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Research Article
Assessment of Zambezi River Water Quality Using Macroinvertebrates Population Diversity

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Abstract
Background and Objective: The section of Zambezi river in Katima Mulilo has currently come under intense anthropogenic pressure due to the increasing economic activities in and around the river. The main objective of this study was to assess the river water quality using macroinvertebrates population. **Materials and Methods:** Samples of macroinvertebrates were collected on bi-monthly basis (January-November, 2015) at four different locations along the Zambezi river in Katima Mulilo. D-net (1µm) was used to trap the macroinvertebrate species using a three-minute single-habitat kick sampling method in which the net was swept five times per sites. At each sampling site, the abiotic factors: pH, temperature, dissolved oxygen and electrical conductivity of the river water were determined *in-situ* using a hand held multifunction sensor HQ40d portable meter and their levels compared with recommended freshwater quality criteria. **Results:** Sixty-two macro-invertebrates made up of 9 different species were recorded at two sampling points, Stone city and Bezi bar. The assessment of these macroinvertebrates based on pollution tolerance sensitivity scale revealed 54.84% (highly tolerance), 40.32% (moderately tolerance) and 4.84% (very low tolerance) to pollution categories. *In-situ* measurement of the abiotic factors revealed pH, temperature, dissolved oxygen and conductivities values of 6.68-8.93, 18.40-28.73°C, 5.01-7.92 mg L^{-1} and 37.73-105.27 µS cm^{-1}, respectively. **Conclusion:** The various pollution tolerances of the macroinvertebrates recorded in this study suggests varying degree of the river water contaminations. However, the levels of the abiotic factors were within reported safe limits for aquatic organisms. Therefore, further study should be undertaken to establish the chemical components' pollution status of the Zambezi river in order to provide a versatile baseline data for future monitoring of the river quality.

Key words: Macroinvertebrates, abiotic factors, quality criteria, Katima Mulilo, population diversity

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The increasing anthropogenic pressure in and around several freshwater bodies today has altered their natural compositions with attendant effects on the overall aquatic health. In the study on biological monitoring using macroinvertebrates as bioindicators of water quality of Maroaga stream, the authors opined that even pristine aquatic ecosystems can be threatened by anthropogenic activities[1]. Several research reports have also indicated the negative influence of human impacts, especially pollution, on macro- invertebrate fauna[2-8]. In separate studies on freshwater ecosystems, the authors noted that the special typology of macro-invertebrates makes them fragile and vulnerable to environmental changes, especially those related to disturbances of anthropogenic origin[9,5]. Furthermore, it was indicated that such disturbances often imply irreversible degradation of aquatic biota[9,5]. Due to anthropogenic effects, researchers have also reported significant changes in the chemical compositions of river water and communities of organisms living in the water environment[8,10,11].

Following a 10-years research on rivers with different degrees of anthropogenic impacts, the report held that freshwater contamination due to pollutants such as fertilizers, sewage, heavy metals and pesticides has become a serious problem worldwide[12]. Thus, with the proliferation of irrigation agriculture, hospitality and cottage industries along the bank of the Zambezi river, the water quality could face threat from non-point source pollutions and hence, the macro-invertebrate population. In an earlier research report, the author opined that increasing urbanization and industrialization generate different non-point sources of contamination and causing impairment of water quality of rivers[9]. According to the Environmental Protection Agency's report, non-point source pollution is the leading cause of water quality problems[13]. The report further indicated that the effects of non-point source pollutants on specific waters vary and may not always be fully assessed; however, these pollutants have harmful effects on drinking water supplies, recreation, fisheries and wildlife[13].

It has been reported that different groups of macro-invertebrates are excellent indicators of human impacts, especially contamination[12]. Most macro-invertebrates have quite narrow ecological requirements and are very useful as bioindicators in determining the characteristics of aquatic environments[14-16]. In addition, the ecological requirements of macro-invertebrates could be used to identify the segments of a polluted river where self-purification of organic inputs is under process[17]. As observed by earlier researchers, several freshwater macro-invertebrates maintain relatively fixed positions in the aquatic environment and thus, can reflect both short and long term shifts in water quality. In the book, "A Guide to Common Freshwater Invertebrates of North America", it was noted that freshwater invertebrates are very sensitive to stresses produced by pollution, habitat modification, or severe natural events, while others are more tolerant[18].

