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Assessment of River Water Quality using Macroinvertebrate Organisms as Pollution Indicators of Cirhanyobowa River, Lake Kivu, DR Congo

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A B S T R A C T

Biotic indices to monitor water quality are helpful tools for evaluating the health of rivers. Water quality analysis is mainly done using physical and chemical attributes in the DR Congo. The objectives of this study were to assess the biological water of Cirhanyobowa River using macroinvertebrate index and the relationship between physicochemical parameters and the ecological index from January to December, 2017. Eight physicochemical parameters and abundance of macroinvertebrates were obtained for 6 sites from upstream to downstream part, with different land uses. Result showed a decrease in biotic index from upstream (very good water quality) to downstream (bad) due to human activities along the river flows. Brick mining in the downstream part had more effects than agriculture in the upstream part. A correlation analysis showed the variation between the ecological index, abundance of macroinvertebrates and their correlation with physicochemical parameters in Cirhanyobowa River. The findings show that traits can be indicative for different kind of stress but that more effort has to be put in gathering data sets to separate the effect of habitat quality, pollution, and the physicochemical properties of high mountain rivers.

Introduction

A major concern in several regions of developing countries are water resource contamination in which polluted waters pose serious risks to human health and the environment. Macroinvertebrates are useful component to evaluate the state of a river.

Freshwater benthic macroinvertebrates contribute in important ecological functions in rivers, such as decomposition, nutrient recycling and play an important role in aquatic food webs as both consumers and prey (Mola and Gawad, 2014; Abdel-Gawad and Mola, 2014). They provide a more accurate understanding of changing in aquatic conditions than chemical and microbiological data, which at least give short-term fluctuations (Ravera, 1998, Ravera, 2000).They may show the cumulative impacts of multiple stresses, like habitat loss, which are not always detected by the traditional water quality assessments using physico-chemical measurements. Biological methods are valuable to determine natural and anthropogenic influences on water resources and habitats (Weigel and Robertson, 2007; Resende *et al.,* 2010). Some species are indicators of poor water quality such as in the family Chironomidae (Moss, 1993; Fishar and Abdel Gawad, 2009) and others species of Caddisflies are always associated with cleaner habitat (Rosenberg *et al.,* 2008).

The assemblages of macroinvertebrate are structured according to physical and chemical parameters that define habitat and other biological parameters that influence their reproductive success (Abdelsalam and Tanida, 2013).

In Africa countries, many studies have been assessed for environmental health of rivers using benthic macroinvertebrate communities (Guenda, 1996; Kabré *et al.,* 2002; Sanogo, 2014).The index has recently been successfully used for assessing the ecological water quality of a river basin in many countries. Current knowledge of benthic macroinvertebrates and water ecosystem health in DR Congo Rivers is still very fragmentary except the study on the effect of land use on river quality in river Lwiro (Bagalwa *et al.*, 2013). This study shows that the forest site had the highest abundance values, indicating enrichment or pristine site were anthropogenic activities are low. And the agricultural site, however, was characterized by low species richness for most groups and very low abundance values. In Irhambi/Katana sub-county, freshwater ecosystems have been altered by human disturbances such as agriculture, urban development, impoundment, channelization, brick and mineral mining, forest fire and road construction. All of these have led to severe degradation and loss of biodiversity and as a result these ecosystems have become unsuitable for human activities such as drinking, washing and irrigation.

In Irhambi/Katana sub-county studies on benthic macroinvertebrates in streams and rivers are sparse. Bagalwa *et al.*, (2012, 2013) and Ngera *et al.*, (2009 a et b) were the first to study macroinvertebrates. But these studies doesn’t use them to assess the pollution status of streams.

