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Variation in Macro Invertebrates Communities in Streams in Above and Below Dam: A Case of Kulekhani Dam, Makawanpur, Nepal

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Research Article

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ABSTRACT

Damming of rivers disrupts hydrological cycle and negatively impacts the structure, function of riparian ecosystems and alters the abundance and composition of biological conditions in the aquatic environment. Macroinvertebrates play important role in stream ecosystem function and research related on their responses to dam construction is lacking. This study was to assess the variation in Benthic Macro Invertebrates (BMIs) communities in streams in above and below Kulekhani Dam in relation to physico-chemical parameters. Multi habitat qualitative samplings for four sites were conducted with 100 m stretch in each study river section during winter season, 2019. The Ganga River System biotic (GRS bios) score method was used for the biological water quality assessment. High value of DO, pH with fewer temps, TDS and EC was found above the dam while inversed below the dam. The water quality was high in the site SA02 with Average Score Per Taxa (ASPT) value 6.1 (i.e. River Water Quality Status (RWQS)-I) which is slightly polluted above the dam site and immediate site SB01 was found to be critically polluted with ASPT value 5.4 (i.e. RWQS-III) which was recovered in the reference site SB02 with ASPT value 6 (i.e. RWQS-I). A total of 25 families and 8 orders of aquatic BMIs were identified in different sampling sites. The taxa richness was found higher above the dam and lower in below sites. Whereas, abundance of macro-invertebrates was found higher above the dam and lower below the dam. Percentage of EPT taxa and abundance was decreased below the dam and found higher above the dam respectively. The SA01 showed the high concentration of Shannon and Simpson’s diversity index.

INTRODUCTION

Hydropower dam has many advantages as a robust technology and one of the most environmentally benign energy technologies. However, damming of rivers disrupts hydrological cycle and negatively impacts the structure and function of riparian ecosystems and alters the abundance and composition of biological conditions in aquatic environments. Dams are also the structure for habitat changes of aquatic macroinvertebrates. Effects of dams on Benthic Macro-Invertebrates (BMIs) communities are important because of the role that macroinvertebrates play in stream ecosystem function. The creation of an impoundment can alter numerous physical and chemical factors such as pH, dissolved oxygen and water temperature [1].

Surface water status is defined in the article 2 of as the general expression of the status of a body of surface water, determined by the poorer of its ecological status and its chemical status. In order to describe the status of the waters, WFD Water framework directive of the European Union includes consideration of biological elements such aquatic flora, benthic invertebrates and fish; hydro morphological elements such as water flow, groundwater dynamics, river depth, width and continuity; and chemical and physiochemical elements such as thermal and oxygenation conditions, salinity, acidification, nutrients and specific pollutants. A healthy river is one which has retained its ecosystem integrity which depends on its ability to maintain its structure and function, to recover after disturbance, to support local biota. A river has become un healthy, they lose their capacity to provide valuable goods and services [2].

The study of biological indicators with physical and chemical parameters to integrate the quality of water is called bio assessment. Now, the bio assessment of water can be done through the monitoring of ecological as well as chemical status. Bio-monitoring is a method of observing the impact of external factors on ecosystems which is defined as “the systematic use of living organisms or their responses to determine the condition or changes of the environment”. Biological monitoring is one of the best and integrated approach which helps to assess the water and overall environmental quality. Number of different index have been developed, about 60% of which biotic index was based on macro invertebrates analysis. Biotic index or family biotic index measure for indicating the quality is measure for indicating the quality of an environment by indicating types of organisms present in it. It is usually applied to assess the quality of river water. It is measured from (1-10) and corresponds four basic water quality i.e. excellent, good, fair or poor. The concept was given by Cherie Stephens to measure the stream pollution and its effects on its biology. The biotic index is mainly based on two principles i.e. the number of taxonomic groups is reduced when pollution increases and sensitive species disappear when organic pollution rises [3].

