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River Health Assessment of Mohana Watershed, Nepal: Implication for River Conservation

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Abstract Lowland rivers are being deteriorated from urban runoff, agricultural runoff, and industrial wastewater. Additionally in stream human activities impact water quality as well as ecological status of surface water bodies. This study examines seasonal changes on assemblage of macroinvertebrate communities and establishes relationship with the environmental variables and determines the river health of lowland rivers. Altogether six sites were sampled in tributaries of Mohana river for pre and post-monsoon seasons in the year 2017 and 2018. Water quality parameters were measured in in-situ by using the digital multi-parameter probe. The benthic macroinvertebrate samples were collected using multi-habitat sampling approach and identified upto family level. Redundancy analysis was used to explore environmental variables in relation to the macroinvertebrate communities. High density of macroinvertebrates was found in post-monsoon than pre-monsoon season i.e. 875 ind/m^2 and 561 ind/m^2, respectively while the diversity was recorded higher in pre-monsoon. The Ephemeroptera, Trichoptera and Odonata taxa were more abundant group in the rivers. Diptera was dominant taxa i.e. 43% and 66% in pre-monsoon and post-monsoon seasons, respectively. Moreover, there was no significant difference of macroinvertebrate abundance in both seasons but diversity was significantly different. Environmental variables like pH, EC, DO, TDS and water temperature were significant parameters influencing macroinvertebrates composition in low land's river. The ecological status of lowland river of Mohana watershed was ranging from good to bad water quality class (i.e. ranging from 3.833 to 5.714 index value). The waste dumping, washing, and bathing, intensive use of chemical fertilizer and hydro-morphological alteration across the river section were the major stressor to deteriorate river water quality. Therefore, the water manager and local bodies should implement river management actions on time for the preservation of good status rivers for long-term use by the local people.

Keywords: *benthic macroinvertebrate, diversity, ecological health, Godabari river*

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1. Introduction

The availability and quality of water resources provide sustainable economic development and ecological integrity [1] which directly link with the life of human population. River basin generally constitutes areas with high population density due to the favorable living condition, water and food availability as well as easy access for transportation [2]. In the last few decades, an accelerated of industrial development and progressive growth of population caused in increasing the demand for freshwater [3]. Moreover, rivers are getting more pollution by discharge of agricultural waste, chemical and industrial effluent and municipal waste across the world [4]. Increasing pollution not only deteriorate of water quality but also threatens human health, aquatic ecosystem and biodiversity, impacts on economic development and social prosperity [5]. Furthermore, it reduces the natural scenic beauty of the river and highly impacts on bio-physical environment of the river.

A river comprises system from both main course and tributaries, which carrying one-way flow of significant load of particulate matter from both natural and anthropogenic sources [6]. The change in river water quality at any point reflects influenced by the geology of river basin, land use pattern, anthropogenic inputs and climatic condition [7]. Also, due to the seasonal variation in precipitation, surface runoff, groundwater flow and pumped in or outflow have a strong effect on the river discharge [2]. Thus, pollution concentration has changed with the river discharge and it subsequently changes in the chemical parameter of water quality as well as aquatic biodiversity. The composition and abundance of aquatic flora [8] and fauna [9] highly depend on several abiotic factors including river elevation, discharge, and substrate. Increasing organic pollution in the river produces odor and aesthetic nuisance, also decrease diversity of aquatic organism and its life. The pollution source might be the point and/or non-point sources of river and water make unsuitable for human use.

In Nepal, rivers are highly impacted by the human-generated contamination from agricultural, industrial and municipal waste discharge without any treatment into the river, which significantly increases the nutrient amounts and organic pollution [10]. This is one of particular concern in most of the developing country where untreated industrial and municipal wastewater discharged into surface water [11]. Urban river gets significant loads of pollution from storm runoff due to the paved surface. Pollutants include solid waste/debris, pesticides, fertilizer, oils and vehicular exhaust and tears which are the common source of organic and inorganic compounds and heavy metals in the surface water [12]. In major cities of Nepal, the surface water and environmental degradation is ongoing serious concerns. High water turbidity, low dissolved oxygen and presence of nitrogen and phosphorus compounds in urban river have not only produced the odor and aesthetic nuisance but have also led to decrease the aquatic life [13]. The study of Davids, et al. [14] in Kathmandu valley has been found low dissolve oxygen but increment of electrical conductivity and water temperature with buildup and agricultural land used increase. Also, this study shows that the ecological health of the stream had deteriorated with increasing the buildup and agricultural land area.