To characterize ecological conditions of rivers and streams in Irhambi/Katana sub-county, the development of a single index from biological and environmental variables is preferred (Bagalwa *et al.*, 2013; Masese *et al.*, 2013). This approach involves integration of a number of structural and functional attributes of the macroinvertebrate community into a composite index with the rating of each metric based on quantitative expectations (based on comparisons with reference conditions) of what represents high biotic integrity. This methods of evaluate water quality has not been much used in DRC in general and in Irhambi/Katana in particular. Biotic indices have not been used in these studies mostly because of the lack of knowledge of water resources modelers about these indices and also limited interval of limnological measurements in the sub-county. The objectives of the present study are to assess the spatial and seasonal variation of physicochemical parameters and macroinvertebrate diversity and ecological qualities for different sites in Cirhanyobowa river.

Materials and Methods

Area of study

Cirhanyobowa is an extensive river that drains in a rural area and a tributary of Lake Kivu in the DR Congo side. The river bank is rich in vegetation with shrubs, grasses and some cultivated plants such as cassava, maize and beans and has dominated by mudded substrate. Ciranyobowa River is found in Mabingu and Kabamba villages in Irhambi/Katana sub-county, Southern Kivu region, DR Congo. Sampling stations were established according the accessibility, diversities of substrate and the richness of macrophytes in the river. Six sampling sites were determined in Cirhanyobowa River. Two sites in the upper stream, two in middle stream and two in downstream (Fig. 1).

Macroinvertebrates collection and identification

The collection of macroinvertebrates was done from January 2017 to December 2017 using kick-net method. Collection was done in a standard five minute kick/sweep method (Armitage *et al.,* 1990). The sampling was done starting from the upper-stream (Site 1) to the last sampling point on the downstream (Site 6) between 7 to 12 pm. The collected organisms were placed in a container with water with proper label. Collected specimens were sorted in the laboratory and were preserved with 70% ethanol. Identification was done up to its lowest possible taxa using the key guides of Micha et Noiset (1982) and Pennack (1989).

Water sampling and analysis

The physicochemical parameters in the different site were measured *in situ*, temperature and pH were measured by a digital thermometer and pH-meter (HANNA). Water samples were collected in glass stoppered bottles at each sampling site for dissolved oxygen (DO) using Winkler's method (APHA, 2005). The sample used to determine DO was fixed using 0.5 ml manganous sulphate followed by 0.5 ml of Winkler's reagent.

Samples for determination of total phosphorus (TP) and total nitrogen (TN) were collected using acid-washed polyethylene sample bottles of 500 ml. The samples were transported in a cool-box to the laboratory for further analyses. The same water was also use to analyzed calcium using standard method (Golterman *et al.,* 1978). Water current velocity was estimated by timing an orange flowing through a known distance from a bridge or vantage point. Depth of water at the sampling point was measured using a meter.

Water quality index

The collected macroinvertebrates were grouped into 3 Taxa: Taxa 1, Taxa 2 and Taxa 3 based on their sensitivity or tolerance to pollution or aquatic disturbance (Barbour *et al.,* 1999).Taxa 1 includes species belonging to orders Ephemeroptera, Plecoptera, Trichoptera and Coleoptera and was found in good water quality and are pollution-sensitive organisms. Taxa 2 species can exist in a wide range of water quality conditions, or moderate water quality and include species belonging to orders Hemiptera, Diptera, Odonataand Decapoda. Taxa 3 are species that are highly tolerant to poor water quality. This taxon includes Tubificida, Gastropoda, Hirudinidae and Isopoda. The identified macroinvertebrates were sorted and scored with their particular points based on Water quality index (WQI) scores developed by Armitage *et al.*, (1983); the sum was obtained and subsequently divided by the number of species scored. The resulting value is the WQI and described in Table 1.

Family biotic index

Family Biotic Index developed by Hilsenhoff, (1977, 1988a, 1988b) was also used as another means in determining water quality in the sampling sites. This was obtained by multiplying the number in each family by Family-level pollution tolerance value/scores, summing the products, and dividing by the total species in the sample. The value obtained is the FBI and described in Table 2.

Statistical analysis of data

Data collected was statistically analyzed using PAST Software to obtain biodiversity indices such as Evenness, Species Richness index (d`), Shannon-Wiener index (H'), and Simpson's Dominance index (D).To determine if there is significant difference between sampling sites, T-test was employed using 5% level of significance. The diversity values for Shannon-Weiner (H') were classified based on the scale developed by Fernando in Cuadrado and Calagui (2017) and described in Table 3.

