Journal of Institute of Science and Technology, 29(1), 13-24 (2024)
ISSN: 2467-9062 (print), e-ISSN: 2467-9240
https://doi.org/10.3126/jist.v29i1.52941

Research Article

SEASONAL VARIATIONS IN MACROINVERTEBRATE DIVERSITY AND COMMUNITY COMPOSITION IN KAMALA RIVER OF CHURIA RANGE, NEPAL

Ram Devi Tachamo-Shah[1,2], Deep Narayan Shah[3*], Anusha Pandey[1], Junu Maharjan[1], Tanya M Doody[4], Susan Cuddy[4]

[1]*Aquatic Ecology Centre, School of Science, Kathmandu University, Dhulikhel, Nepal*
[2]*Department of Life Sciences, School of Science, Kathmandu University, Dhulikhel, Nepal*
[3]*Central Department of Environmental Science, Institute of Science and Technology, Tribhuvan University, Nepal*
[4]*Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia*
**Correspondence: dnshah@cdes.edu.np*

(***Received***: *March 04, 2023;* ***Final Revision***: *December 23, 2023;* ***Accepted***: *March 25, 2024)*

ABSTRACT

Macroinvertebrates have long been utilized in the ecological assessment of streams and rivers as they respond to multiple stressors present in aquatic environments. However, the application of macroinvertebrates as bioindicators in the assessment of hydro-morphologically degraded rivers in Nepal is limited. Therefore, we studied the macroinvertebrate diversity and community composition in 10 sites along the Kamala River and its tributaries, one of the hydro-morphologically degraded rivers in the Churia range of central Nepal, during the winter and spring seasons of 2019. The elevation of the sites ranges from 60 m asl to 636 m asl. Twelve water quality parameters and three hydrological parameters were measured for each site in addition to macroinvertebrates data. Water temperature (winter- 19.3 ±2.2 ^{0} C; spring- 31.3 ± 2.3 ^{0} C), pH (winter- 8.7 ± 0.5, spring- 7.4 ± 0.5), turbidity (winter-3.0± 3.8 NTU, spring- 22.9 ± 22.8 NTU), total alkalinity (winter-156 ± 70.7 mg/L, spring- 33.8 ± 6.0 mg/L), phosphate (winter-3.0 ± 1.8 mg/L, spring- 0.4 ± 0.3 mg/L) and river discharge (winter- 2.01 ± 0.75 m^3/s, spring- 0.77 ± 0.28 m^3/s) differed significantly between seasons ($p<0.05$). In total 62 taxa representing 42 families and 13 orders for winter season and 69 taxa representing 49 families and 18 orders of macroinvertebrates were recorded for spring season. NMDS revealed two distinct clusters based on macroinvertebrates abundance data for the river. Ephemeroptera, in particular *Baetis* spp., *Torleya coheri* and *Caenis* sp., and Trichoptera- *Chuematopsyche* spp. were the major taxa contributing to dissimilarity across sites between seasons.

Keywords: Bio-assessment, Churia, discharge, macroinvertebrate community composition, river health, seasonal variability

INTRODUCTION

Macroinvertebrates have long been utilized in ecological assessment of streams and rivers due to their ubiquitous and diverse nature and restricted mobility when compared to fishes upon disturbances, making them appropriate indicators for disturbances responses (Leunda *et al.*, 2009). As biological indicators, macroinvertebrates can integrate the effects of cumulative stressors (Bonada *et al.*, 2006). In human dominated landscape, hydro-morphological river degradation and poor water quality are known to be the most significant threats affecting natural assemblages of biotic communities and ecological functions (Allen *et al.*, 2007; Feld *et al.*, 2004). Morphological degradation includes changes on banks through removal of riparian vegetation, removal of natural river bed materials and construction on the banks and various alterations of the riverbed, such as dams or reinforcements with concrete and/or rocks, all of which adversely impact the biodiversity (Allen, 2004), resulting in the reduction of richness or abundance of sensitive taxa of macroinvertebrates (Kennen, 1999; Tachamo-Shah & Shah, 2013). But the level of impact differs across the types of stressors such as organic pollution, water diversion, habitat alteration (Tachamo-Shah & Shah, 2013; Tachamo-Shah *et al.*, 2020a). Similarly, natural factors such as hydrological regimes, water temperature, water chemistry, food resources also influence the distribution and composition pattern of macroinvertebrates (Rampel 2000; Álvarez-Cabria *et al.*, 2010;). Though the relative influence of these factors between seasons are minimal in least disturbed river systems (Tachamo-Shah *et al.*, 2020b), the distinction in community composition is large in human altered river ecosystems (see Tachamo-Shah & Shah, 2013; Tachamo-Shah *et al.*, 2020a). Therefore, seasonal variability on macroinvertebrate community composition is important and generally taken into consideration in impacted sites for biomonitoring purposes (Jacobsen & Encalada, 1998; Irvine, 2004; Chi *et al.*, 2017).