The water quality assessment and monitoring is mainly based on chemical data analysis in most of the Asian country [4]. While biological approach as well as chemical data analysis was widely used in Europe, Australia, the United States and Great Britain for detecting the river degradation and are widely accepted all over the world [15]. Biological indicators are commonly used to evaluate and characterize the ecological changes of stream [16]. Among these biological indicators such as algae, benthic macroinvertebrate, fish, macrophytes and periphyton, benthic macroinvertebrates are most commonly used as a biological approach across the world [17]. Benthic macroinvertebrate (BMI) is the key indicator of environmental stresses, especially identify the impact of specific pollutants in an aquatic body. In a recent year, many publications have critically reviewed the use of BMI as a bio-indicator. Several researchers used BMI for the monitoring of water quality and the ecosystem health [10,18,19]. Because, macroinvertebrates are differently sensitive to pollution of various types, broad capable pollution tolerance to sensitive, reflect the quick response in their communities. Moreover, it has long lifespan enough to provide environmental stresses and these organisms are abundant, heterogeneous communities and consists the representation of several phyla [20]. Also, they are used to determine eutrophication, pollution stress and water quality in freshwater body studies in the worldwide [21].

The aim of this study was 1) to assess the seasonal variation in assemblage of macroinvertebrate communities and the relationship between the environmental variables and 2) to assess the ecological status of low land rivers of Mohana watershed. The rivers of Mohana watershed are originated from Churiya region (elevation of Churiya region ranged from 610-1872 meters) and these rivers are seasonal with less flow in dry season. These types of river are unsuitable for year round irrigation and hydropower development without the surface storage [22]. Due to the fragile ecosystem in Churiya region, the surface erosion was very high [23]. In addition, the haphazard land use practices, river bank modification and extraction of river bed materials might impact on community assemblage of benthic organism and river ecological status. Therefore, this study helps to the policymakers, river managers and biological conservationist of Nepal with a scientific understanding.

2. Materials and Methods

2.1. Study Area

Mohana watershed (28˚ 22 N - 29˚ 05 N, 80˚ 30 E - 81˚ 18 E) is located in Kailali district of province 7, Nepal. The watershed covers with a catchment area 2918.22 Km^2. The major tributaries of Mohana river are Godabari, Manahara, Chaumala, Kandra, Patharaiya. Among these rivers, the four sampling sites at Godabari, Manahara, Chaumala rivers are above 200 masl and rest of two sites Kandra and Patharaiya rivers have below that level (Figure 1) because the upstream of these two rivers had dried during the dry season. The dominant land use in Mohana watershed was forest land (about 64%) followed by 27% cropland and 5% buildup area including settlement and urban area and industrial area [24]. Moreover, the flat plain area was dominated by agriculture land while the higher elevation area was covered by forest land. The major crop cultivated in the study area was paddy, wheat, and maize, while oilseed and pulse are secondary crops. Also, animal husbandry was common in rural areas' household. Therefore, the use of organic fertilizer is common; also almost the entire farmer used chemical fertilizer in agricultural land. The river water was mainly used for irrigation and aquaculture purpose. Sanitation including washing and bathing, cattle drinking and recreational activities were commonly used by the local people.

2.2. Site Selection

A total of 6 sites were sampled for biological water quality assessment from the five major tributaries of Mohana river. Site selection based on the land use cover, bottom substrate, pollution stress area, river bank condition and solid waste dumping. The two sites Kandra and Patharaiya rivers were dominated by agriculture land, Chaumala was dominated by forest land, Manahara downstream was dominated by forest land and settlement area, Manahara upstream was dominated by forest and agriculture land and Godabari was dominated by agriculture, forest and buildup land. The water velocity, discharge and composition of the bottom substrate were different in each site shown in Table 2.

2.3. Sampling and Data Collection

Sampling was conducted in two seasons i.e. pre-monsoon (April 2017) and post-monsoon (January 2018). Monsoon season was not considered for sampling because frequent flood events reduce the differentiation between inter-sites [25], also possibility of drifting benthic macroinvertebrate during the flood events [26] could either under or overestimate of ecological status of river segments [4]. The water sample was taken in a bucket using the composite sampling upto 10 cm depth [27] and 1 meter distance from the river bank. The selected environmental parameters, such as pH, EC, TDS and water temperature were obtained by using the multi-parameter handy probe (PCSTestr 35) and dissolved oxygen was obtained using a DO probe (EcoSene DO200A) in *in-situ* measurement. The water velocity was measured by using the digital flow probe (Global Water Flow Probe) with an accuracy of 0.1 FPS which displayed by averaging the water velocity of the channel's flow. The velocity was measured in one-meter river section from the right bank to left bank or vice versa as approximately 40% below from surface water. Also, the depth of the river was measured by using the flow probe scale and noted in centimeter.

