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Full Length Research Paper

Bioassessment of Water Quality of an Urban Stream: A Case Study of Marlborough Stream, Harare, Zimbabwe.

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The economic meltdown in Zimbabwe which started around 2000 and lasted almost a decade led to the intensification of already existing environmental problems. Local authorities were not able to fully regulate the treatment and disposal waste and some sewerage system often burst and raw sewage flowed into streams and rivers unmonitored. In Marlborough, Harare, sewage from burst Marlborough sewerage system was flowing into Marlborough stream which flows through the suburb. Water quality in Marlborough river was monitored by collecting benthic macro-invertebrates once a month from February to April 2012 at four sites, one upstream and three downstream of the point of sewage discharge. Macroinvertebrates metrics of abundance, taxa richness, Shannon Wiener diversity index, tolerance average score per taxon (ATSPT) and South African Scoring System (SASS) scores were used in the determinations of water quality of the stream. Abundance, taxa richness and Shannon Wiener index differed significantly ($p<0.05$) spatially but no significant differences were found among the sampling months. SASS scores and ATSPT differed significantly ($p<0.05$) among sampling sites in each sampling month indicating that water quality differed significantly among sampling sites but no significant difference were found among the sampling months. The reference site had the highest number of pollution sensitive families, while the site 1, just after point of discharge had the highest number of pollution tolerant families. The abundance of pollution tolerant families decreased from site 1 going down stream possibly due to self-purification and dilution. The outcomes of the research showed that the inflow of sewage into the stream reduced water quality of the stream.

Keywords: Water quality, Benthic macro-invertebrates, Bio-assessment; Marlborough river, Sewage effluent

INTRODUCTION

Water pollution is a major problem in the global context. Disposal of sewage effluent is a major threat to water resources since most urban areas of Zimbabwe face serious challenges when it comes to sewage disposal (Moyo, 1997). The rapid development and expansion of urban areas, concentrating people and their wastes and the development of industries is reported to have led to the deterioration of water quality and the degradation of urban environments in Africa (Chakona, 2005). Zimbabwe's cities and towns have been experiencing a lot of burst sewer challenges in the last few years (Moyo, 1997). Rapid urbanization has presented serious challenges on the management and disposal of sewage (Chiuta et al., 2002; Moyo and Mtetwa, 2002). Most sewage treatment works and sewerage are old and are poorly maintained and are also overdue for rehabilitation (Mangizvo, 2009). The challenges the local authorities have been facing when it comes to sewage disposal have been exacerbated by the economic meltdown which lasted almost a decade having started in 2000. The meltdown which crippled virtually all waste management operations around the country was at its height in 2008. In Marlborough, a western suburb of Harare, raw sewage has been flowing into the streets of parts of the neighbourhood and ultimately flows into Marlborough stream. This poses risks of water pollution of the stream resulting in deterioration of water quality of the stream (Chutter, 1994). Healthy riverine ecosystems are not only essential in terms of maintaining good water quality, but are needed to preserve rare or sensitive species which contribute to the health of the food web and the overall biological diversity of the area. (Gratwicke, 1999)

When a water body is contaminated with sewage, during

Table 1. The location of sampling sites in the study area

Site	Position
R	Upstream (Reference site)(17°44'46"S, 30°58'50"E)
1	100 metres downstream of the point of entry of sewage(17°44'56"S, 30°58'59"E)
2	2km downstream of the point of entry of sewage (17°44'40"S, 30°59'12"E)
3	4km downstream of the point of entry of sewage (17°44'22"S, 30°59'24"E)

the decomposition process of this organic waste, the dissolved oxygen in the receiving water may be used up at a greater rate than it can be replenished, causing oxygen depletion and having severe consequences for the stream biota (Clements et al., 2000). Sewage effluents also frequently contain large quantities of suspended solids which reduce the light available to photosynthetic organisms and, on settling out, alter the characteristics of the river bed, rendering it an unsuitable habitat for many invertebrates which cause an ecological imbalance of the stream ecosystem (Moyo, 1997). Other negative impacts resulting from contamination by sewage include, reduced self-purification ability of the stream (as food chains are shortened, the buffering capacity of the stream is lost) reduced aesthetic qualities, making the water unsuitable for recreation or tourism (Marshall, 1997).