Nepal is developed a bio-assessments to better incorporate river ecosystems into water quality programs through Ganga River System biotic score, Hindu Kush Himalayan biotic score and Nepalese biotic score extended. On the basis of 10-point taxa scores in all these biotic systems, 1 and 10 are given as highly pollution tolerant taxa and highly sensitive taxa respectively by using Average Score Per Taxon (ASPT) where the River Quality Class (RQC) is determined by comparing biotic index value with respective index’s class boundary. In this study we used GRSbios for assessing the ecological health of rivers because GRS bios included many insect groups and require species level identification for non-insects. So the stability of GRSbios index in different geographic regions makes it a promising bio-monitoring tool in Nepal [4].

About 8 × 102 MJ of biomass has been recorded in Nigeria while 144 million tons of biomass potential in Nigeria. Very limited study has been performed in the river water quality by means of biological parameters. In the context of

Nepal, in general and more specifically in the Kulekhani reservoir, a very few limnological studies have been carried out. In order to fulfill this knowledge gap, the present study aims to investigate the present status of benthic communities in before and after the Kulekhani reservoir dam and to determine water qualities as well. The overall aim of this research is to study the variation in macro invertebrate communities in streams in above and below dam [5].

MATERIALS AND METHODS

Study area

The research was conducted in tributaries of Kulekhani Reservoir (i.e. above dam) and River stretches (i.e. below dam) in Makwanpur district. The Kulekhani watershed is comprised of 43.6% forest, 34% sloping agricultural land, 9.2% shrub, 5.7% level and valley terraces and 7.5% other land uses. Kulekhani watershed has the total population of 31,562, with more than 80% of them depends on agriculture for their livelihood. Among them, 239 households have been involved in fish culture in 1630 cages in 2009. The climate of Kulekhani watershed varies from subtropical at low land to temperate at higher elevation. The average temperature of study area is 15 °C to 25 °C in summer whereas 1 °C to 15 °C in the winter season. As per the whole area of the country, this area has also four distinct season; pre-monsoon (March to May), monsoon (June to September), post monsoon (October to November) and winter (December to February). The average rainfall within reservoir is ~ 1400 mm of rainfall in the monsoon season and ~ 60 mm during other dry seasons and the level of water in the reservoir was different with season and power generation (Figure 1 and Table 1) [6].

Figure 1. Study area with sampling sites.

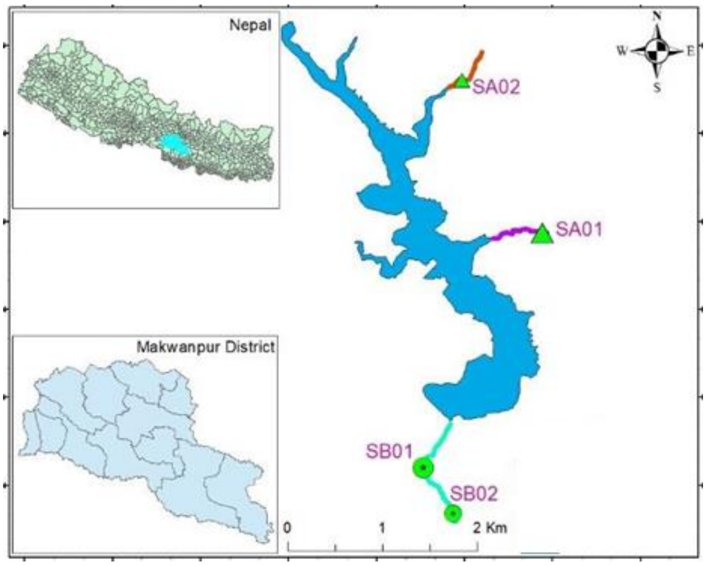

Table 1. Geographic location of sampling sites above and below Kulekhani Reservoir.