Macroinvertebrate samples were collected using the multi-habitat sampling approach [28,29], which reflect the proportion of microhabitat types and represent greater than or equal to 10% habitat within 100 meters river stretch. Macroinvertebrates were sampled from the 10 sub-sites according to the habitat types and percentage of coverage [10]. In each sub-sampling, (0.25×0.25) m^2 area sampled using the hand net with the mesh size 500 µm, i.e. each sampling site covered 0.0625 m^2 area. The net was placed in river bed surface and the area of 0.0625 m^2 upstream of the net was disturbed and wash the macronvertebrate from the river bed. Individual rock in the sampled area was picked up and the attached organisms were removed into the net [30]. Macroinvertebrates were collected in plastic vile with clear labeling and were preserved in 85% ethanol in the field. Moreover, the benthic organisms sorted and identified the entire sample in laboratory to the family level based on available keys [31] [unpublished keys of ASSESS-HKH project (www.assess-hkh.at)] with the help of a stereo microscope.

2.4. Data Analysis

The several biotic score system has been used in Nepal to assess the river ecosystem health. However, the study of Shah and Shah [10] shows that the Ganga River System Biotic Score (GRSBios) has better performance than the other biotic system in the context of Nepal. Therefore, BMI taxa were scored using the GRSBios and it is calculated by dividing the sum of total taxa score by number of scored taxa that result in Ganga River System Biotic Score/Average Score per Taxon (GRSBios/ASPT). This result reflects that the overall river ecosystem health by accounting for the cumulative effects of organic pollution, land use and hydro-morphological changes [4].

Table 1. Calculation methods of biological metrics

Matrices	Calculation
Total abundance	Total number of individual in a site
Taxa richness	Total no. of taxa present in a site
Percentage of ETO	(Sum of individual of ETO/Total no. of individual)×100
Shannon diversity (H)	$-\Sigma pilnpisi=1$, where, pi=n/N, n= individual of particular species, N= total number of individual present
Evenness (E)	$HlnS$, Where, S= number of taxa present

Furthermore, the diversity indices such as Shannon diversity and evenness were calculated. Total abundance, taxa richness and percentage of Ephemeroptera, Trichoptera and Odonata were calculated separately [32]. The calculation methods are presented in Table 1.

All the data were arranged on Microsoft excel 2013 version. The BMI abundance data were transformed to log(x+1) for multivariate analysis [33]. Since the data did not follow the normal distribution, the two dependent samples Wilcoxon signed rank test was run to understand the significant difference between pre and post-monsoon seasons [34]. The statistical analyses for all variables were tested at 95% level of confidence. Redundancy analysis (RDA) was performed with seasonal variation and site as a factor as well as the relation between the BMI and environmental variables. All the above statistical analysis was performed in RStudio (version 1.1.442, RStudio Team, 2016).

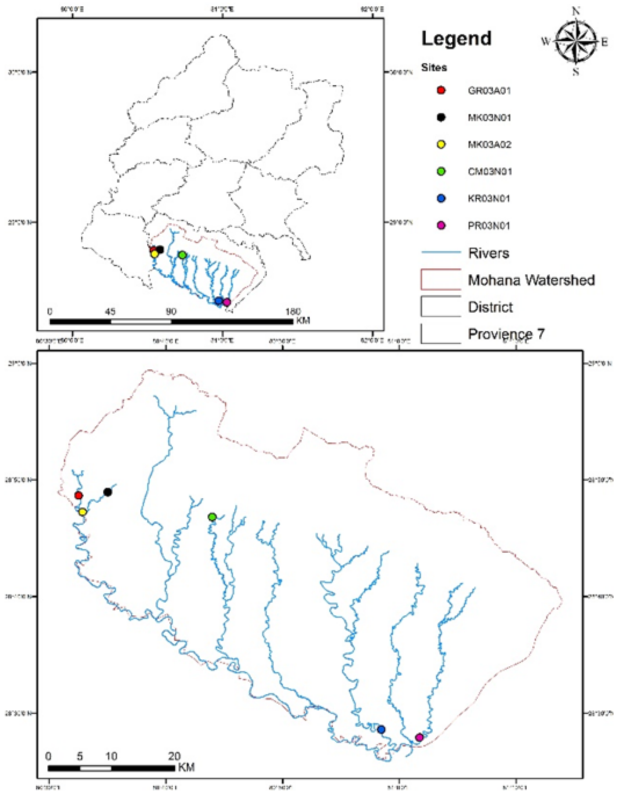

Figure 1. Location of macroinvertebrate sampling sites (Where site code GR03A01 means Godawari river abstracted site, MK03N01 means Manahara Natural sites; MK03A01 means Manahara abstracted site; CM03N01 means Chaumala natural site; KR03N01 means Kandra natural site; PR03N01 means Patharaiya natural site, hereafter site code is explained by the rivers name)

