Journal of Water Resource and Protection, 2023, 15, 393-412
https://www.scirp.org/journal/jwarp
ISSN Online: 1945-3108
ISSN Print: 1945-3094

Macroinvertebrates as Bio Indicators of Water Quality in Pinyinyi River, Arusha Tanzania

Rajabu Ramadhani Omary[1*], Makarius C. S. Lalika[1,2], Mariam Nguvava[1], Emmanuel Mgimwa[3]

[1]Department of Geography and Environmental Studies, College of Natural and Applied Science (CoNAS), Sokoine University of Agriculture, Morogoro, Tanzania
[2]UNESCO Chair on Ecohydrology and Transboundary Water Management, College of Natural and Applied Science (CoNAS), Sokoine University of Agriculture, Morogoro, Tanzania
[3]Nature Tanzania, Arusha, Tanzania
Email: *rajabuomary35@gmail.com

How to cite this paper: Omary, R.R., Lalika, M.C.S., Nguvava, M. and Mgimwa, E. (2023) Macroinvertebrates as Bio Indicators of Water Quality in Pinyinyi River, Arusha Tanzania. *Journal of Water Resource and Protection*, **15**, 393-412.
https://doi.org/10.4236/jwarp.2023.158023

Received: April 28, 2023
Accepted: August 11, 2023
Published: August 14, 2023

Abstract

Rivers are important for aquatic biodiversity. Anthropogenic activities degrade rivers and decrease their capacity to offer ecosystem services. This study used macroinvertebrates to assess the impact of anthropogenic activities on the Pinyinyi River during dry and wet season. Abundance of macroinvertebrates, average score per taxon and Shannon Weiner Species Diversity Index were used to state the ecological status of Pinyinyi River. Because the abundance of macroinvertebrates can be affected by change in water quality, some of the physicochemical parameters were also measured. A macroinvertebrates hand net is used to collect the macroinvertebrates per sampling point. DO, temperature, pH, turbidity and TDS were measured *in-situ* using HI-9829 Multiparameter and BOD was measured in the laboratory using Oxydirect levibond method. A total of 164 macroinvertebrates were collected and identified from Pinyinyi River during dry and wet season. They belong to 13 families. The most abundant taxa were mosquito larva, Diptera (41.07%) and aquatic caterpillar, Lepidoptera (23.21%) during dry season representing about 64.28% of the total macroinvertebrates whereas the least abundant taxa were pouch snail (16.07%) and dragonflies, Odonata (19.64%) during dry season representing about 35.72% of the total macroinvertebrates. The most abundant taxa collected during wet season were aquatic earthworm, haplotaxida (19.44%), midges, Diptera (17.59%), black flies, Diptera (15.74%) and creeping water bugs, hemiptera (12.96%) whereas the least abundant were pigmy back swimmers, hemiptera (2.78%), snail (3.7%), predacious dividing beetle (4.63%) and coleopteran (4.63%). Average Score per taxon of Pinyinyi River during dry season was 5.25 and 3.6 during wet season. The Shannon Weiner Species Diversity Index was 1.318 during dry season and 2.138 during wet season. Based on the score, Pinyinyi River is moderately polluted during dry season and seriously polluted during wet season. Based on index, Pinyinyi River has low diversity of macroinvertebrates during dry season and highly in diversity of macroinvertebrates during wet season. Moreover, it was found that, agricultural activities, livestock keeping, bathing and washing alter physicochemical parameters of Pinyinyi River and hence change the abundance of macroinvertebrates as well as the quality of water. The study, therefore, recommends that the source of pollutants should be controlled and the river regularly monitored by the relevant authorities.

Keywords

Bioindicators, Ecosystem Services, Macroinvertebrates, Shannon Weiner Diversity Index, Water Pollution, Water Quality

1. Introduction

Rivers are among the important fresh water ecosystems used for a variety of life-sustaining purpose [1]. These water resources serve multiple functions, most of them being critical to human settlement and survival. For example, river water resources are important for domestic uses, agriculture, habitat and biodiversity, water supply, soil and sediment regulation, nutrient regulation, cultural values aesthetics and livestock keeping [2] [3]. River water also plays a big role in maintaining the tourism activities in certain areas due to water availability for wild ecosystems. Anthropogenic activities such as deforestation, unsustainable agricultural activities, overgrazing and water abstraction are described as threats to river ecosystem [2]. These activities have negative impact ranging from declining water quality to the total destruction of the fresh water ecosystem [1] [4] [5]. Suthar *et al.* [6] reported that rapid population growth, and land development along the river subjected the rivers to increase stress, giving rise to water pollution and environmental deterioration.

Lalika *et al.* [2] reported that, Pangani and Wami Ruvu Rivers are polluted due to small scale-irrigation, excessive harvesting of forest products, mining and overgrazing. Based on documentations it shows that river pollution in Tanzania is mainly due to agriculture, industrial and livestock activities [2] [3] [7]. Therefore, these trends on human disturbances over aquatic ecosystem require serious follow-up. Monitoring of water quality is necessary particularly where the water is used as sources of drinking water [8]. Sharifinia *et al.* [9] reported that the selection of suitable bio-indicators used to evaluate the status of water quality and environmental conditions are crucial component in water resource assessment. Bio-indicators present in aquatic environment are a mirror of water quality. Bio-indicator is defined as a species or a community of fauna that reflects the abiotic and biotic status of an environment and represents the effect of environmental alteration on habitat and community or ecosystem [10]. To understand the status of water quality and to reduce the pollution rate in our water ways (stream and rivers), knowledge about status of aquatic environment including biodiversity is important [11]. This can be done by using various recognized macroinvertebrates as bio-indicator [10]. Ojija and Laizer [10] documented that macroinvertebrates have been widely used as bio-indicators in many developed countries such as Canada, Europe and the United States and are included in their national and technical standards of water quality monitoring. Among these bio-indicators, the most frequently used are the macroinvertebrates [12]. Therefore, it is important to use macroinvertebrates to assess water quality, especially in developing countries such as Tanzania.