Several studies have attempted to relate environmental variables such as substrate type, water velocity, and physical and chemical parameters that influence macroinvertebrates in aquatic systems globally and in Nepal (Kaiser *et al.,* 2001; Armonies *et al.,* 2003; Shrestha *et al.,* 2021). In undisturbed rivers, riverbeds usually comprise of diverse substrate types such as boulders, cobbles, pebbles, gravels, coarse organic particulate matters including twigs and leaves that support diverse macroinvertebrates (Bhandari *et al.,* 2018) but with extraction of natural riverbed materials, fine substrates remain in the river proliferating few taxa like Chironomidae, Caenidae. Kamala River flows through the Churia range in the Sindhuli district of central Nepal and is one of the hydro-morphologically deteriorated rivers as much of the riverbed materials such as boulders and cobbles have been removed leaving only stone and pebbles in many sites of the river (Field observation, 2019). River water is found tapped for drinking water at the source while diverted for irrigation along the river course that has led relatively low river discharge throughout the river stretches. These kinds of disturbances are common in human centric landscapes that alter natural assemblages of biotic communities and reduce water quality and aesthetic values. In this present study, we investigated macroinvertebrate community composition from upstream to downstream of the Kamala River for winter and spring seasons of 2019.

MATERIALS AND METHODS

Study area

The Kamala River is a rain-fed river, originated in Churia range at Chiyabari, Sindhuli at an elevation of around 1200 m asl (Fig. 1). The river is about 117 km long within Nepal. The river flows through four districts namely-Sindhuli, Udayapur, Siraha and Dhanusha. Major tributaries such as the Tawa, the Baijnath, the Mainawati, the Dhauri, the Soni, the Balan, the Trisula, and the Chadaha Rivers meet in different sections of the Kamala River. More than 60% of the basin is situated in the Terai-Siwalik region, with the remaining 40% located in the mountainous region. The annual average rainfall is around 1681 mm while the average annual temperature is around 24°C (based on three meteorological stations at Sindhuligadhi, Janakpur Airport and Udayapur Gadhi) (NDRI & CSIRO, 2016). The seasonal variation of rainfall in the basin is high because almost 80 percent of annual rain is confined to monsoon in Nepal. The annual average stream discharge of the Kamala River Basin is around 100 cubic meters per second (Joshi & Shrestha, 2008). The minimum and maximum discharge recorded are for April (17 cubic meters per second) and August (303 cubic meters per second), respectively (Shrestha, 2016). The river flows through the Mahabharat Range, the Churia range and the Plains in Nepal territory. The upper catchment of the Kamala River is made up of black shales and argillaceous sandstones and Siwalik is the deposits of alluvial detritus brought by rivers and streams making it susceptible to weathering and heavy erosion (NDRI & CSIRO 2016). Similarly, the Plain comprises a succession of sand beds with the varying texture of silt and clay with occasional gravels.