Six water quality parameter mean measurements (temperature, DO, BOD, TN, TP and pH) to determine if there is any significant difference in these measurements among the stations, between the months, if there is any interaction between stations and the months sampled. Further analysis of the above six water quality parameters related to the stations was done with multivariate method using PAST Software. Person correlation analysis of the sites and six mean water quality parameters (temperature, DO, BOD, TN, TP and pH) measurements were evaluated for the variation of the sites with these measurements. To determine if there is significant difference between sampling sites, T-test was employed using 5% level of significance.

Results and Discussion

Macroinvertebrates diversity

A total of 4314 macroinvertebrate individuals belonging to 15 orders and 41 families. The distribution of different family of macroinvertebrate and their specific richness on families' level are present in table 1.

Higher taxa were collected at Batanga (944 individual, upstream site 1) during the sampling period and the low taxa was recorded at Bucecebe (509 individual, downstream site 6) in the river Cirhanyobowa. The total number of orders is 15 with 7 main groups include Ephemeroptera, Plecoptera, Odonata, Trichoptera, Diptera, Coleoptera and Hemiptera. Lepidomastidae was the most abundant family (1572 individuals), followed by Petaluridae (786 individuals), Coenagrionidae (616 individuals) and Hydropsychidae (258 individuals). The seasonal change ranged from 3205 and 1109 individuals during wet and dry seasons, respectively. The highest richness was recorded at Batanga (37) while the lowest was at Magenge (15).

Physicochemical Parameters

High temperature was recorded at Bucecebe (20.7±0.4^{o}C) the outlet of the river to Lake Kivu. While the lowest temperature was record up stream at Batanga and Kagomero (14.63±0.3^{o}C). Bucecebe site is located at high altitude in Cirhanyobowa river at the edge of Kahuzi/Biega National Park. At the site no human activities are done. Temperature at Bucecebe site with average temperature of 20.7^{o}C increases the metabolism of aquatic insects which reduce the DO concentration in the water and abundance of species. pH is also follow the same trend as temperature with the highest at Bucecebe and the lowest at Batanga and Kagomero. The trend for DO is different, the high values was recorded at the upstream (Batanga) and the lowest at downstream at Bucecebe.

Calcium concentration in all the site doesn't change much even TP. But TN is high downstream at Bucecebe then in others sampling site during the sampling period. The depth varied from site to site in general even the current velocity. The high current velocity was found at Batanga site and the lowest at Bucecebe.

The results reveal that the abundance of aquatic macroinvertebrates depends on the physicochemical factors of the river coursesuch as water temperature, water velocity, no deeper water, nitrogen, phosphorus, calcium concentration and high dissolved oxygen level. Anthropogenic activities reduce the abundance of sensitive macroinvertebrates in the course of the river. Due to this some no tolerant taxa disappear in the river sites and with found tolerant taxa such the order of Diptera, Ephemeroptera and Coleoptera.

Diversity and biotic indices

	Batanga	Kagomero	Cabadagi	Magenge	Ruvoma	Bucecebe
Index water quality	4.70	4.91	5.04	4	4.88	5.32
Shannon H'	2.546	1.76	1.99	1.69	1.985	1.915