Attribute	Tributaries		Downstream	
	Seti khola (SA01)	Chitlang river (SA02)	Immediate (SB01)	Spill way after 4 km of I M (SB02)
Location	Markhu	Markhu	Along the highway	Along the highway

Longitude	85°10’1.86”E	85°15’73.09”E	85°15’58.05”E	85°9’33.47”E
Latitude	27°36’28.1”N	27°62’12.14”N	27°58’38.04”N	27°34’47.81” N
Width (m)	1.5	5	2.5	3.5
Depth (m)	0.06	0.4	0.19	0.32
Velocity (m/s)	0.4	0.8	0.5	0.7

Data collection

The sampling of benthic macroinvertebrates was carried out and hydrological and physicochemical parameters were measured during the winter season (2019) following the protocols. Total 2 tributaries sampling site was selected above the dam (SA01 and SA02) and river stretches below Kulekhani dam and immediate after dam (SB01) and after 4 km (SB02). Prior to the sampling of BMIs, the habitat coverage of the studied river bed within 100 m of river stretch was estimated. At least 5% habitat coverage of the substrate was sampled. This technique is according to the multi-habitat sampling approach which is an improvement sampling approach over the traditional one as it acts as representative for sample collection on the entire major habitat. The kick net of 500 μm mesh size was used for collection of BMIs from 20 micro-habitats and was composited into a single sample [7].

The depth and width of the river were measured by using measuring- tape and the velocity of the River were measured by a current meter in the study areas. The physico-chemical parameters - pH, water temperature, Dissolved Oxygen (DO), Total Dissolved Solids (TDS) and Electrical Conductivity (EC) were measured using a handheld multi-parameter probe. The use of such multi-parameter portable meter is helpful in determining water quality parameters accurately on site which helps to reduce workload in laboratory (Tables 2 and 3) [8].

Table 2. Different indices with their calculation formula.

Metrics	Calculation
Taxa richness	Total number of present taxa in a site
Total abundance	Total number of individuals in a site
No. of EPT taxa	Total sum of EPT taxa
Diversity Indices	
Shannon's diversity index(H)	−Σpi*lnpi pi=relative abundance of ith taxa
Simpson's diversity index(D)	1−Σ(pi*pi) pi=relative abundance of ith taxa
Eveness measures(e)	H/lnS with H=Shannon’s diversity index, S=Taxa richness

Table 3. Method of sampling technique.

Parameters	Method/Equipment
pH	pH meter
Conductivity	Conductivity meter
Oxygen content	DO meter
Temperature	Thermometer
Mean and maximum depth	Measuring tape

Data analysis

The benthic macroinvertebrates were refined in the laboratory and were sorted and identified at family level. Then they were counted and preserved in 90% ethanol for future reference [9]. Assessment of ecological River water quality class quality is based on the extent of deviation from these references conditions. The meaning of ecological status include the specific aspects of the biological quality elements, for example composition and abundance of aquatic flora or composition, abundance and age structure of aquatic fauna [10]. Biological water quality class calculation, Ganga River System Biotic Score per Average Score Per Taxon (GRS-ASPT) was calculated by dividing the number of taxa score to the total GRS-BIOS score and the obtained numerical value was compared with its transformation table for evaluation of biological water quality classes of running as well as stagnant water bodies. The description of river water quality classes was done with respect to GRS/ASPT value [11].

A diversity index is a regarded as the computable measure of species diversity in a community. Beside species richness (i.e. the number of species present), Diversity indices provide further instruction about community composition too. They also estimate the relative abundances of different species take into the account [12]. Also, these indices are means for the important information about rarity and commonness of species in a particular community [13]. Likewise, tolerance values provide the information about sensitivity of aquatic organisms towards pollution. It is useful tool for assessing the biological condition of the aquatic bodies [14]. Tolerance measure of the particular water bodies can be obtained through GRSbios ASPT. Composition of different taxa also helps to know the water quality condition and to compare them by dam effect [15]. The percentage of the composition of EPT taxa was determined. Richness Measures was evaluated [16].

Multivariate analysis

CCA function in vegan package in R Studio Version 1. 2. 1335 were used to determine the association between environmental variables and BMIs assemblage through Redundancy Analysis [17-25]. The appropriate ordination technique whether Re-Dundancy Analysis (RDA) or Canonical Correspondence Analysis (CCA) was selected and was performed amongst hellinger transformed BMIs abundance data with the transformed explanatory variables [26-30].