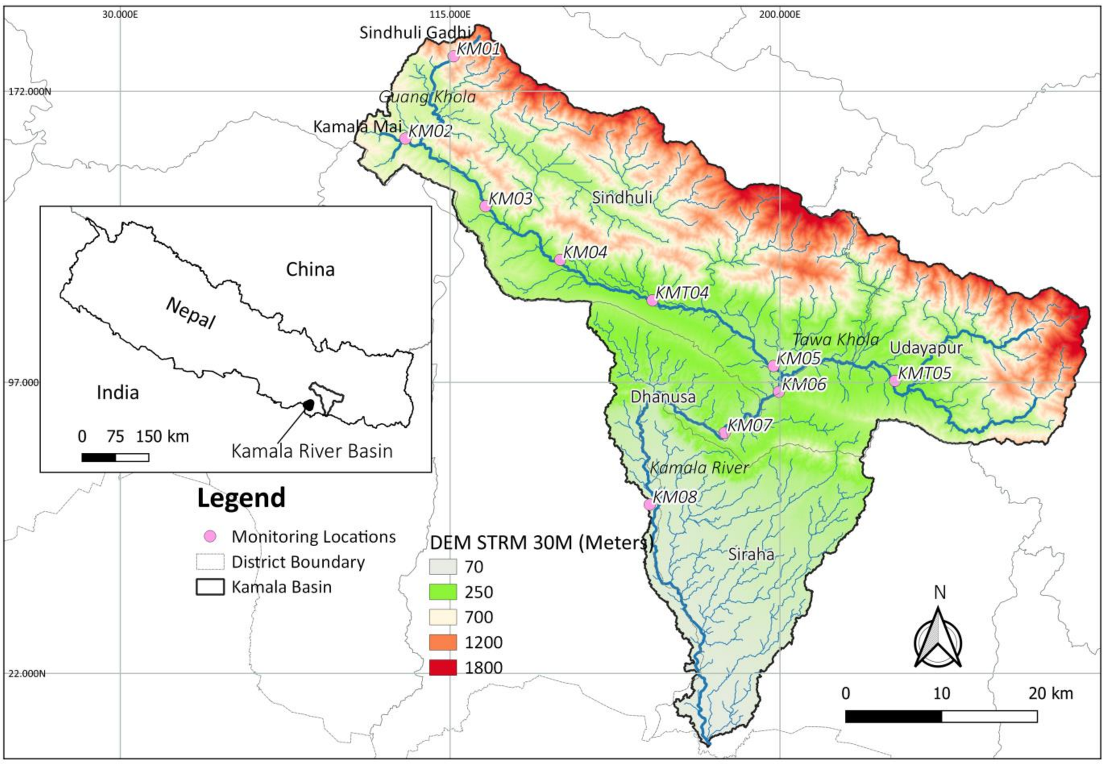

Figure 1. Distribution of sites in the mainstem of Kamala River and its tributaries. Sampling sites are indicated in shaded circles.

Sampling sites

A total of ten sampling sites were chosen in river's mainstem and tributaries of Kamala River, selected based on presence of various stressors (Table 1). The Chiyabari site is downstream of the Guang stream in Sindhuli, which later joins the Kamalamai stream immediately after Kamalamai temple. Downstream further, it is called the Kamala River.

Table 1. Description of sampling sites in the Kamala River and its tributaries.

S.N.	Site name	River types	Latitude (Degree decimal)	Longitude (Degree decimal)	Altitude (masl)	Substrates (Visual estimation at 10% interval in 100 m river stretch)	Stressors
1	KM01	Mainstem	27.249	85.935	636	Boulder 10%, Cobbles 40%, Stones 40%, Pebbles 10%	Reference
2	KM02	Mainstem	27.171	85.885	460	Stones 60%, Pebbles 40%	Modified riverbeds and riparian banks (devoid of natural vegetation), frequent crossing of vehicles)
3	KM03	Mainstem	27.627	85.581	366	Cobbles 10%, Stones 50%, Pebbles 40%	Intensive mining of riverbed materials; frequent fishing; modification and diversion of water channels for fish capture
4	KM04	Mainstem	27.058	86.049	276	Stones 50%, Pebbles 50%	Extensive mining of stone and pebbles; regular vehicle crossing
5	KMT04	Tributary	27.030	86.139	245	Stones 60%, Pebbles 40%	Alteration in natural riverbanks and riverbed materials; regular crossing of heavy vehicles
6	KMT05	Tributary	26.946	86.402	225	Cobbles 10%. Stones 40%, Pebbles 50%	Alteration in natural riverbanks and riverbed materials; regular crossing of heavy vehicles
7	KM05	Mainstem	26.945	86.282	154	Stones 30%, Pebbles 70%	Modified riverbed (loss of cobbles due to river mining); high organic loads due to cremation on its banks; crossing of vehicles
8	KM06	Mainstem	26.935	86.280	145	Cobbles 20%, Stones 40%, Pebbles 30%, Sand 10%	Modified riverbed materials (loss of cobbles due to river mining); high organic loads due to cremation on its bank; crossing of vehicles; cultural activities: holy bath during festive period (Dec-Jan) each year
9	KM07	Mainstem	26.895	86.223	121	Cobbles 40%, Stones 30%, Pebbles20%, Sand 10%	Regular intensive fishing through locally manufactured electrofishing gear
10	KM08	Mainstem	26.828	86.145	60	Stones 20%, Pebbles 10%, Sand 70%	Water diversion, and modified riparian vegetation and riverbanks, and extensive extraction of sand