Earlier research report on freshwater biodiversity, importance, threats, status and conservation challenges showed that there are five major threat categories to freshwater biodiversity, namely, overexploitation, water pollution, flow modification, destruction or degradation of habitat and invasion by exotic species[19]. These threats are very evident along the Katima Mulilo length of the Zambezi river as the river has assumed a major economic source supporting irrigation agriculture, fishing and recreational activities in the area. Elsewhere in the Mediterranean region, over-exploitation of rivers and aquifers for irrigation has already been reported as a severe problem in many places[12]. This activity can lead to changes in physical and chemical characteristics[20] with adverse effect on macro-invertebrates population in the water ecosystem. At the moment, there is no known scientific monitoring of aquatic health of the Zambezi river which has lately come under intense anthropogenic pressure as a result of increasing economic activities in and around the river. Thus, a better understanding of the Zambezi river water quality through diversified studies has become expedient in order to devise management plan of the Katima Mulilo axis of the river. Improving researchers understanding of freshwater ecology is very important not only because of its biological implications, but also because the proper management of freshwater is of practical interest to mankind[21]. This study therefore, has the major objective of assessing the Zambezi river water quality in Katima Mulilo Namibia, based on macro-invertebrates' population diversity.

MATERIALS AND METHODS

Study area: The study area is the Zambezi river in Katima Mulilo located on 17°30′00″S and longitude 24°16′00″[22]. The Zambezi river has been identified as the fourth largest river in Africa after rivers Congo, Nile and Niger[23]. The river basin drains large agricultural fields where there is intensive usage of agrochemicals (chemical fertilizers and pesticides)[24]. Such activity constitutes pollution threat to the river due to its possibility to receive residual chemicals via surface run-off[24]. Apart from the proliferation of irrigation agriculture, there are also high fishing and recreational activities as well as increasing hospitality industries along the Zambezi river. These anthropogenic activities could seriously affect the

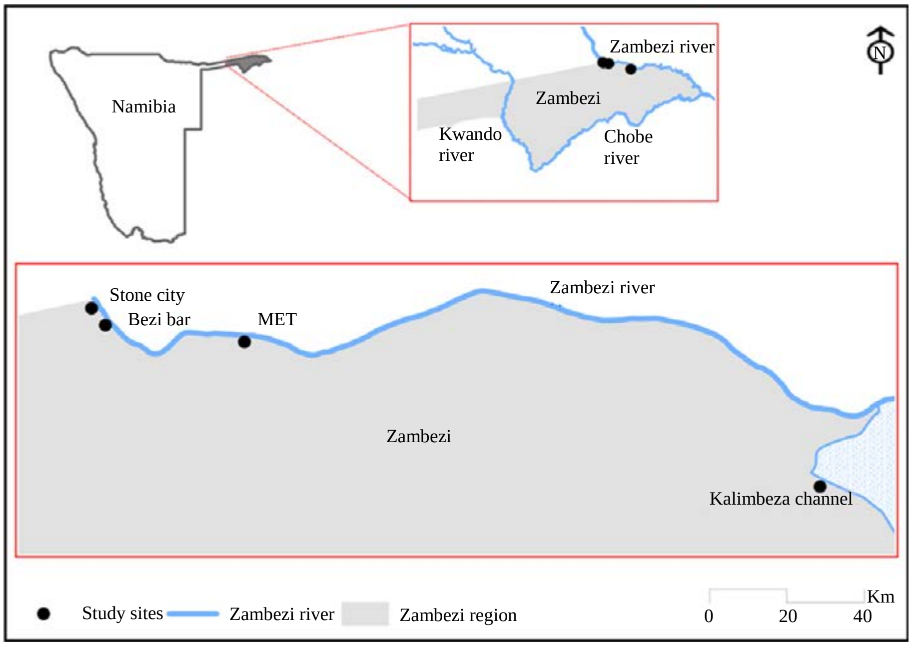

Fig. 1: Geographical map of Namibia showing the study area of Zambezi river
MET: Ministry of Environment and Tourism, Source, Field GPS data

natural aquatic health of the river. Thus, for the purpose of this study, four different locations were identified for sample collection along the Katima Mulilo axis of the Zambezi river. The map of Namibia representing the study area was shown in Fig. 1.