3. Results and Discussion

3.1. Composition and Diversity

A total of 5218 individuals under the 46 families representing 12 orders of macroinvertebrate were recorded in both pre and post-monsoon season. In overall, the abundance of macroinvertebrate was recorded high in post-monsoon than pre-monsoon seasons (i.e. 3283 and 1935 individuals respectively). Among these river

Godabari and Manahara upstream have lower abundance in post-monsoon season (Figure 2). However, there was no significant difference of macroinvertebrate abundance with the season ($p<0.05$). In addition, the higher density of benthic macroinvertebrate was recorded in post-monsoon season than pre-monsoon season (i.e. 875 ind/m^2 and 561 ind/m^2 respectively) [35,36,37]. The forest dominated land use sites have higher abundance of BMI in both pre- and post-monsoon season [38]. The higher abundance of macroinvertebrate in post-monsoon support the lower the organic nutrient concentration due to the high discharge dissolve the pollutants concentration in the river [2]. Also, the similar results were found in agriculture land dominated sites like Patharaiya and Kandra river. The heterogeneous habitat in these sites with wide riparian habitat supports the higher abundance of BMI in post-monsoon season.

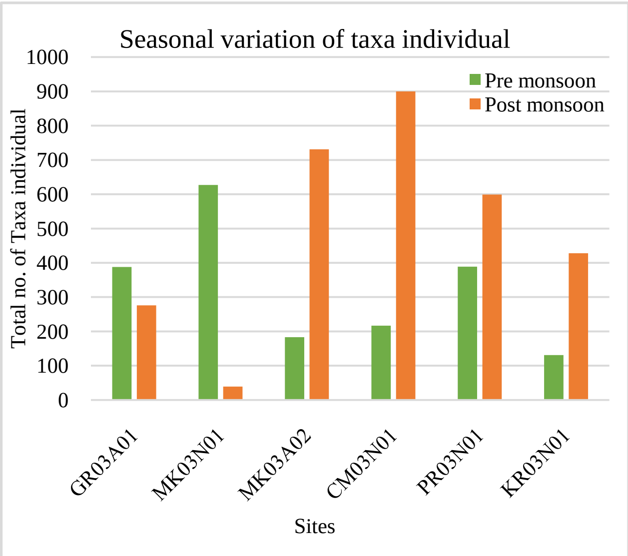

Figure 2. Seasonal change in taxa abundance

In addition, the agricultural land and settlement area are the source of non-point pollution into surface water body which might be affected the population of benthic macroinvertebrate [38] in pre-monsoon season. Also, the mechanism behind the decline observed in post-monsoon in these two streams is likely to be the catastrophic substrate mobilization and continued sediment input from the bank erosion [35].

Ephemeroptera, Trichoptera, Diptera, Odonata, and Coleoptera were common taxa in all sites for both seasons (Figure 3). The similar result was reported by Shah [32] in lower gangetic plains moist deciduous forest. The number of families of Diptera, Odonata, Hemiptera, and Haplotaxida were found little bit higher in pre-monsoon season. Although, the families of Mollusca were found higher in post monsoon season due to the higher water conductivity and silt habitat in post-monsoon season [39]. Also, habitat with soft mud in shallow depth might be the favorite for high colonization for the richness of Mollusca. The Plecoptera taxa were absent in both seasons in all sites however it was common taxa for the midland and high land [40] of small tributaries. The study of habitat distribution of Plecoptera is mostly the concern in hilly and mountain region, while less concern in lowland areas [41]. According to the study of Bispo, et al. [42], the most important factor that affects the spatial distribution of Plecoptera was altitude, stream order, and anthropic influence. The researcher also states the cause of Plecoptera abundance reduction in lower river stretches, pronounced anthropogenic influence and larger stream order. The habitat like sandy and unstable habitat might not be suitable for the growth of Plecoptera taxa.