Highest diversity index (H'=2.546) was recorded at Batanga site and the lowest diversity index recorded at Magenge site (H'=1.69) as stated in Table 3. Using index water quality all the sites was good or very good according to the classification. A study about diversity and abundance of aquatic macroinvertebratesin Brazil reports that the sampling station with the highest dissolved oxygen level had the highest Shannon-Weiner diversity index (Silva *et al.*, 2009).Higher Shannon indices indicate less stress in ecosystems, higher abundance and more even distribution of species in the ecosystem. This was observed in the site of Batanga with high DO and low water quality index (4.70). Proportions of species belonging to Ephemeroptera varied between 0.36% and 7.75%. The lowest value was observed at Kagomero and the highest value at Batanga, differences between downstream stations (Bucecebe) and stations upstream (Batanga) were large. Differences among sampling sites were significant ($p<0.05$). For the species belonging to trichoptera, they was ranged from 45.54% at Batanga and to 55.84% at Kagomero. Differences between downstream stations (Bucecebe) and stations upstream (Batanga) were not large. Differences among sampling sites were not significant ($p>0.05$). And the proportion of the species belonging to Diptera was high at the site of Ruvoma (9.05%) and Batanga (8.71%) than the site downstream at Bucecebe (0.78%) and Magenge (1.01%).

Correlations between physicochemical parameters and macroinvertebrate abundance

The effect of physicochemical factors on the abundance of macroinvertebrate has been investigate in this studies in Cirhanyobowa river. Spearman's correlation coefficients between physicochemical parameters and macroinvertebrate abundance in the site are presented in Table 4.

The results reveal that the abundance of macroinvertebrate is high when water temperature increases, pH, TN and Depth are negatively correlated to macroinvertebrate abundance. The negative correlation (r=-0.946) with temperature is contrary to the results observed elsewhere a strong, positive correlation between water temperature and abundance of macroinvertebrate (r=0.937) was observed in Ethiopia (Abrehet *et al.*, 2014).

The same observation was also observed for the correlation of depth and abundance of macroinvertebrate while Abrehet *et al.*, (2014) found a positive correlation but for Cirhanyobowa River we found negative correlation. DO and water velocity are positively correlated with abundance of macroinvertebrate. High dissolved oxygen (DO) level are preferable by macroinvertebrate as also found by Nur *et al.*, (2017).

The site of Batanga (upstream site) has high abundance and diversity of macroinvertebrate with high level of DO but with high water velocity. This is in disagreement with the result of Nur *et al.*, (2017), who found that the abundance of aquatic macroinvertebrate is high when water temperature increases, low water velocity, high dissolved oxygen (DO) level and deeper water. The site downstream with high temperature was colonized with tolerant taxa such as Lepidomastidae and Coenagrionidae but the site upstream with low temperature and high DO was colonized by no tolerant taxa. These sites was not disturbed by human activities and located at high altitude. Stoyanova *et al.*, (2014) found that some aquatic macroinvertebrates are affected by conditions that reduce the dissolved oxygen of the water, like pollution; therefore the presence of these macroinvertebrates indicates high stream quality.

Temperature is also affect abundance of macroinvertebrate in Cirhanyobowa river as observed in this table. High temperature affect negatively the abundance of macroinvertebrate in Cirhanyobowa river contrary to the found of Abrehet *et al.*, (2014) and Nur *et al.*, (2017). Burgmer *et al.*, (2009) shown that the emergence of many aquatic macroinvertebrate is influenced by water temperature and leads to earlier emergence of insects for example, egg may hatch when temperature reaches a certain level.

The level of temperature was not determined such as we can compare the optimal temperature with the temperature obtained at Batanga site upstream. This show that the abundance of macroinvertebrate in a site is a combination of environmental factors but not one factors alone.

Table.1 Water quality index scores and indication

Score	Indication
7.6 – 10	Very clean water
5.1 – 7.5	Rather clean-clean water
2.6 – 5.0	Rather dirty-water average
1.0 – 2.5	Dirty water
0	Very dirty water (no life at all)

Table.2 Water quality using the family-level biotic index

Biotic	Index Water quality	Degree of organic pollution
0.00–3.50	Excellent	No apparent organic pollution
3.51–4.50	Very good	Possible slight organic pollution
4.51–5.50	Good	Some organic pollution
5.51–6.50	Fair	Fairly significant organic pollution
6.51–7.50	Fairly poor	Significant organic pollution
7.51–8.50	Poor	Very significant organic pollution
8.51–10.0	Very poor	Severe organic pollution