Sample collections and analyses

Macro-invertebrates: Samples of the macro-invertebrates were collected at four different locations: Stone city, Bezi bar, Ministry of Environment and Tourism (MET) and Kalimbeza channel along the Zambezi river in Katima Mulilo. The samples were collected using a 3 minutes single-habitat kick sampling method[25] formulated by Environmental Protection Agency and based on a methodology manual[26]. D-net (1 μm) was used to trap the macro-invertebrate species and the net was swept 5 times per sites. The samples were collected on bi-monthly basis in the first week of every sampling month from January to November, 2015. All collected samples of the macro-invertebrate were carefully washed out of the net, transferred into transparent containers and transported to the laboratory at the University of Namibia Katima Mulilo Campus for identification and quantification.

The identification of the macro-invertebrates was carried out using the aquatic invertebrates of South African rivers field guide[27] and the classification according to tolerance to pollution was based on the South African Scoring System (SASS) version 5 scoring system[28].

In order to assess the quality indicator of the Zambezi river water based on the macro-invertebrates population recorded over the sampling period, the percentage of macro-invertebrates that fall within a given pollution sensitivity scale was calculated using the following formula:

$$\text{Macroinvertebrate pollution sensitivity (\%)} = \frac{\sum \text{MSS}}{\sum \text{MR}}$$

Where:

ΣMSS = Total sum of macro-invertebrates in a given sensitivity scale

ΣMR = Total sum of macro-invertebrates recorded

The percentage macro-invertebrate pollution sensitivity was used to summarized the presence and pollution tolerance of the species present at a site.

Water: At each sampling site, water samples were collected at three random points using 1.5 L pre-acid washed plastic containers and used for the determination of pH, temperature, dissolved oxygen and conductivity of the river water. These parameters were determined *in-situ* using a hand held multifunction sensor HQ40d portable meter and their levels were compared with recommended freshwater quality criteria. All the sampling sites were marked and identified using a hand held Global Positioning System (GPS).

Table 1: Different macro-invertebrate species of the Zambezi river, Katima Mulilo axis

		Macro-invertebrate obtained per sampling location							
Common name	Family name	A	B	C	D	Total	Habit characteristics	Sensitivity scale[28]	Remarks
Small minnow flies	Baetidae	4	21	X	X	25	Stones, coarse sand, slow flowing water	1- 5	HTP
Prongills	Leptophlebiidae	9	X	X	X	9	Stones, submerged woods, slow flowing water	6-10	MTP
Crab	Potamonautidae	4	X	X	X	4	Under stones, slow flowing water	1-5	HTP
Caseless caddisflies	Philopotamidae	8	3	X	X	11	Under stones, fast flowing water	6-0	MTP
Biting midges	Ceratopogonidae	2	X	X	X	2	Coarse sand, river edges	1-5	HTP
Snail	Thiaridae	1	2	X	X	3	Coarse sand, slow flowing water	1-5	HTP
Damselfly	Platycnemididae	X	5	X	X	5	Under stones, fast flowing water	6-10	MTP
Flat-headed mayflies	Heptageniidae	X	2	X	X	2	Stones, submerged woods, moderate flowing water	11-15	VLTP
Water specs	Prosopistomatidae	1	X	X	X	1	Floating wood, fast flowing water	11-15	VLTP
Total recorded		29	33	0	0	62			
Percentage of pollution sensitivity of the macro-invertebrates								54.84%	HTP
								40.32%	MTP
								4.84%	VLTP

A: Stone city, B: Bezi bar, C: Ministry of Environment and Tourism (MET), D: Kalimbeza channel, X: Not detected, HTP: Highly tolerant to pollution, MTP: Moderately tolerant to pollution and VLTP: Very low tolerance to pollution

RESULTS AND DISCUSSION

Population diversity of the macro-invertebrates: The results in Table 1 showed the different macro-invertebrate species recorded at four different sampling points on the Zambezi river along Katima Mulilo during the study. A total of 62 macro-invertebrates were obtained from two sampling points, Stone city and Bezi bar while no macro-invertebrate was obtained at the Ministry of Environment and Tourism as well as Kalimbeza channel sampling points. This may be due to different habit characteristics of the sampling points. While Stone city and Bezi bar sampling points have features such as rocks, coarse gravels, submerged woods and mostly slow flowing water, the Ministry of Environment and Tourism and Kalimbeza channels are mostly characterized by inaccessible thick vegetations and fast flowing water. Rocks, coarse gravels, submerged substrates and slow flowing water have been identified as suitable freshwater habitats for macro-invertebrate species[27].