The abundance of macroinvertebrates present in aquatic environment is a mirror of water quality [12]. This is due to the fact that different taxa of aquatic macroinvertebrates have different requirements to live [11]. Ojija and Laizer [10] documented that some macroinvertebrates need cooler temperatures, moderately high dissolved oxygen levels or certain habitat while others can survive where there are low dissolved oxygen levels or more sediment and or where the water temperature is warmer. Fresh water macroinvertebrates have been divided into three groups or classes, one is pollution-sensitive organisms, that need good water quality to survive and they may require clear or non-turbid water and or high dissolved oxygen levels, such as stonefly, water penny, mayfly and caddis fly [13]. Another group is of moderately pollution-tolerant organisms, that can survive in fair water quality and their habitat requirements are not as strict as pollution-sensitive organisms, for example, crane fly, crayfish, dragonfly, damselfly, sow bugs, clams and scuds [12]. Moreover, pollution tolerance organisms, which can survive in poor water quality and their adaptation, allow them to survive in turbid water, nutrient-enriched waters or in water with low dissolved oxygen, for example leeches, pouch nails, aquatic worms, midges, water striders, back swimmers, water bugs and true bugs [10]. Furthermore, macroinvertebrates are easy to collect and identify [1]. These features make macroinvertebrates among the low-cost and quick water quality monitoring methods to assess the water quality and ecological health of Rivers [1].

Pinyinyi River found in northern Tanzania is currently facing an uncertain future due to unsustainable anthropogenic activities such as unsustainable agriculture activities, water diversion, deforestation and overgrazing [14]. Pinyinyi River shows ecosystem deterioration and reduction of its services due to mentioned unsustainable anthropogenic activities, but to what extent is still unknown. Because Pinyinyi River pours its water to Lake Natron Ramsar Site (LNRS), the water quality and quantity of the Lake are also affected [14]. Change in water quality and water level of Lake, affected the breeding and feeding sites of Lesser Flamingoes and other aquatic fauna [14]. However, the death of Lesser Flamingoes is also increased (**Figure 1**).

Mezgebu *et al.* [1] reported that dissolved oxygen, water turbidity, phosphate, nitrate and ammonium in the LNRS were poor and threatened the breeding, feeding and death of Lesser Flamingoes. However, the study was conducted on

Figure 1. Dead flamingoes at Lake Natron Ramsar site.

the lake waters and didn't consider data from Pinyinyi River which is intensively utilized for agricultural activities associated with the use of industrial fertilizers, herbicides, insecticides and pesticides. Furthermore, overgrazing, deforestation, water diversion, bathing and washing is also threats the ecological health of Pinyinyi River. This study intended to bridge the missing link to check the water quality of river and to come up with different monitoring techniques to reduce the death of Lasser Flamingoes. The study used macroinvertebrates to assess the impacts of anthropogenic activities on Pinyinyi River. Because the abundance of macroinvertebrates can be affected by poor water quality caused by anthropogenic activities such as agricultural activities, overgrazing, bathing and bathing, few physicochemical parameters namely, BOD, DO, temperature, turbidity, pH and TDS were also measured to state the ecological status of Pinyinyi River. The important of this study was to establish the impacts of anthropogenic activities conducted at Pinyinyi River on the river water quality to safeguard the Lesser Flamingoes in the Lake. The findings of this study are crucial to providing recommendations to the Ngorongoro District Council, Arusha regional government, Tanzania Wildlife Management Authority and other stakeholders on the best approaches for sustainable management of Pinyinyi River.

2. Materials and Methods

2.1. Description of the Study Area

The study carried out along Pinyinyi River in Pinyinyi ward at Ngorongoro district, Arusha, Tanzania in three sampling sites namely upstream (U_1 and U_2), midstream (A_1 and A_2) and downstream (M_1 and M_2) (**Figure 2**). Upstream points (U_1 and U_2) are defined as a point where there are no any anthropogenic activities taking place because the land is covered by hard rock. Upstream points were used as the reference points because there was very minimal level of disturbance. Animal pollutants washed away to the river during rainfall and affect the level of water quality in the river. Agricultural points (A_1 and A_2) defined as

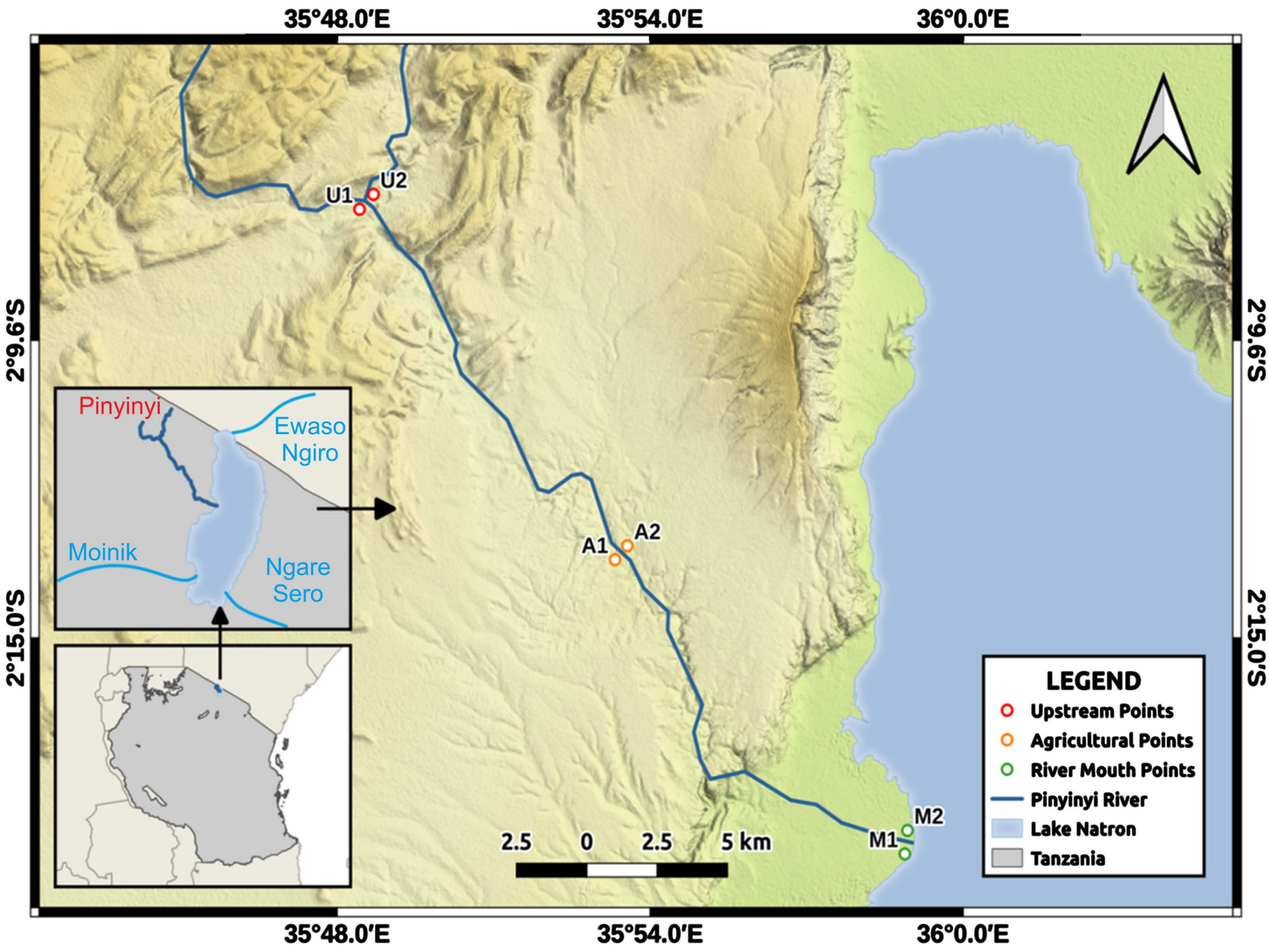

Figure 2. Map showing the location of the study area.