Most studies on water quality in Zimbabwe have been concerned with assessing the physico-chemical parameters of water (Mathuthu et al .,1997). Biological agents however provide information on prolonged exposure of the stream to pollution and reflect clearly the impact of pollution on water quality. Bioassessment of water quality provides an insight to the human impacts upon stream systems and provides clues regarding where we need to protect streams or where we can start helping to restore their integrity. Biological assessment is the use of living organisms to determine the condition of the environment (Clements et al .,2000). Bioassessment is based on the straightforward premise that living organisms are the ultimate indicators of environmental quality (Voshell et al., 1997). In streams, bioassessment can be done with benthic macroinvertebrates, fish, or periphyton, but benthic macroinvertebrates are generally the assemblage of choice. They have several characteristics that make them particularly useful for bioassessment. (1) Benthic macroinvertebrates occur in almost all types of freshwater habitats (2) There are many taxa of benthic macroinvertebrates, and among these taxa there is a wide range of sensitivity to pollution and environmental stress. (3) They have mostly sedentary habits so they are likely to be exposed to pollution or environmental stress. (4) Their life cycles are sufficiently long that they will likely be exposed to pollution and environmental stress, and the community will not recover so quickly that the impact will go undetected. (5) Sampling the benthic macroinvertebrate assemblage is relatively simple and does not require complicated devices or great effort. (6) Taxonomic identification is almost always easy to the family level and usually relatively easy to the genus level. (Voshell et al.,1997).

The general objective of this study was to determine environmental water quality of Marlborough stream by monitoring the macro-invertebrate communities upstream and downstream of the point of sewage discharge. This study investigated the temporal variability of macro-invertebrate communities from month of February to April 2012 in addition to the spatial variability. Specifically, the objectives of this study were (1) To determine the biodiversity of benthic macroinvertebrates at each site and compare the values across sites and months (2) To determine the pollution tolerances of benthic macroinvertebrates and compare values across the sites and the months.

MATERIALS AND METHODS

Study area

The study was carried out in Marlborough stream in Marlborough, Harare, which lies approximately 20km north-west of Harare town centre. The suburb has been experiencing the problem burst sewerage for more than a year and as of April 2012 the situation was not yet resolved. The sewage flows in the streets causing foul smell and presence of abundant flies which pose the risk of transmission of diseases such as diarrhoea. The sewage ultimately flows into Marlborough stream which is a tributary of Mazowe River.

Selection of sampling sites

Four sampling sites were chosen to obtain significant statistical data and for analysis of the influence of spatial variability on water quality. Table 1 below shows the sampling sites and their positions in the study area and in the stream .

Table 2. Abundance of benthic macroinvertebrates sampled in February, March and April 2012

Sampling Sites	February	March	April
Site R	$336^{r,\ fmx}$	$342^{r,\ fmx}$	$223^{r,\ fmx}$
Site 1	$476^{ab,\ fmx}$	$545^{ab,\ fmx}$	$577^{ab,\ fmx}$
Site 2	$428^{abc,\ fmx}$	$434^{abc,\ fmx}$	$524^{ab,\ fmx}$
Site 3	$306^{bcr,\ fmx}$	$325^{bc,\ fmx}$	$398^{c,\ fmx}$

Key:
r- site R mean, a- site 1 mean, b- site 2 mean, c-site 3 mean
f- February mean, m- March mean, x- April mean

Sample collection and analysis

Three replicate samples of benthic macroinvertebrates samples were collected at each site from February to April 2012. Three sampling months were used to take into account the temporal variability effect on water quality. A 500 micrometer sweep net was used to collect samples of benthic macroinvertebrates for a standard period of three minutes. Macroinvertebrates were picked for a maximum period of 30 minutes and were preserved in 90% ethanol prior to counting and identification in the laboratory. In the laboratory benthic macroinvertebrates were identified to family level with the exception of porifera and turbellaria which were identified to order level the number of individuals in each family recorded in Appendix 1. A microscope and macroinvertebrate identification manuals were used during identification of organisms.