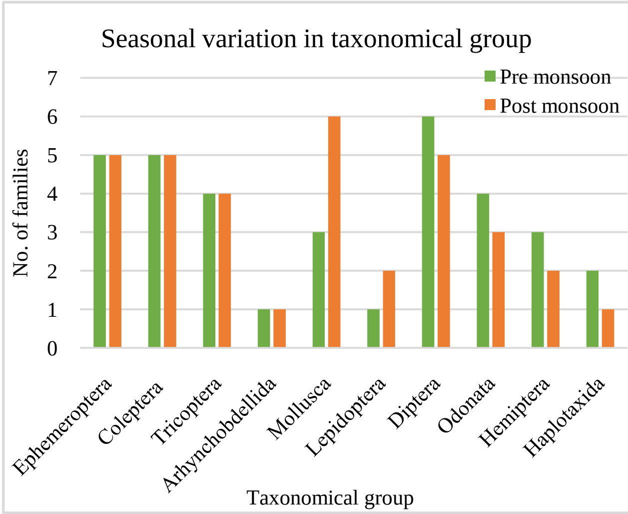

Figure 3. Seasonal variation of macroinvertebrate order

The percentage of relative species abundance of Diptera was recorded highest i.e. 43% and 66% for pre and post-monsoon seasons respectively followed by Gastropoda 22% in pre-monsoon but less than 4% in post-monsoon season (Figure 4 & Figure 5). Similarly, relative species of the abundance of Odonata was recorded 12% in pre-monsoon but it was less than 5% in post-monsoon season. The percentage of Trichoptera was increased in post-monsoon season by 6% than pre-monsoon. Chironomidae taxa were dominated in all sites in both pre and post-monsoon season (i.e. 35% and 61% respectively), the similar result was reported by [35,36]. During the low water period, such taxa Baetidae and Chironomidae are generally fast growing [43] and quicker colonizer is able to become dominant taxa. These taxa are especially well adapted in the unstable environment. They possess behaviors that allow them to resist flash floods and life history adaptations that impart resilience [35].

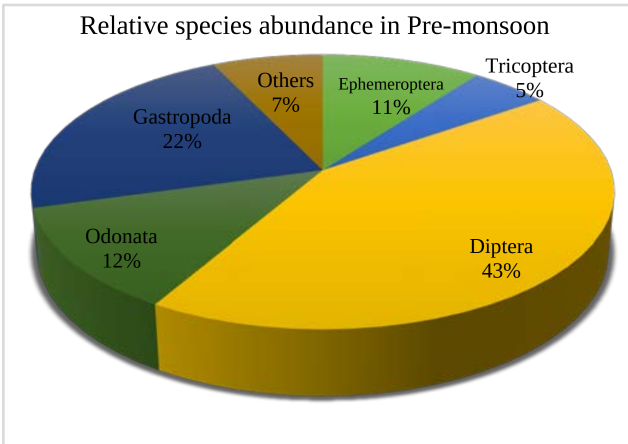

Figure 4. Relative taxa abundance in pre monsoon season, others include Coleptera, Hemiptera, Haplotaxida, Dacapoda, Lepidoptera and Arhynchobdellida

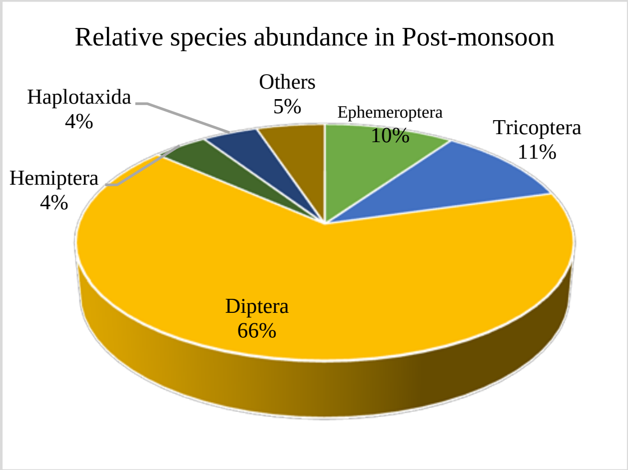

Figure 5. Relative taxa abundance in post monsoon season, others include Coleptera, Odonoata, Gastropoda, Lepidoptera, Arhynchobdellida and Uniodia

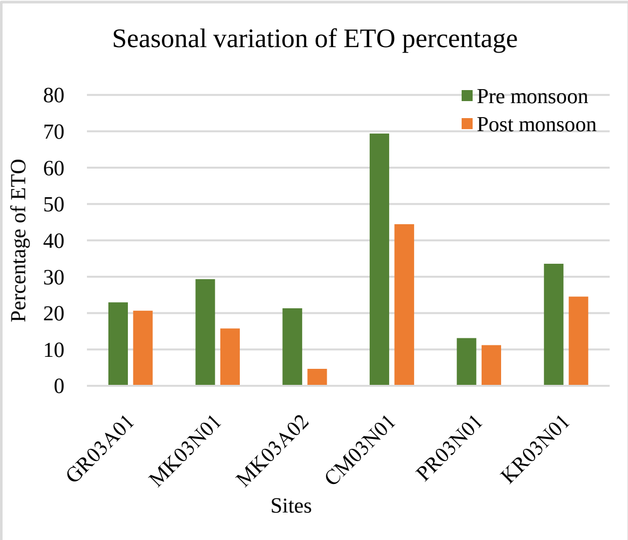

Figure 6. Site wise seasonal variation of ETO percentage

The evenness diversity index, Shannon Wiener diversity index and percentage of Ephemroptera, Trichoptera and Odonata (ETO %) were found higher in pre-monsoon seson than post monsoon (Figure 6). The Shannon and evenness index and ETO percentage were significant difference between the seasons (*p<0.05*). The diversity was recorded higher in Chaumala river where the forest land dominated and mostly cobble, stone dominated sites. In addition, the ETO percentage also higher in the same site. The significant difference between the season might be attributed to severally change in the bottom substrate due to the monsoonal flood and other environmental variables. The similar cases were reported by Brewin, et al. [44] in 600 to 800 meter elevation of streams in Nepal.