At the Stone city, seven different species of the macro-invertebrate were recorded. These include small minnow flies (n = 4), prongills (n = 9), crab (n = 4), caseless caddisflies (n = 8), biting midges (n = 2), snail (n = 1) and water specs (n = 1). At the Bezi bar, five macro-invertebrate species were recorded namely, small minnow flies (n = 21), caseless caddisflies (n = 3), snail (n = 2), damse fly (n = 5) and flat-headed mayflies (n = 2).

Based on the pollution tolerance sensitivity scale (PTSC)[28], the results (Table 1) showed that 54.84% of the macro-invertebrates fall within the highly tolerance to pollution category (PTSC, 1-5), 40.32% of them fall within moderately tolerance to pollution classification (PTSC 6-10) while only 4.84% fall within very low tolerance to pollution classification (PTSC, 11-15). The varying distributions of the macro-invertebrates across the sampling points with varying tolerance to pollution may suggest varying degree of the river water contamination across the length of the Zambezi river.

It has been reported that different groups of macro-invertebrates were excellent indicators of human impacts, especially contamination[1]. Therefore, various degrees of contaminations are probable in the study area because of the presence of diverse anthropogenic activities such as agriculture, recreational activities, fishing and hospitality industries across the Katima Mulilo axis of the Zambezi river. The study on the influence of stream habitat and water quality on water beetles assemblages in two rivers in Northwest Spain, the authors observed that one of the major impacts that affect rivers is the pollution of their waters by both domestic and industrial wastes[14]. Also, agriculture with intensive use of fertilizers and pesticides has contributed significantly to eutrophication and contamination of aquatic ecosystems[29].

Abiotic factors of the river water

pH: The pH of the Zambezi river water during the study period is shown in Fig. 2. The results obtained varied between 6.68-8.93. Within the same sampling month, the analysis of variance in the pH levels between sampling points was not statistically significant ($p>0.05$) except between the sampling months of September and November. This may be due to the transition in water quality from the peak of dry season (September) to the on-set of rainy season (November) in the study area. During rainy season, the river flowed from

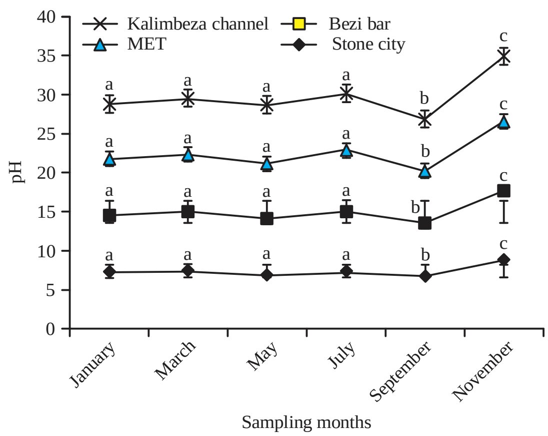

Fig. 2: Variation in mean pH levels of the river water across the sampling months,
MET: Ministry of Environment and Tourism, The same alphabets showed that within the same sampling month, the analysis of variance in the pH levels between sampling points was not statistically significant (p>0.05) except between the sampling months of September and November

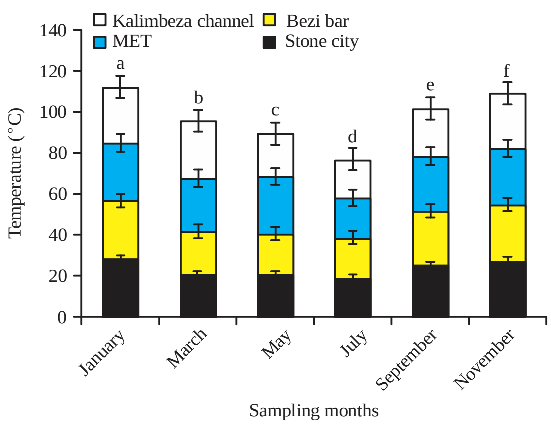

Fig. 3: Variations in mean temperature (°C) levels of the river water across the sampling months
MET: Ministry of Environment and Tourism, Alphabets showed that within the same sampling month, the analysis of variance in the levels of temperature between sampling points was not statistically significant (p>0.05) but the results differed statistically (p<0.05) between sampling months