Methods

River discharge

A SonTek Flow Tracker handheld Acoustic Doppler Velocity meter (ADV, YSI, Xylem brand) was used to measure velocity and river discharge (ADV, YSI, Xylem brand; Rantz, 1982). During the measurement, the velocity meter was placed at a depth of 0.6 m of the total water depth in each sub-section.

Water quality parameters

Water quality parameters such as pH, dissolved oxygen (mg/L), electrical conductivity (μS/cm), temperature (°C), total dissolved solids (mg/L) and turbidity (NTU) were measured in-situ using a multi-parameter portable meter (Hanna Probe HI 9829). Furthermore, nitrate (Hanna probe HI96728C), ammonia (Hanna probe HI96715C) and phosphate (Hanna probe HI96717) were measured on site using portable spectrophotometers. 1L water sample was collected at each site for the determination of total alkalinity, total hardness and chloride in-situ by titration method (APHA, 2005).

Macroinvertebrates

The multi-habitat sampling approach was used to collect macroinvertebrates samples using a hand net of mesh size 500 µm from 100 m river stretch in a site (Tachamo-Shah *et al*., 2015). In total 10 sub samples were taken from the dominant substrates covering at least 10% of habitat coverage (Table 1). All 10 sub samples were transferred into a half-filled bucket, rinsed with water and sieved through 500 µm mesh net. Prior to rinse, coarse materials like twigs, leaves, stones and cobbles were removed. The sieved sample was then transferred into a labelled plastic container and preserved in 95% ethanol.

In the laboratory, samples were well-washed using tap water and passed through 500 µm mesh net. The samples were transferred onto a white enamelled tray for sorting macroinvertebrates from sediment. All macroinvertebrate individuals were identified into the highest possible taxonomic level (genus and family) using stereo-microscope and available region-specific identification keys (Morse *et al*., 1994; Nesemann *et al*., 2007; Nesemann *et al*., 2011; Tachamo-Shah *et al*., 2020c).

Site-specific information

The information such as hydro-morphology (wetted river width, depth, flow types, bank structure), substrate (% Boulder, % Cobble, % Pebble, % Gravel, % Sand and clay) and prevailed stressors were measured/ estimated and documented for each site.

Land use Land cover

QGIS 2.18.11 with SAGA 2.3.2 was used to delineate Kamala River Basin and sub-basins. A threshold of 06 was set to generate streams as it was more accurate based on our field research. Upslope Area module was used to generate watershed basin using DEM and point at the Indo-Nepal border as the outlet point. Then, r.to.vect module was used to vectorize streams and watershed basin generated from the DEM. Similarly, sub-watershed basins for all ten sampling locations of Kamala River were generated using sampling points as outlet point. Forest is the major land use land cover in the basin (Table 2).

Table 2. Land use land cover characteristics for each site of mainstem and tributaries of Kamala River. Values are presented in percentage

	Site Name	*KM01*	*KM02*	*KM03*	*KM04*	*KMT04*	*KM05*	*KMT05*	*KM06*	*KM07*	*KM08*
Drainage LULC	Forest	69.03	74.31	69.90	67.68	72.85	66.68	69.10	66.20	66.31	65.24
	Shrubland	9.07	4.87	5.24	5.73	2.25	5.20	5.83	5.23	5.15	4.85
	Grassland	6.67	4.77	5.38	5.88	3.46	5.48	5.46	5.38	5.43	5.11
	Agricultural Land	15.23	14.22	18.72	19.80	20.29	21.00	18.46	21.49	21.29	22.36
	Barren Land		1.83	0.65	0.78	1.05	1.25	1.07	1.35	1.43	1.95
	Water Bodies			0.10	0.13	0.10	0.40	0.08	0.36	0.39	0.48
	Built-Up Area			0.01							0.01