Table.3 H' diversity value and its qualitative equivalence

H' value	Relative values
>3.5	Very high
3.0-3.49	High
2.5-2.99	Moderate
2.0-2.49	Low
<1.99	Very low

Table.4 Number and specific richness of macroinvertebrate collected at 6 sites in Cirhanyobowa River

Taxa	Batanga	Kagomero	Cabadagi	Magenge	Ruvoma	Bucecebe
O. Plecoptera						
F. Isogeninae	9	0	0	0	0	0
F. Nemourinae	2	0	0	0	0	0
O. Trichoptera						
F. limnephilidae	20	12	11	5	2	19
F. Rhyacophilidae	3	0	0	0	4	0
F. Lepidostomatidae	247	396	241	278	227	183
F. Leptoceridae	15	4	3	0	6	5
F. Hydropsychidae	88	41	62	67	43	57
F. Philopotamonidae	53	11	15	17	13	6
F. Polycentropodidae	3	0	0	0	0	0
O. Diptera						
F. Psychodidae	14	19	6	6	11	0
F. Thaumaleidae	1	0	0	0	0	0
F. Similidae	50	0	40	0	0	1
F. Ceratopogonidae	11	4	1	0	0	0
F.Chironomidae	0	23	0	0	47	3
F.Tabanidae	4	0	0	0	0	0
F. Tipulidae	2	1	0	1	0	0

O. Hemiptera						
F. Mesovelidae	1	0	1	0	0	1
F. Naucoridae	0	0	1	0	0	0
F. Corixidae	4	0	0	0	0	2
F. Pleidae	6	0	0	0	0	0
F. Gerridae	1	0	0	0	0	0
F. Nepidae	1	1	0	0	0	0
F, Elmidae	1	0	1	0	0	2
O. Lepidoptera						
F. Pyralididae	5	1	0	0	0	0
O. Ephemeroptera						
F. Heptagenidae	30	0	4	3	0	1
F. Baetidae	23	3	6	1	6	9
F. Caenidae	11	0	2	2	0	2
F. Adenophlebiodidae	6	0	0	0	0	0
F. Hastaperdidae	3	0	0	0	0	0
O. Odonate						
F. Aeschnidae	2	2	4	9	2	0
F. Petaluridae	179	144	181	112	93	77
F. Gomphidae	60	31	31	31	28	23
F. Coenagrionidae	49	117	61	155	128	106
O. Coleoptera						
F. Elimidae	9	3	10	3	1	1
F. Gyrinidae	0	4	2	0	0	1
O. Megaloptera						
F. Corylidae	2	0	0	0	0	0
O. Lumbriculida						
F. Lumbriculidae	1	3	0	0	8	2
O. Gordiida						
F. Gordidae	6	2	2	0	7	2
O. Arhynchobdellide						
F. Glossiphoniidae	0	0	0	0	15	1
O. Arenida						
F. Agynectidae	1	3	7	3	0	5
O. Hemiptera						
F. Nepidae	0	2	1	0	0	0
O. Decapoda						
F. Potamonidae	19	4	3	0	0	0
Number of individual	942	831	696	693	641	509
Specific richness	37	23	24	15	17	22