Data analysis

Abundance, taxa richness and Shannon Wiener diversity index were used to measure biodiversity. Abundance was the number of individual benthic macroinvertebrates belonging to the same family in a sample. Taxa richness was obtained by counting the number of families found in a sample. The Shannon-Wiener index (H') was calculated using the formula:

$$H' = -\sum_{i=1}^{s} pi \ln pi$$

s: number of families.
pi: proportion of individuals per family in the community made up of s families with known proportions p1, p2, p3, . . . ,ps.

The South African scoring system version 5 was used to provide the tolerance scores for families of benthic macroinvertebrates. South African scoring system score were obtained by adding score of each taxon found at a site. Average score per taxon values were obtained by diving the SASS score for each sample by the number of taxa at that site. SASS scores and averages score per taxon were compared with standards in guidelines for interpreting water quality to determine water quality and the results were recorded in Appendix A2. Minitab 16 was used for the ANOVA to test for significant differences between means of taxa richness, tolerance scores per taxon and Shannon Wiener index of diversity. Microsoft Excel was used for calculating average score per taxon, South African scoring system scores and Shannon Wiener diversity index.

RESULTS

Biodiversity

Abundance

Significant differences ($p<0.05$) in abundance, taxa richness and Shannon wiener diversity index of benthic macroinvertebrates among sampling sites in each month were obtained. Abundance of benthic macroinvertebrates at site R was significantly different ($p<0.05$) from abundance at site 1, site 2 and site 3 in March and April. In February site R was not significantly different ($p>0.05$) from site 3 in February. Site 1 and site 2 were not significantly different ($p>0.05$) from each other for all sampling months. Site 3 was significantly different ($p<0.05$) from site 1 but not significantly different ($p>0.05$) from site 2 and site R in February. Site 3 was significantly different ($p<0.05$) from site 1 but not significantly different ($p>0.05$) from site 2 in March. In April site 3 was significantly different ($p<0.05$) from all sites. Abundance at each sampling site did not differ significantly ($p>0.05$) among sampling months (Table 2).
Site R had the highest abundance of families sensitive to pollution such as calopterygidae, chlorocyphidae, notonemouridae while tolerant families were least abundant however chironomids which are pollution tolerant were abundant at site R (Appendix A1). Site 1 had the highest abundance of pollution tolerant families such as the chironomids, physidae, culucidae, and oligochaeta the chironomids being the most abundant (Appendix A1). Sensitive families were least abundant

Table 3. Taxa richness of benthic macroinvertebrates sampled in February, March and April 2012.

Sampling Sites	February	March	April
Site R	$34^{r, fmx}$	$35^{r,fmx}$	$28^{r, fmx}$
Site 1	$22^{abc, fmx}$	$18^{abc, fmx}$	$17^{abc, fmx}$
Site 2	$22^{abc, fmx}$	$20^{abc, fmx}$	$18^{abc, fmx}$
Site 3	$24^{abcr, fmx}$	$23^{abc, fmx}$	$21^{abc, fmx}$

Key:
r- site R mean, a- site 1 mean, b- site 2 mean, c-site 3 mean
f- February mean, m- March mean, x- April mean

Table 4. Shannon Wiener Diversity Index of benthic macroinvertebrates sampled in February, March and April 2012.

Sampling Sites	February	March	April
Site R	$1.39852^{r, fmx}$	$1.38723^{r, fmx}$	$1.387332^{r, fmx}$
Site 1	$0.922878^{abc, fmx}$	$1.016123^{abc, fmx}$	$0.957491^{abc, fmx}$
Site 2	$0.967331^{abc, fmx}$	$1.001132^{abc, fmx}$	$0.93042^{abc, fmx}$
Site 3	$1.077856^{abc, fmx}$	$1.068016^{abc, fmx}$	$0.943464^{abc, fmx}$