upstream and carried a lot of dissolved substances and surface run-off from agricultural lands which were capable of altering the water pH. The pH being one of the most important water quality parameters has been found to have profound effects on the ecology of macro-invertebrates in aquatic systems[30]. The pH affects the dissolved oxygen level of the water, photosynthesis of aquatic organisms (phytoplankton) and the sensitivity of these organisms to pollution, parasites and diseases[31]. Although, benthic macro-invertebrate sensitivities to pH vary[32], research reports indicated that river water pH values below 5.0 and greater than 9.0 were considered harmful[30]. The United States Environmental Protection Agency (USEPA) also indicated that a pH range of 6.5-9.0 provides adequate protection for the life of freshwater fish and bottom-dwelling macroinvertebrates[33]. Thus, the pH range of the Zambezi river recorded during the study period was not considered as a risk factor affecting the macro-invertebrates population diversity of the river.

Temperature: The results in Fig. 3 showed the temperature (°C) of the Zambezi river water during the study period. The temperature obtained varied between 18.40-28.73°C. Within the same sampling month, the analysis of variance in the levels of temperature between sampling points was not statistically significant (p>0.05) but the results differed statistically (p<0.05) between the sampling months. This may be due to fluctuations in climatic factors throughout the year. As stated by Hussain and Pandit[30], river water temperature is an important ecological factor related to the latitude, altitude, season and in spring fed or lake fed streams to the distance from the source. The benthic macroinvertebrates have evolved to live within a specific temperature range, which limits their distribution and affects the community structure[34].

Temperature affects their emergence patterns and growth rates[35], metabolism[36], as well as reproduction[37]. Macro-invertebrate species vary in their tolerance to temperature ranges, but few were able to tolerate temperatures beyond their upper tolerance limit[36]. According to Virginia Department of Education's report, a temperature of <20°C is optimal for all organisms, 20-25°C is optimal for most organisms, 25-32°C is too warm for some organisms, while >32°C is too hot for most organisms. Thus, the range of temperature recorded in this study suggests that apart from Kalimbeza channel and Ministry of Environment and Tourism sampling points, the temperature values recorded in the months of March, May and July are within the optimal conditions classifications while the temperature values recorded in January, September and November fell within the too warm classification. This may partly account for why no macro-invertebrate was recorded at the Kalimbeza channel and Ministry of Environment and Tourism sampling points during the study period as these sampling points have characteristically too warm temperature which could affect sensitive organisms' habitation.

Dissolved oxygen: The results (Fig. 4) presented the dissolved oxygen (DO) of the Zambezi river water during the study period. The results obtained showed that the water's DO varied between 5.01-7.92 mg L^{-1}. The analysis of variance in the DO levels between sampling points was not statistically

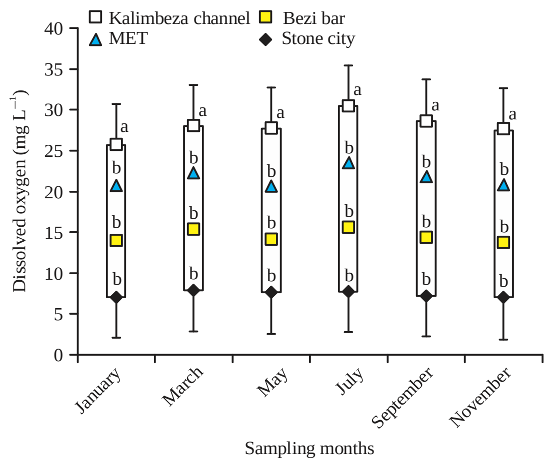

Fig. 4: Variation in mean levels of dissolved oxygen (mg L^{-1}) of the river water across the sampling months
MET: Ministry of Environment and Tourism, Alphabet showed that the analysis of variance in the DO levels between sampling points was not statistically significant (p>0.05) except at the Kalimbeza channel sampling point