Data analysis

A paired t-test was carried out to evaluate the dissimilarity in physico-chemical parameters and water discharge between two seasons. ANOSIM and SIMPER analyses were run on macroinvertebrates abundance data using Bray-Curtis distance measure and 9999 permutations, with free software PAST (Paleontological Statistics version 3.20). Prior to analysis, the physico-chemical data were log transformed based on their skewedness where necessary. A non-metric multidimensional scaling (NMDS) was conducted to disentangle sites with similar composition of macroinvertebrates. Prior to NMDS, macroinvertebrates abundance data was transformed into log (x+1). NMDS ordination is a reliable ordination technique for examining similarities and differences in biological data since it does not rely on multivariate normality assumptions and produces satisfactory findings even when a considerable number of data sets contain zero values. The Bray-Curtis distance was utilized as a distance metric in the analysis.

A detrended correspondence analysis (DCA) was used to see if the macroinvertebrate abundance data followed a linear or unimodal distribution (Clarke, 1993). The linear ordination method, canonical-correlation analysis (CCA), was carried out on macroinvertebrates abundance data as the length of the first DCA axis (3.69 SD, longest gradient) was larger than 3.0 SD. Prior to CCA, a multicollinearity test was performed, TDS, Alkalinity were excluded from the final CCA plot due to significant collinearity ($r > 0.70$) with electrical conductivity and pH, respectively. Also, physico-chemical variables contributing less than 50 % in the axis: temperature, turbidity, ammonia and catchment scale: built-up, grassland and shrubland were removed from the plot.

RESULTS

River discharge

River discharge ranged from 0.03 to 4.8 m^3/s for winter season and from 0.02 to 1.84 m^3/s for spring season.

Mean and Standard deviation were 2.01 ± 0.75 m^3/s and 0.77 ± 0.28 m^3/s for winter and spring. respectively ($p<0.01$). High variability in river discharge was recorded for winter season compared to spring season (Fig. 2).

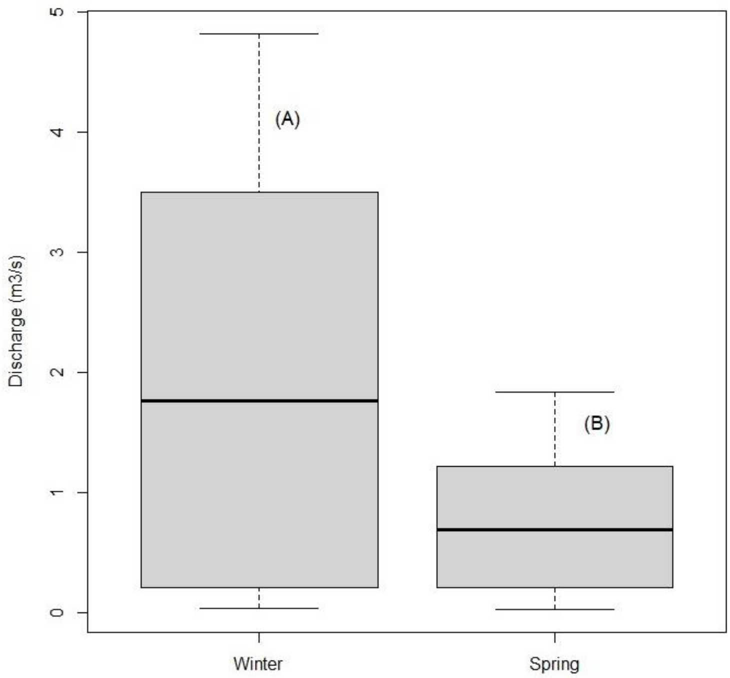

Figure 2. River discharge values recorded for sites in the Kamala River for winter and spring seasons, 2019. The horizontal line in the Box Plot indicates median values. Letters inside bracket A and B denote significant differences in values between seasons