Key:
r- site R mean, a- site 1 mean, b- site 2 mean, c-site 3 mean
f- February mean, m- March mean, x- April mean

and most of them were absent such as families of polycentropodidae, glossosomanidae, calamoceratidae, pyriidae and athericidae. Site 2 had the second highest abundance of tolerant families such as chironomidae, culucidae, physidae and oligochaeta the chironomids being the most abundant. Pollution sensitive families were least abundant some being absent such as the families of glossosomanidae and calamoceratidae however some sensitive families such as athericidae and polycentropodidae that were absent at site 1 and present at site R were present at this site and generally sensitive families were more abundant at site 2 than at site 1. Site 3 like site 1 and 2 had higher abundance of tolerant families than sensitive families, the chironomids having the highest abundance. Pollution sensitive families were increasing in abundance from site 1 to site 3 and almost all pollution sensitive families were present at site 3 with the exception of, glossosomanidae and aeshnidae while tolerant families were decreasing from site 1 to site 3 (Appendix A1).

Taxa richness

Taxa richness for site R was significantly different ($p<0.05$) from site 1, site 2 and site3 for almost all the sampling months except in February where it was not significantly different from site 3. Site 1, site 2 and site 3 were not significantly different ($p>0.05$) in all sampling months. Taxa richness at each site did not differ significantly ($p>0.05$) with each sampling month. Taxa richness was highest at site R and lowest at site 1 for all sampling months (Table 3).

Shannon Wiener Diversity Index

Shannon Wiener diversity index at site R was significantly different ($p<0.05$) from site 1; 2 and 3 for all the sampling months. Site 1; 2 and 3 were not significantly different ($p>0.05$from each other for all the sampling months. Shannon Wiener diversity index did not differ significantly ($p>0.05$) with each sampling month. Site R had the highest Shannon Wiener diversity index for all the sampling months (Table 4).

Pollution tolerance

Average Tolerance Score Per Taxon (ATSPT)

Average tolerance score per taxon at site R was significantly different ($p<0.05$) from site 1 and site 2 in March and April however it was not significantly different ($p>0.05$) from site 2 and site 3 in February. Site 1 and 2 were significantly different ($p<0.05$) from site R and site 3 in all sampling months but not significantly different ($p>0.05$) from each other. In March and April average score per taxon at site 3 was significantly different ($p<0.05$) from all sites. Average score per taxon at each site did not differ significantly ($p>0.05$) with among sampling months. Site R had the highest average score per taxon followed by site 3 then site 2 and site 3 had

Table 5. ASPT of macroinvertebrates sampled in February, March and April 2012.

Sampling Sites	February	March	April
Site R	6.4421$^{bcr, fmx}$	6.9295$^{r, fmx}$	7.1885$^{r, fmx}$
Site 1	3.9474$^{ab, fmx}$	4.1783$^{ab, fmx}$	4.0225$^{ab, fmx}$
Site 2	4.5442$^{ab, fmx}$	4.7530$^{ab, fmx}$	4.5019$^{ab, fmx}$
Site 3	5.6280$^{cr, fmx}$	5.6326$^{c, fmx}$	6.1820$^{c, fmx}$

Key:
r- site R mean, a- site 1 mean, b- site 2 mean, c-site 3 mean
f- February mean, m- March mean, x- April mean

Table 6. Water quality with respect to average score per taxon as measured by comparison with the guidelines for interpreting water quality for South African Scoring System 5

Water Quality at Site	February	March	April
R	Good (largely natural with few modifications)	Good (largely natural with few modifications)	Natural (unmodified)
1	Seriously or critically modified	Seriously or critically modified	Seriously or critically modified
2	Seriously or critically modified	Seriously or critically modified	Seriously or critically modified
3	Fair (moderately modified)	Fair (moderately modified)	Good (largely natural with few modifications)

Table 7. SASS scores for macroinvertebrates sampled February, March and April 2012.