the points where agricultural activities, livestock keeping, bathing, washing, sand mining and water diversion taking place. Herbicide, pesticides and industrial fertilizers are washed away to the river which also contributes to change in water quality. River mouth points (M_1 and M_2) are defined as a point where livestock keeping is taking place, no agricultural activities taking place, because the land is covered by soda ash. Animal feces washed away to the river during irrigation and rainfall, which causes an increase in organic pollutants that, lowered the level of dissolved oxygen in the river. To control this, the study suggested sustainable agricultural activities. Moreover, the source of water for animal must be constructed far away from the river. The sampling site was classified based on the slope of the River and speed of water. The speed of water upstream is high compared to midstream and downstream.

The whole catchment of LNRS covers approximately 7600 km^2 [15]. This catchment is made up of four major rivers: the Ewaso Ngiro River, Pinyinyi River, Ngaresero River and Moinik River [14]. No human activities take place around Ewaso Ngiro River because it is a conserved area. Land type around Monic and Ngaresero Rivers are covered by hard rocks and soda ash which do not influence any human activities. Intensive agricultural activities and livestock keeping are carried out around Pinyinyi River. Pinyinyi River receives water from Ngorongoro and Serengeti national parks and drains its water to the Lake Natron Ramsar Site which is the feeding and breeding site of Lesser Flamingos. Along the Pinyinyi River, there are an estimated 6574 peoples who rely on irrigated agriculture and livestock keeping for their livelihoods [16].

The climate of the area is tropical and characterized by the interaction of the southwest monsoon winds as well as the southeast and northeast trade wind. The surrounding area of the Lake receives irregular seasonal rainfall, mainly between December and May totaling 800 mm per year. Temperature around the catchments is about 28˚C and that of the Lake is frequently above 40˚C (104˚F) [16]. The natural land cover classes around LNRS include sand, bare land, rocks, vegetation and water.

2.2. Data Collection

2.2.1. Water Quality

According to water quality analysis standard methods developed by APHA [17], DO, temperature, pH, turbidity and TDS were measured *in-situ* at each sampling site using portable multi-parameter analyzer, HANNA HI 9829 (**Figure 3(a)**). Triplicates of 500 mL of water samples were collected from each sampling site. The collected samples were tightly closed and kept in the cool box which was maintained at 4˚C for further BOD analysis in the Laboratory conditions. Global Position System (GPS) coordinates were recorded at each sampling site (**Table 1**). In the Laboratory, 360 mL of water sample was measured into the BOD bottle. The water sample in the BOD bottle was mixed with ten drops of Allyl Thiourea (ATH inhibitor), magnetic stirring rod, and three drops of 45% of potassium hydroxide solution in seal gasket (**Figure 3(b)**). After mixing, the BOD bottle was tightly closed and the BOD incubator with temperature about 20˚C was used to incubate the samples for five days. After five days the BOD values was recorded.

(a) (b)

Figure 3. (a) Onsite and (b) Laboratory analysis of physicochemical parameters.

Table 1. Sampling site location at Pinyinyi River.

Site No.	Site name	Latitude	Longitude
1	Upstream	2˚13'50.31"S	35˚53'34.47"E
2	Midstream	2˚16'21.34"S	35˚54'58.39"E
3	Downstream	2˚17'44.94"S	35˚58'31.79"E

2.2.2. Macroinvertebrates

Four biotopes were distinguished at each sampling point namely vegetation, gravel, sand and mud (GSM). A macroinvertebrates hand net with 250 µm mesh size was used to collect the macro invertebrates per each sampling points (upstream, midstream and downstream). The upstream sampling point was covered by gravel and sand biotopes, the midstream sampling point was covered by stones and the downstream sampling point was covered by vegetation, sand and mud biotopes. In the vegetation biotopes, the net was used to sweep the underneath of the riparian vegetation over a distance of 2 m in order to capture the macroinvertebrates that are present in water [12]. In each biotope sampling was carried out for 2 - 5 five minutes to capture the present macro-invertebrates. The GSM biotopes were disturbed by kicking whilst holding the hand net in opposite direction to the water current and continuously sweeping the net over the disturbed area to catch the free organisms for 2 - 5 minutes [18]. The dry season collection was November, 2021 and wet season collection was February, 2022. Collected macroinvertebrates were washed down to the bottom of the net using clear water and the contents were tipped into a white sorting tray for on-site identification (**Figure 4(a)**). Identification was done using the Aquatic Invertebrates of South African Rivers field guidebook. After completing the identification process; the identified taxa were turned into the river. The average score per taxon (ASPT) was calculated by taking the sensitivity score divide by total number of species identified during dry and wet seasons. The average score per taxon was calculated by taking the sensitivity score divide by total number of species identified during dry and wet seasons. The abundance of macroinvertebrates was calculated using Shannon Weiner Species Diversity Index.

$$\text{ASPT}(\text{dry season}) = \frac{\text{Sensitivity score}}{\text{Total number of identified group of species}} = \frac{21}{4} = 5$$

$$\text{ASPT}(\text{wet season}) = \frac{\text{Sensitivity score}}{\text{Total number of identified group of species}} = \frac{36}{10} = 3.6$$

$H = -\sum PiLNPi$

where:

H = Shannon Weiner Species Diversity Index;

Pi = the relative proportion (n/N) of the individual of one particular species found;

LNPi = the natural logarithm (LN) of the value Pi;

(a) (b)

Figure 4. (a) Collection and analysis of macroinvertebrates and (b) Some of the macroinvertebrates collected from Pinyinyi River.

Σ = summation of the outputs with the final value multiplied by negative one (−1).

2.3. Data Analysis

2.3.1. Water Quality Analysis

Descriptive statistics of physicochemical parameters data of the results were done using Statistical Package for Social Scientists (SPSS). The values were compared with Tanzania drinking water quality standard (2008) and World Health Organization guideline (2008) for drinking water. The comparison was done in order to check whether the measured values are within both national and international required standard limits. These standards were used to categorize the status of the river as to guide the allowable required standard limits of each selected water parameters in Pinyinyi River.

