisi River there is no outstanding difference in the Shannon's diversity index among the three sites studied (Table 5) although site 3 was found to have the highest diversity index value (0.82).

Table 6: The relationship between the riffle fauna family diversity and some chemical variables in the Mukuvisi and Umwindisi Rivers

	Correlation coefficient (r)	P
PH	0.90	0.006
DO	0.88	0.010
Conductivity	-0.82	0.023
Ammonia	-0.88	0.009
BOD	-0.66	0.105

The pH, ammonia, conductivity, dissolved oxygen (DO) and temperature recorded at each study site from the two rivers have shown that there was a significant correlation between these physicochemical variables and the riffle fauna family diversity shown by the SASS score at 5% level of significance (Table 6). There was no correlation observed between biochemical oxygen demand (BOD) and riffle fauna family diversity shown by the SASS score at a significance level of 5%. A probability of 0.105 which is greater than 5% (P>0, 05), was found, that is, no correlation existed between riffle fauna family diversity and BOD.

CONCLUSION

Physicochemical factors which negatively impact on riffle fauna diversity and distribution were found to be dissolved oxygen, conductivity, ammonia and pH. These confirm the use of riffle fauna as biological indicators of water quality. There was less diverse riffle fauna in Mukuvisi (9 taxa) as compared to Umwindisi (21 taxa).

- When analyzing water quality it is important to have a holistic view of that includes both physicochemical and biological factors to ensure safety of water.
- Industries should be encouraged to have on site pre-treatment of their waste discharge to reduce aquatic pollution, ensuring safe water for residents.
- Industries require continuous training programmes in waste management to avoid water bodies contamionation.

The SASS scores can be used to monitor the water quality of steams and rivers as it makes the results more accessible to non-biologists who need the data before making decisions on the management of water bodies. The simplicity and low cost of bio-monitoring of water pollution enables it to be carried out in many situations where financial resources cannot support the sophisticated equipment required for chemical analysis of water quality. The riffle fauna can be used to provide early warning mechanisms of possible environmental damage and the impacts of effluent can also be tested and predicated before their discharge. One of the problems encountered with using the Shannon-Weiner diversity y indices and the SASS scores to assess water quality was that they depended on the number of families taken in a sample. This may be a potential source of considerable error as the number of families is itself dependent upon many factors unrelated to water quality such as the sampling method sample size, prevailing conditions at the time of sampling as well as seasonal life cycles Chapman (1996).

The use of biological methods in water quality assessment is strongly recommended in conjunction with chemical and hydrological monitoring. It is also recommended that industries should have adequate on-site pre-treatment of their waste waters.

Training programmes in basic water pollution contro,l pollution prevention and waste numeration awareness are needed. Also already put in place industrial waste discharge fee system should be raised.

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