Table.5 Physicochemical characteristics of sampling sites in Cirhanyobowa River

	Batanga				Kagomero				Cabadagi				Magenge				Ruvoma				Bucecebe			
	Moy	Ecart	Max	Min	Moy	Ecart	Max	Min	Min	Moy	Ecart	Max	Moy	Ecart	Max	Min	Moy	Ecart	Max	Min	Moy	Ecart	Max	Min
Temperature (°C)	14.63	0.39	15	14	14.63	0.39	15	14	16	17.98	0.72	19.3	19	0.59	19.8	18	19.9	0.23	20	19.4	20.7	0.4	21	20
pH	6.93	0.26	7.2	6.5	6.93	0.26	7.2	6.5	6.5	6.75	0.42	7.1	7.08	0.35	7.5	6.5	7.3	0.45	7.6	6.4	7.48	0.38	7.9	6.9
Dissolved Oxygen (mg/L)	8.9	2.73	13.4	5.8	8.9	2.73	13.4	5.8	6.7	7.38	0.66	8.4	7.08	0.9	8	5.6	6.6	0.68	7.2	5.3	6.55	0.42	7.2	6.1
Calcium (mg/L)	0.79	0.1	0.92	0.68	0.79	0.1	0.92	0.68	0.32	0.57	0.23	0.8	0.72	0.28	1.04	0.32	0.9	0.13	1.08	0.8	0.96	0.2	1.28	0.76
Total phosphorus (µmol/L)	0.06	0.02	0.09	0.04	0.06	0.02	0.09	0.04	0.03	0.06	0.01	0.08	0.06	0.02	0.08	0.04	0.12	0.15	0.42	0.04	0.05	0.02	0.08	0.03
Total nitrogen (µmol/L)	0.52	0.21	0.79	0.31	0.52	0.21	0.79	0.31	0.31	0.44	0.22	0.652	0.41	0.25	0.77	0.16	0.28	0.18	0.5	0.02	66	160.7	394	0.311
Depth (cm)	57.67	3.78	63	52	57.67	3.78	63	52	60	82.05	2.89	85.3	79.22	4.57	85.3	73	66.83	4.31	71	59	79.5	6.19	89	71
Current velocity (m/s)	1.05	0.44	1.6	0.5	1.0	0.4	1.6	0.5	0.5	0.88	0.19	1.1	0.97	0.21	1.3	0.7	0.85	0.22	1.1	0.5	0.83	0.21	1.1	0.6

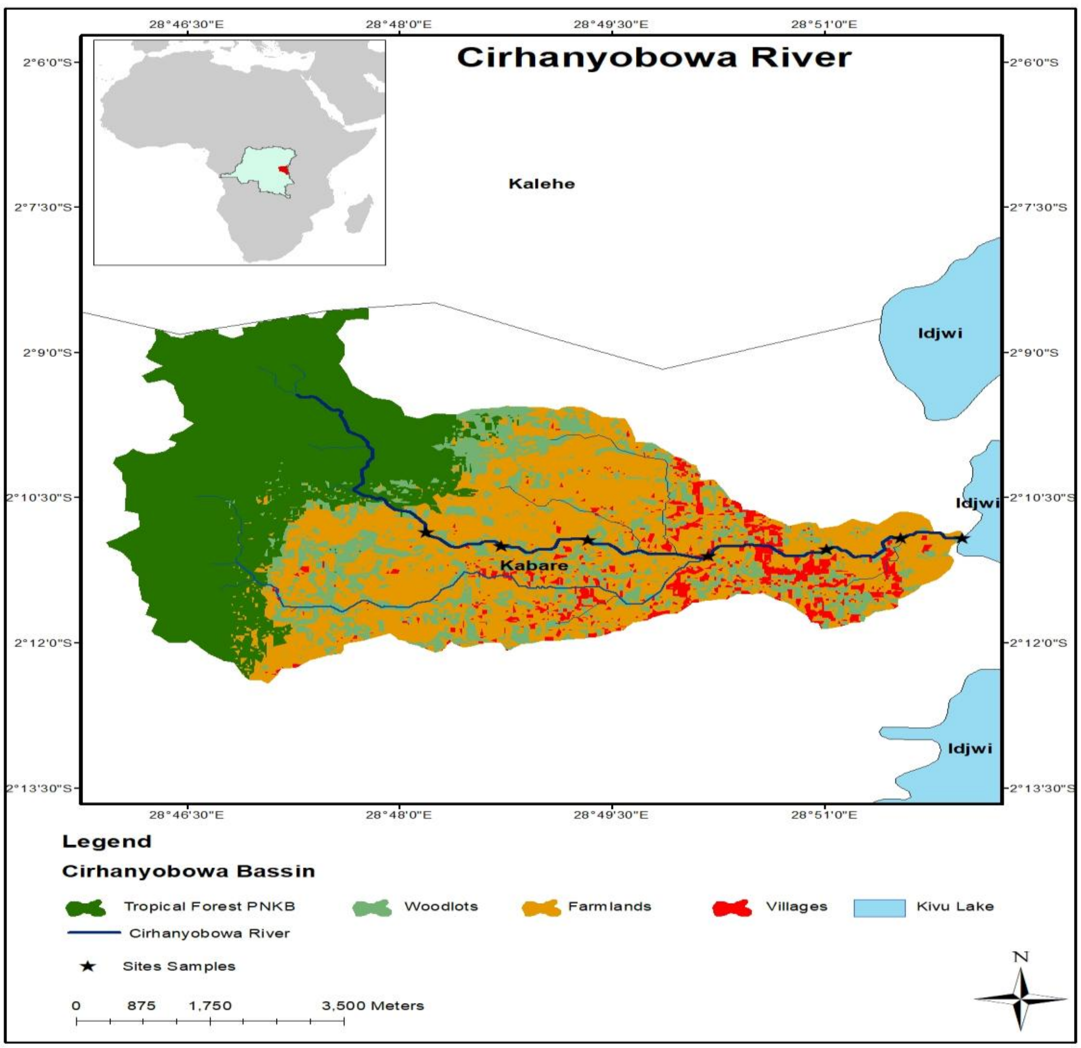
Table.6 Percentage of species belonging to the families of Ephemeroptera, Trichoptera and Diptera in the different sites in Cirhanyobowa River