3.2. Environmental Variabls and Their Relationship

The chemical water quality parameter including the physical features of river was taken as an environmental variable (Table 2). The river flowing on plane land has dominated by sandy habitat, however, the mixed types of substrate compositions such as gravel, sand, cobble, stone and macrophytes with clay mud were recorded during the field study.

The pH values were slightly basic in post-monsoon season in Godabari, Manahara and Chaumala river, however other two rivers Patharaiya and Kandra river had slightly acidic. But EC, TDS and DO were higher in post-monsoon as compared to the pre-monsoon season. pH, DO and TDS were not significant difference (*p<0.05*), however, water temperature and electrical conductivity were significant difference with seasonal variation (*p<0.05*). These rivers are originated from Churiya region, where this region is most fragile landforms. During the monsoon season, the higher intensity of rainfall can increase the surface erosion and sediments come into the river. The ions and dissolved matter come with surface erosion caused increase total dissolved solids and electrical conductivity in river water. In addition, due to agriculture and urban runoff caused supplies the higher concentration of TDS into the surface water [45]. The similar result was found by Paudyal, et al. [46] in Bagmati river section. Moreover, the pH, EC, TDS and DO does not exceed the limit of NWQGIW, NWQGA, NWQGLW and NWQGR, so water from these rivers are safe to use for these proposes. However, surface water was directly contaminated with the different pollution sources, therefore without the proper treatment; the water cannot be used for any purpose.

Table 2. Seasonal variation in physical river features and water quality parameters [GRA mean gravel; SAN mean sand; COB mean cobble; STO mean stone; MAC mean macrophytes; BOU mean boulder]

Environmental parameters	GR03N01		MK03N01		MK03A01		CM03N01		PR03N01		KR03N01	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Substrate	GRA, SAN, COB, STO, MAC		GRA, COB, SAN, MAC, STO		SAN, MAC		GRA, SAN, COB, MAC, STO, BOU		SAN, MAC, COB, STO		SAN, MAC	
Velocity (m/s)	0.3	0.77	0.11	0.44	0.48	0.57	0.195	0.54	0.26	0.67	0.16	0.15
Depth (m)	0.12	0.11	0.09	0.16	0.15	0.17	0.15	0.1	0.37	0.26	0.38	0.18
Discharge (m^3/s)	0.49	0.93	0.07	0.36	0.55	1.13	0.20	0.15	0.53	1.88	0.87	0.47
pH	7.8	8.4	7.5	7.88	7.4	7.76	7.59	8.44	7.5	6.8	6.9	6.86
EC (µS/cm)	470	540	568	610	479	535	517	635	438	547	387	418
TDS (mg/L)	306	384	-	434	293	379	344	452	301	386	219	297
DO (mg/L)	6.2	7.53	6.7	7.3	6.8	8.3	6.9	6.51	7.1	7.2	6.7	7.4
Water Temp (˚C)	30	15.3	31.4	19.7	28.5	18.5	30.2	16.4	29.2	13.8	29.3	10.3

The relationship between the benthic macroinvertebrates and environmental variables were analyzed both seasons (Figure 7 & Figure 8). In pre-monsoon season, the first two axes of RDA graph explained 58.83% of the total variance for the BMI communities. The first RDA axes explain 36.5% and second RDA axes explained 22.33% of the total variance. Dissolve oxygen shows the strong correlation with the RDA1 axes, also, pH and TDS show the positive correlation, however, EC and water temperature shows the negative correlation with RDA1 axes. All the environmental variables show the negative correlation with the RDA2 axes. Similarly, the correlation between the pH and TDS shows the strong correlation with r = 0.86. In post-monsoon season, the first two axes explained 67.47% of the total variance. The accumulated constrained proportion explained by RDA1 and RDA2 axes explained 45.94% and 21.54% respectively of the total variance. Hydropsychidae and Scirtidae taxa shows the positive and strong correlation with the RDA1 axes with r = 0.91 and 0.61 respectively. However, Hydropsychidae shows the negative correlation with RDA2 axes, but positive correlation with Scirtidae. The correlation between the environmental variables, pH, EC, TDS and water temperature had positive correlation with RDA1. Although these variables were negative correlation with RDA2 axes except pH, it shows the strong correlation (i.e. r=0.86).