Sampling Sites	February	March	April
Site R	186$^{r, fmx}$	245$^{r, fmx}$	204$^{r, fmx}$
Site 1	87$^{ab, fmx}$	78$^{ab, fmx}$	68$^{ab, fmx}$
Site 2	100$^{ab, fmx}$	95$^{ab, fmx}$	84$^{ab, fmx}$
Site 3	138$^{bcr, fmx}$	129$^{c, fmx}$	130$^{c, fmx}$

Key:
r- site R mean, a- site 1 mean, b- site 2 mean, c-site 3 mean
f- February mean, m- March mean, x-April mean

Table 8. Water quality with respect to South African scoring system as measured by comparison with standards in guidelines for interpreting water quality for South African scoring system 5

Water Quality at Site	February	March	April
R	Natural (unmodified)	Natural (unmodified)	Natural (unmodified)
1	Fair (moderately modified)	Fair (moderately modified)	Fair (moderately modified)
2	Good (largely natural with few modifications)	Fair (moderately modified)	Fair (moderately modified)
3	Good (largely natural with few modifications)	Good (largely natural with few modifications)	Good (largely natural with few modifications)

the least for all the sampling months (Table 5,6).

South African scoring system score

South African scoring system score at site R was significantly different ($p<0.05$) from site 1 and site 2 in all sampling months. Site 1 and site 2 were not significantly different ($p>0.05$) in all sampling months. Site 3 was not significantly different ($p>0.05$) from site 2 and site R in February. Site 3 was significantly different ($p<0.05$) from all sites in March and April. At each site South African scoring system scores did not differ significantly ($p>0.05$) with each sampling month (Table 7).

DISCUSSION

Biodiversity

Abundance

Significant differences in biodiversities among sampling sites in each sampling month indicated that water quality differed significantly among sampling sites. Highest abundance of pollution sensitive families at site R showed that water quality was the best at this site since these organisms cannot survive in polluted environments (Clements et al .,2000). The presence of pollution tolerant families such as chironomids indicates that some pollutants may be present at site R but they were not induced by the discharge of sewage into the stream since it was upstream of the point of discharge. These pollutants may have been introduced into the stream by runoff from cultivated farms or they may have been introduced from sewage discharges in the past upstream. However the extent of pollution was minimal since the site was dominated by sensitive families. According to Rosenberg and Resh (1993) higher diversity of organisms indicates good water quality therefore site R had the best water quality since it had highest taxa richness and Shannon wiener diversity index. Since site 1 had the highest abundance of tolerant families which are typically found in polluted environments (Clements et al .,2000) had the least water quality. Poorest water quality at site 1 was due to that it was downstream just after the point of inflow of sewage into the stream and pollutants would be in high concentrations at this point because they would have not gone under significant modifications by processes such as biodegradation and dilution. Most pollution sensitive families were absent at this site because water quality was greatly modified at this site.

A higher abundance of pollution tolerant families at site 2 indicated that the site was polluted however it was less polluted than site 1 since it had higher abundance of sensitive families than site 1 however water quality did not differ significantly in all sampling months because there were no significant differences ($p<0.05$) in abundance between these two sites. The site was polluted because it was downstream of the point of discharge of sewage into the stream however the re-emergence of sensitive families at the site indicates that the stream was starting to self purify through processes of dilution, sedimentation, biodegradation and other processes that reduce the concentration or the effects of pollutants (Babour et al .,1999). Site 3 had of pollution tolerant families still indicating pollution however pollution was minimal since almost all pollution sensitive families present at site R were present which indicate that the environment is healthy (Chutter, 1994) with the exception of two families. In February water quality at site 3 was not significantly different indicating that water quality greatly improved downstream in February and the improvement can be attributed to the self-purification capacity of the river or the dilution of pollutants due to increase in water volume downstream (Dallas, 1997). Abundances at each site did not differ significantly with each sampling month because sampling was done during the same season and thus sampling month did not have an effect on water quality at each site.