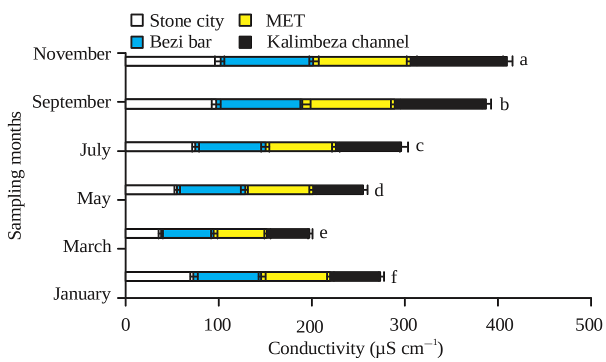

Fig. 5: Variation in mean conductivity (µS cm^{-1}) levels of the river water across the sampling months
MET: Ministry of Environment and Tourism, Alphabets showed that analysis of variance in the conductivity levels between sampling points was statistically significant (p < 0.05)

significant (p>0.05) except at the Kalimbeza channel sampling point. The concentration of dissolved oxygen (DO) was one of the most important parameter to indicate water purity and to determine the distribution of various aquatic insect groups[38]. Generally, the DO levels recorded in this study was within reported safe limit of 5 mg L^{-1} for aquatic organisms[39]. In a different report, the Virginia Department of Education stated that DO of 4.0-7.9 mg L^{-1} is adequate to support aquatic organisms. Thus, the DO levels recorded in this study suggested that the Zambezi river water contained dissolved oxygen sufficient enough to support many aquatic lives during the study period. Among the dissolved gases, dissolved oxygen played the most important role with regard to water quality[39] and it is a critical factor for aquatic organisms' respiration[40]. Therefore, dissolved oxygen was among the determining factors for the survival and growth of aquatic organisms[39].

Conductivity: The results of the conductivity of the Zambezi river water during the study period was shown in Fig. 5. The results obtained varied between 37.73-105.27 µS cm^{-1}. The analysis of variance in the conductivity levels between sampling points was statistically significant (p<0.05). Conductivity was a function of total dissolved solids known as ion concentration, which determined the quality of water[41]. Water conductivity provides a rapid means of obtaining approximate knowledge of total dissolved solids concentration and salinity of water samples[42]. Several factors influence the conductivity of water bodies, namely, temperature, ionic mobility and ionic valencies[43,44]. The electrical conductivity of water served as an indicator of other water quality problems[45]. If the conductivity of a stream suddenly increased, it indicated that there is a source of dissolved ions in the vicinity. Therefore, conductivity measurements can be used as an efficient way to locate potential water quality problems[46]. According to an earlier research report, the conductivity of most streams range between 50-1500 µS cm^{-1} while freshwater should have conductivity between 150-500 µS cm^{-1} to support diverse aquatic life[47]. Elsewhere in the United States, EPA[48] reported that the conductivity of rivers generally ranges from 50-1500 µmhos cm^{-1} while studies of inland fresh waters indicate that streams supporting good mixed of fisheries have conductivity range between 150 and 500 µhos cm^{-1}. The report further indicated that conductivity outside this range could indicate that the water was not suitable for certain species of fish or macroinvertebrates[48].

CONCLUSION AND FUTURE RECOMMENDATIONS

This study recorded a total of 62 macro-invertebrates made up of nine different species. Based on their assessment using pollution tolerance sensitivity scale, the greater percentage (54.84%) of the macro-invertebrates fall within highly tolerance to pollution category while only 4.84% fall within very low tolerance to pollution classification, the rests fall within the moderately tolerant category. The various degrees of pollution tolerance sensitivities of the macro-invertebrates suggest varying degree of the Zambezi river contamination at the time of this study. However, the levels of the pH, temperature, dissolved oxygen and conductivity of the river water were within reported levels that can support diverse aquatic lives. Thus, this study recommends further studies to establish the chemical parameters pollution status of the river.

The macro-invertebrates sampling in this study was affected by thick vegetative cover coupled with very fast flowing water at two sampling points where no species was recorded. Therefore, similar future research should consider the accessibility of the sampling points. Furthermore, in planning for successful macro-invertebrates sampling, consideration should be given to the portion of the river with slow moving water.

SIGNIFICANCE STATEMENT

Despite the increasing economic activities in and around the Zambezi river in the Katima Mulilo area which has inadvertently put the water ecosystem under intense anthropogenic pressure, there is no known scientific monitoring of the aquatic health of the river. This study, therefore, provides baseline data necessary for assessing the river water quality based on macro-invertebrates population diversity. This is necessary for future monitoring of the aquatic health. The present study also made useful recommendations for further research in order to establish a versatile baseline data of the pollution status of the river. This is critical for monitoring the impact of the increasing anthropogenic activities on the health of the river system.

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