2.3.2. Macroinvertebrates Analysis

Aquatic invertebrates of South African Rivers field guidebook was used to record the sensitivity score, common name and scientific name of each taxon in each sampling site [19]. The average score per taxon was calculated by taking the total sensitivity score and the total number of identified groups of species from each sampling site. From the calculated average scores per taxon (ASPT), TARISS *fupi* was used to state the status of the water quality and the health of Pinyinyi River (Sand type River) during dry and wet seasons. Shannon Weiner Species Diversity Index was used to compute the abundance and diversity of macroinvertebrates.

3. Results

3.1. Water Quality

See Table 2 and Table 3 and Figures 5-10.

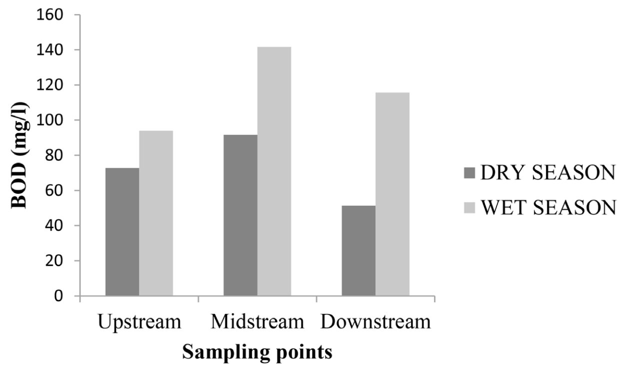

Figure 5. Variation of BOD at Pinyinyi River sampling sites during dry and wet seasons.

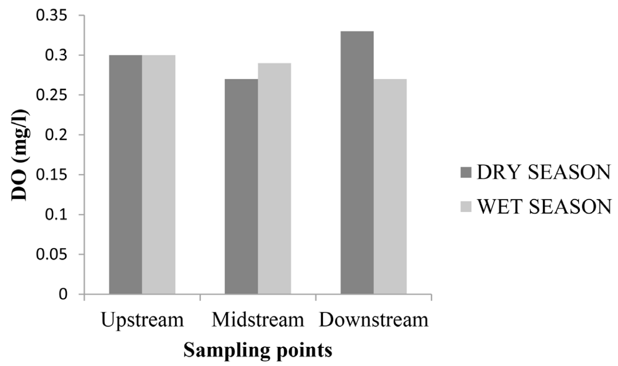

Figure 6. Variation of DO at Pinyinyi River sampling sites during dry and wet seasons.

Table 2. Physicochemical parameters (mean ± standard deviation) of samples analyzed during dry season in three sampling site.

Parameters	Unit	Upstream	Midstream	Downstream	TBS	WHO
BOD	mg/L	72.67 ± 6.81	91.67 ± 5.86	51.33 ± 7.57	2 - 6	10
DO	mg/L	0.297 ± 0.01	0.27 ± 0.02	0.32 ± 0.02	5 - 7	8 - 10
Temperature	˚C	30.0 ± 0.78	30.0 ± 0.78	29.0 ± 0.78	20 - 25	20 - 25
pH	Unit	8.20 ± 0.10	8.00 ± 0.10	8.17 ± 0.153	6.5 - 8.5	6.5 - 8.5
Turbidity	NTU	19.20 ± 0.82	18.73 ± 0.252	44.67 ± 0.52	25	5
TDS	mg/L	119.00 ± 1.00	128.67 ± 1.53	111.33 ± 1.53	1000	500

Table 3. Physicochemical parameters (mean ± standard deviation) of samples analyzed during wet season in three sampling site.

Parameters	Unit	Upstream	Midstream	Downstream	TBS	WHO
BOD	mg/L	94 ± 9.54	141.67 ± 6.51	115.67 ± 12.50	2 - 6	10
DO	mg/L	0.31 ± 0.01	0.29 ± 0.04	0.27 ± 0.02	5 - 7	8 - 10
Temperature	˚C	29.0 ± 0.78	29.0 ± 0.78	29.0 ± 0.78	20 - 25	20 - 25
pH	Unit	8.63 ± 0.252	7.61 ± 0.12	7.58 ± 0.16	6.5 - 8.5	6.5 - 8.5
Turbidity	NTU	6.00 ± 0.46	5.80 ± 0.46	6.13 ± 0.31	25	5
TDS	mg/L	78.67 ± 0.58	79.33 ± 0.58	82.00 ± 1.00	1000	500

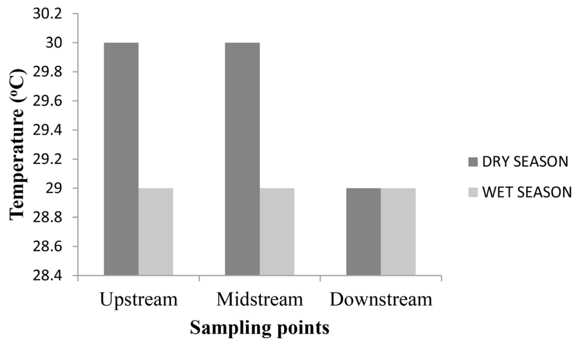

Figure 7. Variation of Temperature at Pinyinyi River sampling sites during dry and wet seasons.

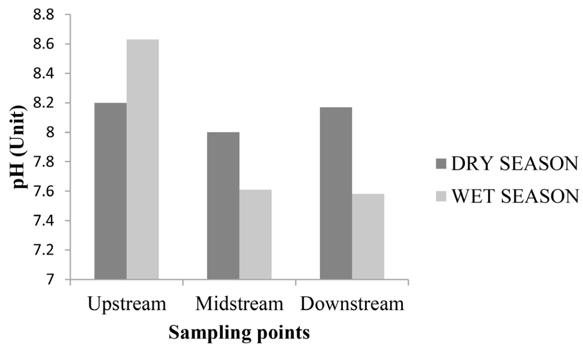

Figure 8. Variation of pH at Pinyinyi River sampling sites during dry and wet seasons.

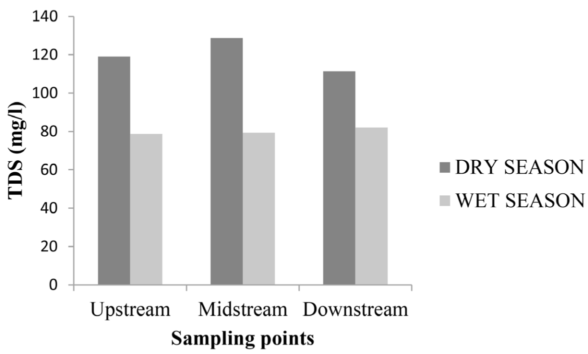

Figure 9. Variation of TDS at Pinyinyi River sampling sites during dry and wet seasons.