The variables like pH, DO, TDS, EC and water temperature were more significant than other variables in this study. The similar result was reported by Pastuchová [47] in low discharge stream. Among these variables dissolve oxygen and pH were the most important variables explaining the distribution of macroinvertebrate assemblage [48]. The pH below 5.0 and above 9.0 are considered harmful for benthic organism and caused decrease assemblage [49]. While constructing of dam or water diversion across the river should consider the water flow which can maintain the dissolved oxygen in the downstream section [50]. Taxa such are Chironomidae, Hydranidae, Micronectidae, and Ephemeridae showed the positive and strong relationship in post-monsoons season. Chironomidae shows the perfect negative relationship with dissolved oxygen in pre-monsoon season. This is because the distribution of Chironomidae taxa in the freshwater system is relative abundance and the habitat like the fine and soft sand are the most preferable [50,51]. High dissolved oxygen in water means less organic pollution which supports the higher diversity of benthic macroinvertebrate assemblage.

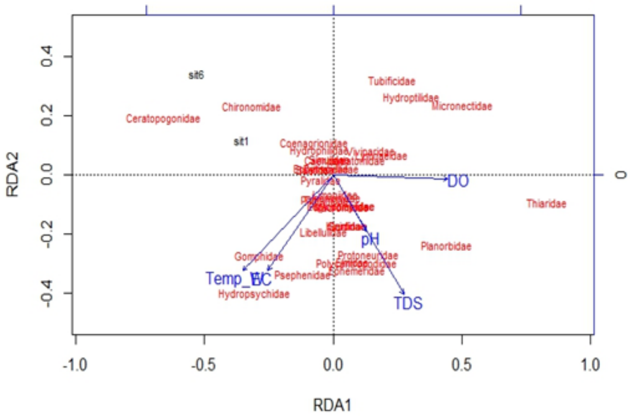

Figure 7. Relationship between BMI and environmental parameters in pre-monsoon season

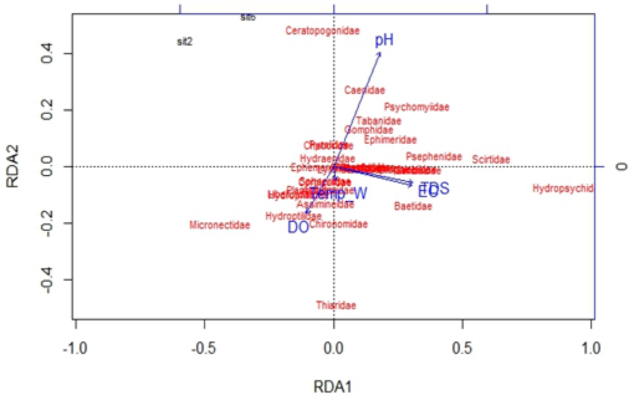

Figure 8. Relationship between BMI and environmental parameters in post-monsoon season

3.3. Ecological Status

The ecological status of Mohana watershed ranged from good, fair to bad (Figure 9). The GRSBios/ASPT value ranged from 3.833 to 5.714 for both seasons. The result shows that, no seasonal change in water quality i.e. good in Chaumala site, fair in Kandra and Pathraiya sites and bad water quality in Manahara upstream site in both seasons. River quality was found deteriorated in Godabari and Manahara downstream from pre to post monsoon seasons shown in Figure 9.