	Batanga	Kagomero	Cabadagi	Magenge	Ruvoma	Bucecebe
%Ephemeroptera	7.75	0.36	1.72	0.87	0.94	2.36
%Trichopera	45.54	55.84	47.7	52.96	46.02	53.05
%Diptera	8.71	5.66	6.75	1.01	9.05	0.78

Table.7 Correlation between some physicochemical parameters and number of individual macroinvertebrate in Cirhanyobowa River

	Tempe_(oC)	pH	DO _(mg/L)	Calcium_(mg/L)	TP _(µmol/L)	TN _(µmol/L)	Depth_(cm)	Velocity_(m/s)	N_of_ind.
Temp_(oC)	0								
pH	0.712	0							
DO_(mg/L)	-0.99	-0.66	0						
Calcium_(mg/L)	0.333	0.892	-0.276	0					
TP _(µmol/L)	0.287	0.269	-0.347	0.283	0				
TN _(µmol/L)	0.537	0.729	-0.461	0.612	-0.353	0			
Depth_(cm)	0.761	0.187	-0.763	-0.262	-0.215	0.391	0		
Velocity_(m/s)	-0.91	-0.578	0.918	-0.258	-0.333	-0.534	-0.704	0	
N_of_individual.	-0.946	-0.709	0.927	-0.361	-0.133	-0.679	-0.754	0.906	0

Fig.1 Map of river Cirhanyobowa and sampling site



Water velocity is one of the factors that effect on the abundance of aquatic insects. But Nur *et al.*, (2017) found that there was a strong, negative correlation between water velocity and aquatic macroinvertebrate (r=-0.969). But in Ciranyobowa River we found a contrary because water current velocity is positively correlated with abundance of macroinvertebrate. Some taxa of macroinvertebrate colonized micro-habitat with high current velocity and are adapted to this environment. Scheibler *et al.*, (2014) stated that a pH range of 6.5 to 8.0 provides adequate protection for the life of macroinvertebrates. Thus, all of the six sites in Cirhanyobowa River are still inthe acceptable range of pH to aquatic life which all freshwater aquatic life is unharmed and no bad impacts occur. But, the correlation of pH and abundance of macroinvertebrates was negatively correlated. These are justified by observed ascertainment before as correlation is not due to individual effect of physicochemical parameters but with a group of parameters. Based on this study, it can be concluded that the physical parameters of Cirhanyobowa River which are water temperature, pH, TP, TN, water velocity, water depth and dissolved oxygen level have strongly influence the abundance of aquatic macroinvertebrate. Thus, we can develop the alternative bioindicator for water condition by using aquatic macroinvertebrate.

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