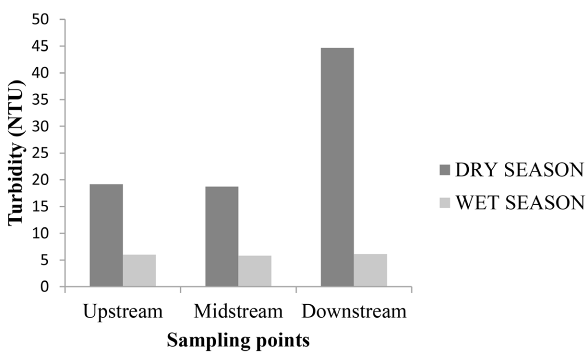

Figure 10. Variation of Turbidity at Pinyinyi River sampling sites during dry and wet seasons.

3.2. Macroinvertebrates

In this study, a total of 164 macroinvertebrates were collected and identified from Pinyinyi River during dry and wet season (**Table A1** and **Table A2**). They belong to 13 families. The most abundant taxa were mosquito larva, Diptera (41.07%) and aquatic caterpillar, Lepidoptera (23.21%) during dry season representing about 64.28% of the total macroinvertebrates whereas the least abundant taxa were pouch snail (16.07%) and dragonflies, Odonata (19.64%) during dry season representing about 35.72% of the total macroinvertebrates. Macroinvertebrates collected during wet season are represented in **Table A2**. The most abundant taxa were aquatic earthworm, haplotaxida (19.44%), midges, Diptera (17.59%), black flies, Diptera (15.74%) and creeping water bugs, hemiptera (12.96%) whereas the least abundant were pigmy back swimmers, hemiptera (2.78%), snail (3.7%), predacious dividing beetle (4.63%) and coleopteran (4.63%). During dry season, the sampling site with large number of macroinvertebrates was downstream (23) and that of the least number of macroinvertebrates was the midstream (11). The sampling site with large number of macroinvertebrates during wet season was midstream (45) and that of the least number of macroinvertebrates was upstream (29) (**Table A2**). These sensitivity scores represent the presence of indicator groups in the sample. It was found that, the calculated average score per taxon during dry season and wet season of Pinyinyi River indicate that, Pinyinyi River was moderately polluted (ASPT = 5.25) and seriously polluted (ASPT = 3.6) respectively. It was found that, somewhat pollution tolerant macroinvertebrates group (Moth flies, predacious dividing beetles, dragonflies, water mites, snail) was collected during dry and wet season and tolerant to pollution (pouch snails, midges, pigmy back swimmers and aquatic earthworm) was also collected during dry and wet season.

4. Discussion

4.1. Water Quality

Biological oxygen demand (BOD)

BOD measures the quantity of oxygen required by bacteria for breaking down to simpler substances of the decomposable organic matter present in water [6]. BOD is an important parameter in the aquatic ecosystem since it shows the status of pollution [20]. The greater the BOD, the more rapidly oxygen is depleted in the water body, because microorganisms are using up DO. The consequences of high BOD are the same as those of low DO where aquatic organisms become frazzled suffocate and die [20].

The average concentration of BOD of Pinyinyi River at upstream, midstream and downstream during wet and dry seasons were 83.33 ± 13.84, 116.67 ± 27.94 and 83.50 ± 36.43 mg/L (**Table 2** and **Table 3**). The maximum BOD values were recorded at midstream sampling point during wet and dry seasons (**Figure 5**). The concentration of BOD above 6 mg/L adversely affects aquatic organisms. Thus, in the present study, BOD from upstream, midstream and downstream were not within the permissible limit [21] [22]. These maximum values of BOD recorded, could be due to agricultural activities, surface runoff, bathing, washing, livestock keeping and underground water movement containing leachates from the solid waste landfill found in Pinyinyi leading to an increase in organic pollution [23].

Dissolved oxygen (DO)

DO is the quantity of gaseous oxygen dissolved in an aqueous solution. Suitable dissolved oxygen is necessary to withstand aquatic biota. Oxygen content is important for the direct need of many organisms and affects the solubility of many nutrients and periodicity of aquatic ecosystem [24]. In summertime dissolved oxygen decreases due to upturn in temperature and increased microbial activities. The lowest acceptable dissolved oxygen concentration for aquatic life, range from 6 mg/L in warm water to 9.5 mg/L in cold water [22]. DO play a role of regulator of metabolic activities of organisms and thus manages metabolism of the biological community as a whole and used as an indicator of tropical status of the water [6]. Low DO is an indication that, the aquatic ecosystem is degraded and some organisms that use aerobic conditions will not be able to survive due to lack of oxygen [20].

The average concentration of DO of Pinyinyi River at upstream, midstream and downstream during wet and dry seasons were 0.302 ± 0.01, 0.28 ± 0.03 and 0.297 ± 0.03 mg/L respectively (**Table 2** and **Table 3**). The maximum DO values were recorded at upstream sampling point during wet season 0.31 ± 0.01 mg/L and at downstream during dry seasons 0.32 ± 0.01 mg/L (**Figure 6**). The values of DO recorded at each sampling site were below the permissible limit. The minimum value of DO recorded from upstream, midstream and downstream, indicated that the studied sampling sites were susceptible to pollution due to nearby agricultural activities, livestock keeping, bathing and washing, [2] [9] [14]. Under low DO the aquatic ecosystem is degraded which in addition risk the aquatic organisms.

Temperature

Temperature influences physicochemical, biological processes and ecosystem balances in water bodies [25]. Temperature influences the density of water, as the temperature increases the density of water decreases. Increase in temperature in water bodies cause the increase in metabolic rates and decrease the solubility of oxygen which threats the aquatic organisms. Temperature also influences the solubility of chemical compounds in water bodies hence the solubility of pollutants. The average temperature values of Pinyinyi River ranged between 29˚C and 30˚C during wet season and dry season respectively (**Table 2** and **Table 3**). The mean temperature at all sampling sites were higher during dry season compared to wet season (**Figure 7**). The mean temperature during dry season and wet season in all sampling sites was not within the permissible limit (**Table 2** and **Table 3**). High temperature causes the rise of BOD which indicates the poor water quality of Pinyinyi River. High water temperature can be attributed to loss of riparian vegetation along Pinyinyi River that opened the canopy cover, resulting in direct heating of the water.

pH

pH indicates the strength of the acidic or alkalinity character of a solution and is controlled by the dissolved chemical compounds and biochemical progressions in the solution [1]. The pH is most essential in determining the corrosive nature of water. The lower the pH value the higher the corrosive nature of water [20]. Low pH increases the solubility of metals and nutrients such as nitrates and phosphates making them available for uptake by plants and animals [20]. It is usually monitored for assessment of water ecosystem health, irrigation and drinking water, industrial discharge and surface water run-off [1]. The recommended pH is 6.5 to 8.5 [21] [22]. Water which has pH value of more than 9 or less than 4.5 becomes unfitting for domestic use like drinking.