RESULTS

Physicochemical parameters: The obtained value of water temperature, TDS and EC found higher below the dam in SB01 and SB02 sites while found to be less above the dam in SA01 and SA02 sites. Likewise pH found to be more

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alkaline above the dam with high DO value and vice-versa below the dam. These environmental variables directly affected on the benthic macroinvertebrates assemblages [31-35].

There seems to be both direct and indirect effect in all aspects of stream ecology due to temperature of water in it. Different organism thrive at different water temperature. It is regarded that the approximate upper limits range from 38°C (100°F) for fish and 50°C (122°F) for aquatic insects to 73°C (163°F). The temperature of sampling sites before dam (SA01 and SA02) was less than the sampling sites after dam (SB01 and SB02). More riparian vegetation was present which might have prevented the light penetration lowering the temperature of water [36-40]. Change in water temperature was found to be related with corresponding changes in atmospheric temperature. The EC was found higher after dam sampling sites (SB01 and SB02) where it was found less low before dam sampling sites (SA01 and SA02). The change of conductivity at site SB01 and SB02 was due to the rise in temperature. As the conductivity measurements are temperature dependent i.e. if the temperature increases, conductivity also increases [41]. Moreover, the geological area through which the stream path could be the reason behind the variation in the level of conductivity. Likewise, TDS concentration was found to be higher below dam sites (i.e., SB01 and SB02) whereas it was found much lower above dam sites (Figures 2 and 3) [42].

Figure 2. Study of pH and temperature.

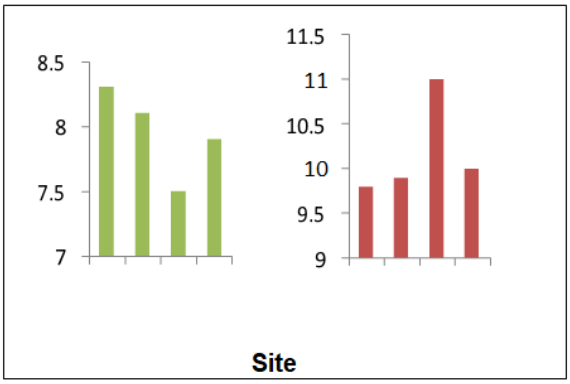
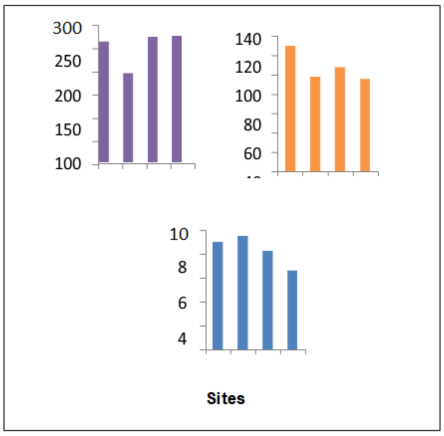


Figure 3. Study of EC, TDS and DO of studied sites.



Typically, natural pH levels fall between 6.5 and 9.0 which is totally varied according to the surrounding soil and vegetation and pH at site SA01 (above dam) was highest with a value of 8.3. Rapidly growing algae removes carbon dioxide from the water during photosynthesis and this can result in a significance increase in pH levels. Low pH was recorded in sites (SB01 and SB02) low pH causes a disturbance of the balance of sodium and chloride ions in the blood of aquatic animals. The pH values were standard for drinking water (6.5-8.5). High DO concentration was recorded in site SA02 above the dam while slightly less DO was recorded below the dam sites (SB01 and SB02). Variation of DO level might be explained by a joint effect of temperature, photosynthesis, respiration, organic waste, aeration and sediment concentration [43]. Since, the distribution of many taxa are affected by Concentrations of DO, it is regarded as the important component for impacting the composition of freshwater communities. Generally, stream water requires 4 mg/L of DO to support a diverse aquatic life. DO levels in streams and other water bodies are affected the photosynthetic rate of aquatic plants by anthropogenic activities.

Tolerance measures with ecological health

The Average Score per Taxon (ASPT) value was slightly decreasing below the dam as shown in table. The table showed that the ecological status was degraded immediate sampling site after dam which then recovered after some km in which the river quality of above the dam found to be higher than below dam (Figure 4 and Table 4).