Taxa richness

Since taxa richness was highest at site R water quality was best at this site relative to other sites and differed significantly from all sites except site 3 in February. Best water quality at the site was because the site was upstream of the point of sewage inflow into the stream. Sites 1, 2 and 3 did not differ significantly in water quality because they were contaminated by sewage. In general, environmental perturbation reduces taxa richness to a few tolerant and generalist groups (Rosenberg and Resh, 1993) and thus site 1, 2 and 3 were impacted. The general increase in taxa richness from site 1 to site 3 indicated improvements in water quality going down the stream and this can be attributed to the self-purification process and dilution of contaminants by increase in water volume down the stream. In February site 3 taxa richness was not significantly different from site R indicating that water quality was almost similar to that of site R. This result can also be attributed to the self purification and dilution effect and in this month it could have been facilitated by high rainfall in previous months. Taxa richness at each site did not differ significantly with each sampling month because sampling was done during the same season and thus sampling month did not have an effect on water quality at each site.

Shannon Wiener diversity index

Shannon Wiener diversity indices also indicated that water quality was best at site R since a diverse community of organisms is indication of favourable environmental conditions and differed significantly from all sites throughout the sampling period. Downstream sites had poor water quality because they had lower biodiversity of benthic macroinvertebrates and this could have resulted from contamination by sewage since they were downstream. Site one had the poorest water quality since it had the least diversity on benthic macroinvertebrates and low diversity of benthic macroinvertebrates is an indication of poor water quality according to (Dickens and Graham, 2002). Site 2 had better water quality than site 1 since it had a higher diverse community of benthic macroinvertebrates and site 3 had the best water quality among downstream sites with the highest Shannon Wierner diversity index. The Shannon wiener diversity indices did not differ significantly among sites 1, 2 and 3 indicating that the sites did not differ significantly in water quality. There was a general increase in the diversity index from site 1 to site 3 throughout the sampling period indicating an improvement in water quality going downstream which can be attributed to the self-purification process and dilution effect. Shannon Wiener diversity indices at each site did not differ significantly with each sampling month because sampling was done during the same season and thus sampling month did not have an effect on water quality at each site.

Tolerance

Average Tolerance Score Per Taxon (ATSPT)

Significant differences in average score per taxon of site R from site 1 and site 2 in March and April indicates that water quality differed significantly between site R and these two sites. Site R had good water quality with few modifications with respect to ASPT as measured by comparing with standards in guidelines for interpreting water quality for SASS 5 (Appendix A2) this result was obtained because the site was upstream and sewage inflow into the stream did not have an effect on water quality at this site. However the few modifications could have been due to past pollution events or they could have resulted from runoff with pollutants from cultivated areas. Critical modifications with respect to ASPT in water quality at site 1 are due to the inflow of sewage into the stream and this site was greatly affected because it was downstream near the point of inflow of sewage and pollutants are highly concentrated at this site. Critical modifications in water quality with respect to ASPT at site 2 are also due to high concentrations of pollutants at this site. Moderate modifications in water quality with respect to SASS score at site 2 indicate an improvement in water quality and this is due to self purification processes of the stream and dilution of pollutants due to increase in water volume down the stream. Moderate modifications in water quality with respect to ASPT at site 3 indicate that the stream was recovering from pollution and the water quality was almost the same as that of the reference site. At site 3 the pollutants would have gone under significant processes of self-purification and dilution. Site 3 water qualities was significantly different from all downstream sites (site 1 and site 2) because at this site the stream water would have gone through significant processes of purification and dilution more than at site 1 and 2.

South African Scoring System Score

South African scoring system score at site R was significantly different ($p<0.05$) from site 1 and site 2 in all sampling months indicating that water quality differed greatly between the upstream site (site R) and downstream sites. Water quality was best at site R relative to other sites throughout the sampling period because it was upstream therefore it was not contaminated by sewage and remained natural as measured by South African Scoring system scores. Site 1 and site 2 were polluted because they were downstream and did not differ significantly in water quality. Good water quality at site 2 in February could have resulted from conditions during the time of sampling. Water volume might have been high in the previous months and could have enhanced the process of self purification and dilution. Site 3 was significantly different in water quality from site 1 and 2 because at this site the stream would have undergone significant processes of self-purification and dilution. Site 3 was not significantly different from site R in February because during this month self-purification and dilution processes could have been facilitated by large stream water volume and water quality at this site was comparable to that at site R. At each site South African scoring system scores did not differ significantly ($p>0.05$) with each sampling month because the sampling months did not have an effect on water quality.