The average concentration of pH of Pinyinyi River at upstream, midstream and downstream during wet and dry seasons were 8.42 ± 0.293, 7.81 ± 0.234 and 7.87 ± 0.3497 respectively (**Table 2** and **Table 3**). The maximum pH values at upstream sampling point were recorded during wet and dry season, 8.42 ± 0.293 units and minimum pH were recorded at midstream and downstream during dry and wet seasons, 7.81 ± 0.234 and 7.87 ± 0.3497 respectively (**Figure 8**). Higher pH at upstream sampling site could be due to bicarbonate and carbonate of calcium and magnesium in water and the main sources of such chemicals could be due to agricultural activities, livestock keeping, bathing and washing in River water course [25]. The pH recorded from upstream to downstream was within the permissible limit [21] [22].

TDS

TDS indicates the ability of water to dissolve various inorganic and some organic minerals or salts like sulphates, magnesium, chlorides, bicarbonate, sodium, calcium and potassium [20]. High levels of TDS reduce algal productivity and growth and give a picture of the poor water quality [1]. The average concentration of TDS of Pinyinyi River at upstream, midstream and downstream during wet and dry seasons were 98.83 ± 22.104, 104.00 ± 27.041 and 96.67 ± 16.108 mg/L respectively (**Table 2** and **Table 3**). The maximum TDS values were recorded during the dry season in all sampling sites, average mean TDS, 119.67 ± 7.62 mg/L and minimum TDS were recorded during wet season in all sampling points, average mean TDS, 80.00 ± 1.66 mg/L (**Figure 9**). However, the statistical analysis at 95% confidence level showed that, there was significant different between sampling sites (P = 0.000). The TDS recorded from upstream to downstream during dry and wet seasons were within the permissible limit [21] [22]

Turbidity

Turbidity is a measure of how clear the water is [1]. Turbidity in most water is due to colloidal and extremely fine dispersion. Turbidity is influenced either naturally by rainfall run off or anthropogenic activities such as industrial activities and livestock keeping. In many aquatic systems such as Rivers and Lakes water clarity is determined by the abundance of suspended algae which reduce water clarity and increase its color [1]. Turbidity water affects photosynthesis because it limits permeation of light [20]. In extreme cases, turbid water can harm animals and deposit heavy sediment, on leaves reducing photosynthesis. Turbid water also affects how well disinfection techniques including ultraviolet light and chlorination work and slows the establishment of vegetables [1].

The maximum turbidity values of Pinyinyi River were recorded during dry season in all sampling sites, average mean turbidity, 27.53 ± 13.15 NTU and minimum turbidity were recorded during wet season in all sampling points, average mean, 5.98 ± 0.39 NTU (**Table 2** and **Table 3**). The turbidity recorded at downstream during dry season (44.67 ± 0.52 NTU) were not within the permissible limit (**Figure 10**). Higher turbidity might be due to agricultural runoff, bathing, washing and livestock keeping [1]. The statistical analysis at 95% confidence level showed that, there was a significant different between upstream and downstream, midstream and downstream, downstream and upstream, downstream and midstream ($P = 0.000$), also there was no significant different between upstream and midstream, midstream and upstream ($P = 0.966$).

4.2. Macroinvertebrates

The abundance and diversity of macroinvertebrates was observed to be highest during wet season than dry season (**Table 4** and **Table 5**). This implied that macroinvertebrates have different ecological requirements and exhibit different degree of tolerance to various anthropogenic impacts. The abundance of pollution tolerant macroinvertebrate was 87% and 57.14% during wet season and dry season respectively. The abundance of moderately pollution tolerant was 13% and 19.64% during wet season and dry season respectively. The total abundance of pollution sensitive macroinvertebrates was 23.21% during dry season (**Table 6**). No pollution sensitive macroinvertebrates collected during wet season (**Table 6**). Therefore, the abundance of pollution tolerant macroinvertebtrates collected during wet and dry season indicate poor water quality of Pinyinyi River. In other hand, pollution tolerant macroinvertebrates can survive in poor water quality. Therefore Pinyinyi River is highly polluted during wet season and moderately polluted during dry season. High runoff from Ngorongoro National Parks, Serengeti National Parks and agricultural areas along Pinyinyi River cause highest abundance of pollution tolerant macroinvertebrates during wet season due to high level of organic pollution and flushing of pit latries. Lack of riparian vegetation for attachment along the river bank may also cause the less abundance of macroinvertebrates during dry season. The average score per taxon (ASPT) obtained during dry season (ASPT = 5.25) was an indication that, Pinyinyi River (Sand type River) was moderately polluted due to low runoff from agricultural and domestic activities [10] [26]. It also implies that, sensitive species may be lost and there is a possibility of tolerant or opportunistic species to dominate other species in the River (**Table 7**). Also the score implies that, the River was under multiple disturbances associated with socio-economic development demands [26]. The average score per taxon (ASPT) obtained during wet season (ASPT = 3.6) was an indication that, Pinyinyi River was seriously polluted during

Table 4. Abundance, diversity index and Sensitivity scores allocated to group of aquatic macroinvertebrates collected from Pinyinyi River at each sampling point during dry season.

Species	#Individual	Abundance Pi		lnPi	Pi * ln (Pi)	SC	SS
Aquaticarterpillar	13	0.232	23.2	−1.460	−0.339	12	U
Pouchsnail	9	0.161	16.1	−1.828	−0.294	3	U
Dragonflies	11	0.196	19.6	−1.627	−0.320	5	M
Mosquitoes	23	0.411	41.1	−0.890	−0.365	1	D
TOTAL	56	1.00	100	−5.806	1.318	21	

Key: SC = Sensitivity Score, SS = Sampling Site, U = Upstream, M = Midstream, D = Downstream.

Table 5. Abundance, diversity index and Sensitivity scores allocated to group of aquatic macroinvertebrates collected from Pinyinyi River at each sampling point during wet season.