Figure 4: Tolerance measures of taxon showing with ASPT and GRS bios values.

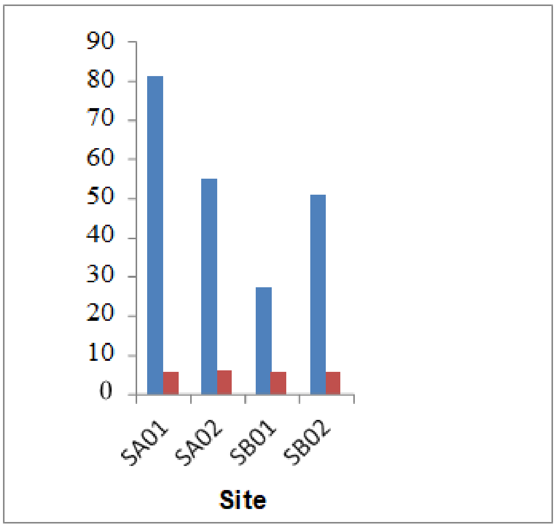


Table 4. Ecological health of different sites in above and below Kulekhani dam.

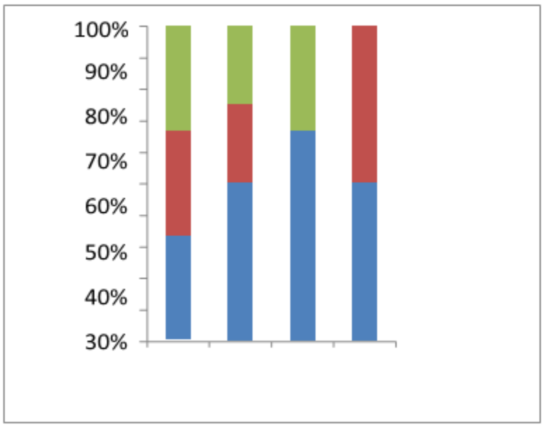
Metrics	Above dam		Below dam	
	SA01	SA02	SB01	SB02
RWQS	II	I	III	II
Status	Good	High	Fair	Good
Description	Moderately polluted	Slightly polluted	Critically polluted	Moderately polluted

Tolerance is refer to the niche breadth or the span of environment that an organism can cope with. On the basis of this it can be said that more tolerant organisms can withstand a broader range of conditions. The biological condition of the river was calculated by using GRS bios method, where the immediate site below the dam was critically polluted according to River Water Quality Class (RWQC) with less taxa tolerance score which then recover after some distance as recovery site in SB02 site which was moderately polluted. The sampling sites above dam characterized by good ecological status specified by the high proportion of pollution sensitive BMIs which have higher GRS bios scores.

Composition measures

Composition measures information on the make-up of the assemblage and the relative contributions of the population of the total fauna. Among the studied candidate metrics of composition measures, % of E (*Ephemeroptera*), % of P (*Plecoptera*) and T (*Trichoptera*) taxa was decreased below dam while found increased above the dam. The total EPT (*Ephemeroptera, Plecoptera* and *Trichoptera*) taxa were recorded higher above the dam sites. Where the EPT composition on any sites was expected to decrease with the increase in disturbance because EPT taxa composition was very sensitive towards temperature and flow regime. Hence, the families of EPT taxa were found higher above the dam (Figure 5) [44].

Figure 5. Percentage of relative abundance of macro-invertebrate in the study sites.



Richness measures

A total of 25 families and 8 orders of aquatic macroinvertebrates were identified from sampling sites above and below dam. There were 18 families belonging to 8 orders and 13 families belonging to 6 orders from above and below dam respectively. The total number of individual macro-invertebrate was recorded from diptera order and lowest individual was recorded from *oligochaeta* order in above the dam. The unique families recorded only above the dam were *ceratopogonidae*, *chironomidae* (not red), *nemouridae*, *hydroptilidae*, *heptageniidae*, *Coenagrionidae* and *oligochaeta*. The total number of individual macro-invertebrate was recorded from *coleoptera* order and lowest individual was recorded from Odonata order in above the dam. The unique families recorded only below the dam were *chironomidae* (red), *Halipidae*, *Dytisicidae*, *Perlodidae*, *Apataniidae*, *Gomphidae*, *Hydraenidae* and Libellalidae.