SASS scores showed that some sites had better water quality while ASPT showed that they had lower water quality that that predicted by SASS however ASPT values are more consistent and should reflect the water quality of a site more accurately than SASS score, Chutter (1998), Dickens and Graham (2002) suggested that ASPT scores are more reflective of environmental water quality status of polluted rivers than SASS values.

CONCLUSION

Biodiversities among sampling sites differed significantly in each sampling month indicating that water quality among sampling sites differed greatly. Abundance, taxa richness and Shannon wiener diversity index all indicated that site R had good water quality since it had a more diverse community of macroinvertebrates than downstream sites. The difference in water quality between the upstream site and downstream site showed that the inflow of sewage into the stream decreased water quality of the stream. Water quality improved from site 1 to site 3 and this was attributed to self-purification and dilution processes in the stream. Since no significant differences in biodiversities at sites did not differ with each sampling month water quality did not change significantly in each sampling month at each site.

South African scoring system scores and average score per taxon at sampling sites in each sampling month differed significantly. Water quality differed significantly between the upstream site (site R) and downstream sites showing that the inflow of sewage into the stream reduced stream water quality. The outcomes also showed that water quality improved from the site 1 downstream and this was attributed to the self-purification and dilution processes as pollutants move downstream.

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Appendix A

A1. The relative abundances of macroinvertebrates sampled

Taxon	Site R	Site 1	Site 2	Site 3
PORIFERA	5	0	0	1
TURBELLARIA	7	32	27	22
Oligachaeta	8	68	47	29
Leeches	8	30	19	16
Aphipoda	11	1	0	6
Notonemouridae	41	1	2	13
Baetidae 1sp	12	1	2	2
Caenidae	5	16	2	4
Leptophebidae	17	0	1	2
Calopterygidae ST,T	64	2	8	15
Chlorocyphidae	65	1	4	13
Coenagrionidae	10	43	26	18
Aeshnidae	0	2	2	0
Corduliidae	17	2	1	4
Gomphidae	16	0	2	5
Pyriidae	15	0	0	2
Corixidae	6	59	46	25
Gerridae	10	30	22	14
Notonectidae	11	31	25	15
Nepidae	11	28	20	15
Naucoridae	7	2	0	2
Pleidae	11	34	30	13
Veliidae/M...veliidae	23	0	1	11
Corydalidae	44	1	2	5
Sialidae	31	0	5	4
Ecnomidae	3	10	7	2
Hydropsychidae 2sp	20	0	0	4
Philoptamidae	23	0	1	3
Polycentropodidae	14	0	2	4
Calamoceratidae SWC	7	0	0	1
Glossosomanidae SWC	2	0	0	0
Hydroptilidae	5	12	4	2
Leptoceridae	26	2	6	6
Dytiscidae	14	78	52	23
Elmidae/Dryopidae	33	2	2	10
Gyrinidae	5	34	21	13
Hydrophilidae	8	67	52	30
Psephenidae	34	4	5	9
Athericidae	18	0	1	3
Blepharoceridae	20	1	2	8
Ceratopogonidae	7	75	58	49
Chironomidae	56	545	424	336
Culucidae	20	179	159	129
Dixidae	32	2	5	9
Simulidae	19	3	5	5
Tabanidae	17	0	0	2
Tipulidae	17	0	0	1
Physidae	46	200	186	124

A2. Guidelines for interpreting water quality for South African Scoring System 5

Biological Band	**Water quality category name**	**Description**	**Range of SASS5 scores**	**Range of ASPT values**
E/F	Seriously/ critically modified	Seriously/ critically modified	< 62.9	< 5
D	Poor	largely modified	63 - 81.9	5.1 - 5.3
C	Fair	Moderately modified	82 - 99.9	5.4-5.9
B	Good	largely natural with few modifications	100 - 148.9	6.0-7.0
A	Natural	Unmodified	149 - 180	7.1-8