Species	#Individual	Abundance Pi		lnPi	Pi * ln (Pi)	SC	SS
Creepingwaterbug	13	0.123	12.3	−2.098	−0.257	6	U
Predaciousdividingbeetles	5	0.047	4.7	−3.054	−0.144	5	U
Pigmybackswimmers	3	0.028	2.8	−3.565	−0.101	4	U
Mosquitoes	7	0.066	6.6	−2.718	−0.179	7	U
Watermites	9	0.085	8.5	−2.466	−0.209	5	M
Blackflies	16	0.151	15.1	−1.891	−0.285	1	M
Midges	19	0.179	17.9	−1.719	−0.308	2	M
Aquaticearthworm	21	0.198	19.8	−1.619	−0.321	1	D
Snail	4	0.038	3.8	−3.277	−0.124	4	D
Mothflies	9	0.085	8.5	−2.466	−0.209	1	D
TOTAL	106.000	1.000	100	−24.873	2.138	36	

Key: SC = Sensitivity Score, SS = Sampling Site, U = Upstream, M = Midstream, D = Downstream.

Table 6. Average score per taxon (ASPT), tolerant level and total abundance of macroinvertebrates during dry and wet season.

Seasons	Average score per taxon (ASPT)	Pollution sensitive	Moderately pollution tolerant	Pollution tolerant
Dry season	5.25	Aquatic carterpillar Total abundance = 23.21%	Dragonflies Total abundance = 19.64%	Pouch snail, Mosquitoes. Total abundance = 57.14%
Wet season	3.6		Predacious dividing beetles, Water mites. Total abundance = 13%	Creeping water bugs, Snail, Midges, Aquatic earth worm, Moth flies, Mosquitoes, Pigmy back swimmers, Blackflies. Total abundance = 87%

Table 7. Interpretation of the results based on TARISS *fupi* guideline [26].

Interpretation table				
River health category	River Type		Ecological perspective	Water resource management perspective
	Sandy type river	Rock type river		
Natural-A	>6.9	>7.9	No or negligible modification	Minimal human impact
Largely natural-B	>5.8 - 6.9	>6.8 - 7.9	Biodiversity and integrity are largely integral	Some human impact but ecosystem is integral/in good state
Moderately Modified-C	>4.9 - 5.8	>6.1 - 6.8	Sensitive species may be lost and possible dominance of tolerant or opportunistic species	Multiple disturbance associated with socio-economic development demands
Largely Modified-D	>4.3 - 4.9	>5.1 - 6.1	Dominated by tolerant species, alien species invasion and possible changes of biotic population dynamic. The system maybe reverted however	Unsuitable overexploitation of resource driven by increasing demography
Seriously Modified-E	≤4.3	≤5.1	Overall species dynamics modification at high intensity, impact is detrimental and may results to ecosystem. The system may be irreversible	Absolute and extensive resource exploitation. Resource no longer sufficient to supply ecological and ecosystem services

wet season and may be due to high runoff from agricultural activities, livestock keeping and domestic activities [10] [26]. This is because during rainfall all the agricultural fertilizers, herbicides, pesticides, insecticides, waste from pitlatrine and animal dungs washed to the Pinyinyi River which causes the death of Lesser Flamingoes. Furthermore, it implies that there was absolute and extensive resource exploitation and the river were no longer sufficient to supply ecological and ecosystem services which may result in ecosystem collapse (**Table 7**). It also implies that there may be an overall species dynamics modification at high intensity and detrimental impacts to ecosystem but the system may be irreversible (**Table 7**). The Shannon Weiner Species Diversity Index during dry season was 1.318 whereas during wet season it was 2.318. This implies that there was high diversity of macroinvertebrates during wet season and less diversity of macroinvertebrates during dry season. The higher the diversity index the higher the diversity of macroinvertebrates (**Table 4** and **Table 5**).

5. Conclusion

The study has provided insights into the water quality of the Pinyinyi River as an impact of anthropogenic activities. The measured high levels of BOD, temperature, turbidity and low level of DO threaten the aquatic life of Pinyinyi River. High abundance of pollution-tolerant macroinvertebrates at Pinyinyi River proves that the water quality of Pinyinyi River is poor. Therefore, macroinvertebrates were shown to be potentially good water quality indicators. High number of pollution-tolerant macroinvertebrates collected during wet season could be an interesting source of information. These results impose further investigation to explore the environmental status and management approaches at Pinyinyi River for ecosystem sustainability. The study therefore proposes watershed management using nature-based solutions including riparian vegetation restoration. Additionally education on environmental conservation and awareness for Pinyinyi River ecosystem sustainability through sustainable agriculture and livestock practices along Pinyinyi River. Moreover, further analysis of physicochemical and bacteriological of Pinyinyi River is required.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Mezgebu, A., Lakew, A. and Lemma, B. (2019) Water Quality Assessment Using Benthic Macroinvertebrates as Bioindicators in Streams and Rivers around Sebeta, Ethiopia. *African Journal of Aquatic Science*, **44**, 361-367. https://doi.org/10.2989/16085914.2019.1685450

[2] Lalika, M.C.S., Meire, P. and Ngaga, Y.M. (2015) Exploring Watershed Conservation and Water Governance along the Pangani River Basin, Tanzania. *Land Use Policy*, **48**, 351-361. https://doi.org/10.1016/j.landusepol.2015.06.010

[3] Su, A., Im, E., Je, U. and Ij, W. (2014) Assessment of Anthropogenic Activities on Water Quality of Benin River. *Journal of Applied Science*, *Environment and Management*, **18**, 629-636.

[4] Alavaisha, E., Mbande, V., Borjeson, L. and Lindborg, R. (2021) Effects of Land Use Change Related to Small-Scale Irrigation Schemes in Kilombero Wetland, Tanzania. *Journal of Environmental Science*, **9**, Article ID: 611686. https://doi.org/10.3389/fenvs.2021.611686

[5] Munoz-Mas, R., Sanchez-Hernandez, J., McClain, M.E., Tamatamah, R., Mukama, S.C. and Martinez-Capel, F. (2018) Investigating the Influence of Habitat Structure and Hydraulics on Tropical Macroinvertebrate Communities. *Ecohydrology and Hydrobiology*, **19**, 339-350.