The taxa richness, total abundance of macro-invertebrates with % of EPT abundance was found higher above the dam and lower below the dam. In present study, immediate sampling site below dam (SB01) consisted of the lower taxa richness than other sites which reflect the decrease in water quality. While the site (SA01) above the dam has high taxa richness but decrease in water quality due to disturbed site and lower taxa score invertebrates. Generally, the total number of families (total taxa richness as well as EPT taxa richness) increases with the increase in water quality. The use of EPT taxa richness (in %) as the most illustrative tool in order to analyze the biological data to sure the most effective investigation of water quality.

The variation in macroinvertebrates was analysed through different diversity indices showed that immediate sampling site have high evenness measures but less shannon value below dam. The sampling site above dam showed the high concentration of shannon and simpson's diversity index as the result showed that shannon diversity index was higher in site SA01 which showed high diversity and abundance than other sites which was decreased immediate site below the dam in SB01, which showed less diversity and abundance which then recover in next site. Overall calculation showed that Shannon diversity index was decreased below dam in immediate site and recovered with next sampling sites where Simpson's diversity index and evenness measures found to be neutral in both the site above and below dam. The high evenness measures obtained in the site showed that the number of species present was highly closed to each other with the environment.

On average, the value obtained of Shannon diversity index, simpson's diversity index and evenness measure was found higher above the dam and low below the dam which showed that the species composition, abundance and diversity were high above the dam. This study supported by where species composition and abundance of EPT depends upon heterogeneous substrate composition and higher concentration of dissolved oxygen; characteristic of less disturbed area (Table 5 and Figures 6, 7).

Table 5. Richness Measure of above and below dam sampling site.

Sampling Sites	Above dam		Below dam		Response to stress
	SA01	SA02	SB01	SB02	
Taxa Richness	17	9	6	12	Decrease
Total Abundance	211	98	34	88	Decrease
No. of EPT Taxa	6	4	2	2	Decrease
% of EPT abundance	35.07	30.61	28.57	28.4	Decrease
Shannon's diversity Index	2.63	1.91	1.795	2.25	Decrease
Simpson's diversity Index	0.99	0.97	0.971	0.99	Neutral

Evenness measures	0.93	0.87	0.957	0.87	Neutral

Figure 6: Percentage of BMIs abundance of sampling sites Influence of environmental variables in macroinvertebrates.

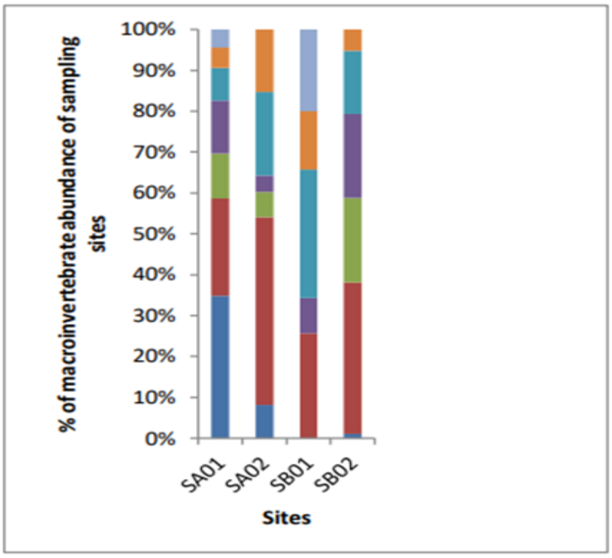
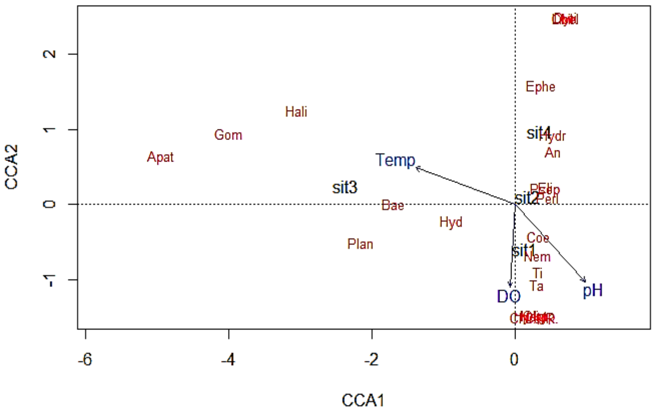