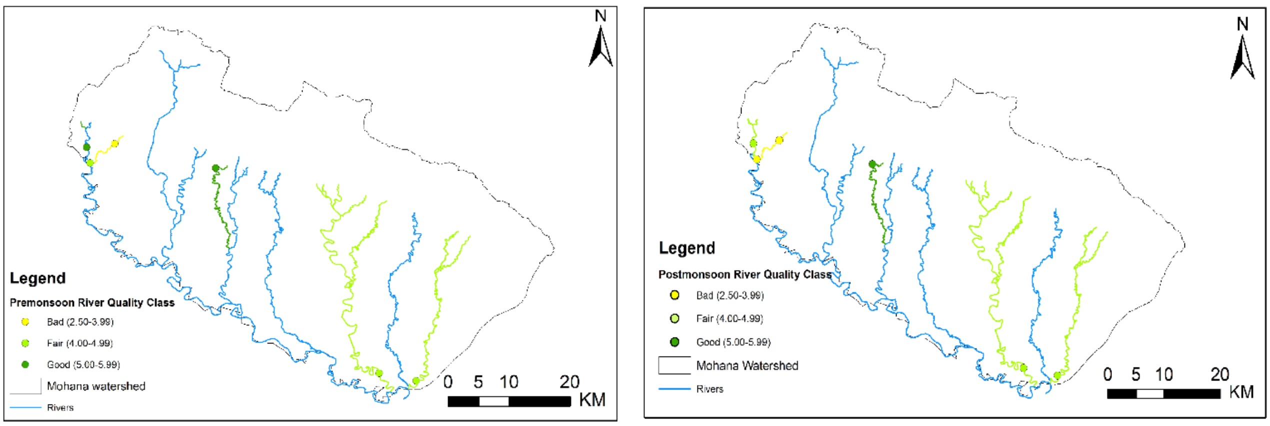

Figure 9. Change in river water quality class with respective season

High abundance, taxa richness and diversity of BMIs were recorded in Chaumala river for both seasons. This might be due to the presence of natural habitat in the river. The higher taxa richness of sensitive group ETO in Chaumala river might be due to dominance of forest in the catchment as opposed to Kandra and Patharaiya river which was surrounded by agricultural land. Similar result was reported by Shah [32] in rivers of lower gangetic plain moist deciduous forests. The member of Ephemeroptera and Trichoptera are considered to be sensitive to the environmental stress and they present in water body indicate clean water [52]. The heterogeneous habitat and bottom sediment supporting the higher taxa richness and abundance [4] with relatively pollution sensitive taxa Baetidae, Ephemeridae, Hydropsychidae were recorded.

The lower taxa richness of ETO in Kandra and Patharaiya showed the fair ecological status. But the abundance of Chironomidae was higher in these rivers as compared to the good water quality class in Chaumala. In addition, Chironomidae recorded higher abundance in sand and macrophyte habitat [51] and agricultural land dominated site [53]. The lower altitude with the downstream of the river accumulate higher pollution from the near settlement area caused the water pollution [40]. The lower gradient and agricultural dominated land use caused the agricultural runoff contaminated into the river [54]. The agricultural land contributed organic nutrient significantly to eutrophication and contaminated to the aquatic ecosystem [55]. The human activities like washing bathing in the river result to increase the concentration of nutrients and start eutrophication.

Godabari and Manahara abstracted sites had the seasonal fluctuation i.e. good to fair in Chaumala river and fair to bad water quality class in Manahara downstream. The minimum water discharge and stable habitat in pre-monsoon season support the higher taxa richness [4] in Godabari and Manahara downstream. The sampling site of Godabari river was dominated by the urban settlement, where the waste dumping was the common practice into the river bank. Also, the dissolved oxygen was lower as compared to the Chaumala, Kandara and Patharaiya river.

Similarly, bad water quality class in Manahara upstream site recorded for both seasons. The human activities like washing, bathing, and swimming were common at this site. Dominance of pollution tolerant taxa such as Chironomidae and Tubificidae led the poor ecological status. Similarly, occurrence non-scored taxa such as Gomphidae, Micronectidae, Hydrophillidae etc. in the site led poor river quality status. Manahara downstream is lower section of Manahara river which is just above the confluence with the Godabari river. The unique habitat of sand and macrophyte along the forested catchment had fair to bad ecological status in pre-monsoon and post-monsoon seasons, respectively. Pyralidae, Protoneuridae, Simulidae, and Limoniidae having higher GRSBios taxa score were present in Manahara downstream site.

4. Conclusion

This study of seasonal variation in benthic macroinvertebrate assemblage in lowland rivers shows the actual status of the ecological condition of these rivers in watershed scale. Study shows that diverse habitat in relatively natural catchment support high abundance and taxonomic richness of macroinvertebrate. Human actions including waste dumping, encroachment river corridor, deforestation and hydro-morphological alteration lead to bad water quality in the river system. The water quality in tributaries of Mohana watershed is still in acceptable state for irrigation except in Manahara river, however, if human actions are not controlled today, organic pollution may threaten the freshwater system into the near future of that area. Also study shows the water quality was not good for domestic purpose but still people used river water for sanitation and cattle drinking. If the deterioration of water quality in Mohana watershed continues, it might be shortage of surface water in the near future. Therefore, the water manager and local bodies should implement river management actions on time for the preservation of good status rivers for long-term use by the local people. The river water quality should be conserved for the ecosystem services and goods that provides from the river ecosystem.

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Conflict of Interest

The authors declare no conflict of interest.

List of Abbreviation

EC	Electrical Conductivity
TDS	Total Dissolve Solid
DO	Dissolve Oxygen
FPS	Flow Probe Specification
ETO	Ephemeroptera, Triocoptera and Odonata
ind	Individual
NWQGIW	National Water Quality Guideline for Irrigation Water
NWQGA	National Water Quality Guideline for Aquaculture
NWQGLW	National Water Quality Guideline for Livestock Water
NWQGR	National Water Quality Guideline for Recreation

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