[6] Suthar, S., Sharma, J., Chabukdhara, M. and Nema, A.K. (2010) Water Quality Assessment of River Hindon at Ghaziabad, India: Impact of Industrial and Urban Wastewater. *Environmental Monitoring and Assessment*, **165**, 103-112. https://doi.org/10.1007/s10661-009-0930-9

[7] Kimambo, O.N., Gumbo, J.R., Chikoore, H., Alfred, T. and Msagati, M. (2021) Harmful Algal Blooms in Aquaculture Systems in Ngerengere Catchment, Morogoro, Tanzania: Stakeholder's Experiences and Perception. *International Journal of Environmental Research and Public Health*, **18**, Article No. 4928. https://doi.org/10.3390/ijerph18094928

[8] Elias, J.D., Ijumba, J.N., Mgaya, Y.D. and Mamboya, F.A. (2014) Study on Freshwater Macroinvertebrates of Some Tanzanian Rivers as a Basis for Developing Biomonitoring Index for Assessing Pollution in Tropical African Regions. *Journal of Ecosystem*, **2014**, Article ID: 985389. https://doi.org/10.1155/2014/985389

[9] Sharifinia, M., Mahmoudifard, A., Namin, J.I., Ramezanpour, Z. and Yap, C.K.

(2016) Pollution Evaluation in the Shahrood River: Do Physico-Chemical and Macroinvertebrate-Based Indices Indicate Same Responses to Anthropogenic Activities? *Chemosphere*, **159**, 584-594.
https://doi.org/10.1016/j.chemosphere.2016.06.064

[10] Ojija, F. and Laizer, H.C. (2016) Macro Invertebrate as a Bioindicator of Water Quality in Nzovwe Stream in Mbeya Tanzania. *International Journal of Scientific and Technology Research*, **5**, 211-222.

[11] Masikini, R., Kaaya, L.T. and Chicharo, L. (2018) Evaluation of Ecohydrological Variables in Relation to Spatial and Temporal Variability of Macroinvertebrate Assemblages along the Zigi River-Tanzania. *Ecohydrology and Hydrobiology*, **18**, 130-141.
https://doi.org/10.1016/j.ecohyd.2018.03.004

[12] Shimba, M. and Johan, F. (2016) Macroinvertebrates as Bioindicators of Water Quality in the Mkondoa River, Tanzania, in an Agricultural Area. *African Journal of Aquatic Science*, **41**, 453-461. https://doi.org/10.2989/16085914.2016.1230536

[13] Pardal, M.A., Almeida, S. and Azeiteiro, U.M. (2010) Use of Biological Indicators to Assess Water Quality of the UI River (Portugal). *Environmental Monitoring and Assessment*, **170**, 535-544.

[14] Mgimwa, E.F., John, J.R. and Lugomela, C.V. (2021) The Influence of Physical-Chemical Variables on Phytoplankton and Lesser Flamingo (*Phoeniconaias minor*) Abundances in Lake Natron, Tanzania. *African Journal of Ecology*, **59**, 667-675.
https://doi.org/10.1111/aje.12863

[15] Gichuki, F.N. (2003) Water Scarcity and Conflicts: A Case Study of the Upper Ewaso Ng'iro North Basin. University of Nairobi, Nairobi.

[16] Kalacska, M., Arroyomora, J.P., Kishemachumu, M.A. and Lucanus, O. (2017) Land Cover, Land Use, and Climate Change Impacts on Endemic Cichlid Habitats in Northern Tanzania. *Remote Sensing*, **9**, Article No. 623.
https://doi.org/10.3390/rs9060623

[17] APHA (1998) Standard Methods for the Examination of Water and Wastewater Analysis. 20th Edition, AWWA.

[18] Bwalya, E. (2015) Assessment of Water Quality in Urban Rivers: A Case Study of Mansa River in Luapula Province of Zimbabwe. MSc Thesis, University of Zimbabwe, Harare.

[19] Gabriel, M. and Gerber, A. (2002) Aquatic Invertebrates of South Africa Rivers Field Guide. Institute of Water Quality Studies, Cape Town.

[20] Mbaruku, S. (2016) Assessment of River Health Using Physico-Chemical Parameter and Macro Invertebrates: A Case Study of Mungonya River in Kigoma, Tanzania. MSc Thesis, University of Zimbabwe, Harare, 102 p.

[21] TBS (2006) TBS (Tanzania Bureau of Standard) Drinking Water Standard.

[22] WHO (2008) WHO (World Health Organization) Drinking Water Standard.

[23] Al-badaii, F., Othman, M.S. and Gasini, M.B. (2013) Water Quality Assessment of the Semenyih River, Selangor, Malaysia. *Journal of Chemistry*, **2013**, Article ID: 871056.
https://doi.org/10.1155/2013/871056

[24] Mustapha, A., Aris, A.Z., Juahir, H., Ramli, M.F. and Kura, N.U. (2013) River Water Quality Assessment Using Environmentric Techniques: Case Study of Jakara River Basin. *Environmental Science and Pollution Research*, **20**, 5630-5644.
https://doi.org/10.1007/s11356-013-1542-z

[25] Machena, C. (1997) The Pollution and Self-Purification Capacity of the Mukuvisi River. In: Moyo, N.A.G., Ed., *Lake Chivero: A Polluted Lake*, University of Zim-

babwe Publishers, Harare, 75-91.

[26] Kaaya, L. (2018) TARISS *fupi* Guideline for River Health Assessment. Ministry of Water, Dodoma.

Appendix

Table A1. Classification and abundance of aquatic macroinvertebrates collected from Pinyinyi River during dry season per sampling site.

Invertebrates	Class	Order	Family	SS	Total abundance per SS
Aquatic carterpillar	Insecta	*Lepidoptera*	*Pyralidae*	U	39%
Pouch snail	Gastropoda	*Archatinoidea*	*Physidae*	U	
Dragonflies	Insecta	*Ordonata*	*Gomphidae*	M	19%
Mosquitoes (Larva)	Insecta	*Diptera*	*Culicidae*	D	41.1%

Key: SS = Sampling site, U = Upstream, M = Midstream, D = Downstream.

Table A2. Classification and abundance of aquatic macroinvertebrates collected from Pinyinyi River during wet season per sampling site.

Invertebrates	Class	Order	Family	SS	Total abundance per SS
Creeping water bugs	Insecta	*Hemiptera*	*Naucoridae*	U	
Predacious dividing beetle	Insecta	*Coleoptera*	*Dytiscidae*	U	26%
Pigmy backswimmers	Insecta	*Hemiptera*	*Notonectidae*	U	
Mosquitoes	Insecta	*Diptera*	*Culicidae*	U	
Water mites	Arachnida	*Trombidiformes*	*Tetranychoidea*	M	
Black flies	Insecta	*Diptera*	*Simuliidae*	M	41.5%
Midges	Insecta	*Diptera*	*Chironomidae*	M	
Aquatic earth worm	Clitellata	*Haplotaxida*	*Acanthodrilidae*	D	
Snail	Gastropoda	*Archatinoidea*	*Physidae*	D	32.1%
Moth flies	Insecta	*Lepidoptera*	*Papilionoidea*	D	

Key: SS = Sampling site, U = Upstream, M = Midstream, D = Downstream.