Figure 7. Cannonical Correspondence Analysis (CCA) ordination plot of macro-invertebrate's abundance and distribution with respect to physicochemical variables-(temp) temperature, pH, Dissolved Oxygen (DO).



The macroinvertebrate acronym represents, Ta-*Tabanidae*, Ti-*Tipulidae*, Chir (NR)-*Chironomidae* (not red), An-*Anthericidae*, Cer-*Ceratopogonidae*, Hyd-*Hydrophilidae*, Eli-*Elimidae*, Psep-*Psephenidae*, Hali-*Halipidae*, Dyti-*Dytsicidae*, Hydra-*Hydraenidae*, m Nem-*Nemouridae*, Perl-*Perlodiadae*, Hydr-*Hydropsychidae*, Hydrop- *Hydroptilidae*, Apat-*Apataniidae*, Hept-*Heptageniidae*, Bae-*Baetidae*, Ephe-*Ephemerellidae*, Coe-*Coenagrionidae*, Gom-*Gomphidae*, Libel-*Libellaldae*,Oligo-*Oligochaeta*, Plan-*Planoibidae* (Table 6).

Table 6. Biplot score for the constraining variables in three CCA axes.

Parameter	CCA1	CCA2	CCA3
pH	0.65	-0.76	0.01
DO	-0.05	-0.81	-0.58
Temp	-0.93	0.37	0.01

For each of these explanatory variables, a correlation was obtained with the CCA axis and pH clearly has a high negative correlation with the second ordination axis and to a lesser extent temperature also displays a negative correlation with the first ordination axis. While DO has a high negative correlation with all ordination axis. Since, the multivariate analysis is the tools to represent different environmental variables, here, it describe the variation in BMIs assemblages' abundance. For instance: BMIs families like *Tabanidae*, *Tipulidae* and *Chironomidae* (Red and Not red) (*Diptera*) showed positive correlation with pH meaning these species tend to have larger abundance at higher pH. Likewise, *Apatanidae*, *Gomphidae* and *Halipidae* have shown positive correlation with temperature also meaning they have higher probability of occurrence at higher temperature. While, *Nemouridae* (*Plecoptera*), *Baetidae* (*Ephemeroptera*) have shown positive correlation with DO.

DISCUSSION

The variation in macroinvertebrates assemblages was affected by physico-chemical parameter. As the study result match with other research finding where higher DO has been seen to be positively associated with EPT taxa as these taxa mostly contain sensitive organism. Similarly, pH and temperature have been regarded as variable response that seen both spatially and temporally, so the study on association of BMIs along a pH-gradient and temperature is require to fully support the results presented here [45].

CONCLUSION

This study examined variation of the physico-chemical parameters and benthic macroinvertebrates in above and below Kulekhani dam. The obtained results showed that the water quality of tributaries above the dam was good with high taxa, abundance (total and EPT taxa), diversity index while found lower immediate below the dam and physico-chemical parameters is determining factor for the benthic macro-invertebrates assemblages. Physico-chemical assessment alone cannot give the river health as it is equally important biological assessment. Hence, overall analysis showed that benthic macro-invertebrates assemblages varied due the presence of dam. However, the environmental variables studied had little influence on the macro-invertebrate family level communities. Thus, species level provides precise information on climate change than family level with more number of streams and seasonal variation are required to better understand the macroinvertebrates assemblages occur by dam effect. This study can be used as baseline information for further research and hydropower dam planning.

CONFLICTS OF INTEREST

"There are no conflicts to declare".

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