Water quality status

Eight out of twelve physico-chemical parameters were found significantly different between winter and spring seasons (Table 3). Average water temperature ranged from 15.1 to 22.24° C during winter whereas during spring it ranged from 26.5 to 34.6° C. pH ranged from 8.13 to 9.41 in winter and 6.42 to 7.78 in spring. Turbidity ranged from 6.1 to 8.3 NTU in winter and 1.9 to 69.20 NTU in spring. Turbidity levels were relatively lower in winter than in spring season. Turbidity was recorded high towards the downstream section of the sampled river stretch. Conductivity ranged from 83 to 372 µS/cm in winter to 107 to 386 µS/cm in spring. Alkalinity ranged from 60 to 260 mg/L in winter and 27 to 46 mg/L in spring. Chloride ranged from 10 to 25 mg/L in winter and 7.81 to 19.05 mg/L in spring. Phosphate ranged from 0.90 to 6.80 mg/L in winter and 0.01 to 1.10 mg/L in spring.

Table 3. Average and standard deviation values of each water quality parameters measured during winter and spring seasons. Significant parameters are indicated with asterisks and made bold

S.No.	Parameters	Winter	Spring	P values
1	**Temperature (^{0} C)**	**19.3 ± 2.2**	**31.3 ± 2.3**	**0.01****
2	**pH**	**8.7 ±0.5**	**7.4 ± 0.5**	**0.01****
3	**Turbidity (NTU)**	**3.0 ± 3.8**	**22.9 ± 22.8**	**0.02***
4	Dissolved Oxygen (mg/L)	6.9 ±1.3	7.0 ± 1.5	0.89
5	**Conductivity (µS/cm)**	**260 ±109**	**306 ± 85.7**	**0.04***
6	**Total Dissolved Solids (mg/L)**	**130 ± 54.4**	**153.4 ± 42.5**	**0.04***
7	**Alkalinity (mg/L)**	**156.2 ± 70.7**	**33.8 ± 6.0**	**0.0005****
8	Hardness (mg/L)	143 ± 39.9	132.7 ± 17.0	0.49
9	**Chloride (mg/L)**	**13.6 ± 4.5**	**9.8 ± 1.8**	**0.03***
10	Nitrate (mg/L)	7.4 ± 2.8	6.9 ± 5.9	0.84
11	**Phosphate (mg/L)**	**3.0 ± 1.8**	**0.4 ± 0.3**	**0.001*****
12	Ammonia (mg/L)	0.1 ± 0.2	0.0	0.07

Macroinvertebrate community composition

A total of 62 taxa belonging to 42 families and 13 orders for winter season and 69 taxa belonging to 49 families and 18 orders of macroinvertebrates were recorded for spring season in the Kamala River (Table 4). Taxa belonging to orders Hemiptera, Decapoda and Mollusca were documented in spring season.

Table 4. List of macroinvertebrates families with orders recorded in Kamala River for winter and spring seasons

S.N	Order	Family	Winter	Spring
1	Ephemeroptera	Baetidae	✓	✓
2	Ephemeroptera	Caenidae	✓	✓
3	Ephemeroptera	Leptophlebiidae	✓	✓
4	Ephemeroptera	Ephemerellidae	✓	✓
5	Ephemeroptera	Heptageniidae	✓	✓
6	Ephemeroptera	Ephemeridae	✓	✓
7	Plecoptera	Perlidae	✓	✓
8	Trichoptera	Hydropsychidae	✓	✓
9	Trichoptera	Glossosomatidae	✓	✓
10	Trichoptera	Brachycentridae	✓	
11	Trichoptera	Philopotamidae	✓	✓
12	Trichoptera	Goeridae	✓	
13	Trichoptera	Hydroptilidae		✓
14	Trichoptera	Leptoceridae	✓	✓
15	Trichoptera	Odontoceridae		✓
16	Trichoptera	Psychomyiidae	✓	✓
17	Diptera	Athericidae		✓
18	Diptera	Ceratopogonidae	✓	✓
19	Diptera	Chironomidae	✓	✓
20	Diptera	Empididae	✓	
21	Diptera	Limoniidae	✓	✓
22	Diptera	Muscidae	✓	
23	Diptera	Simuliidae	✓	✓
24	Diptera	Stratiomyiidae		✓
25	Diptera	Tabanidae	✓	✓
26	Coleoptera	Dytiscidae		✓
27	Coleoptera	Elmidae	✓	✓
28	Coleoptera	Psephenidae	✓	✓
29	Coleoptera	Gyrinidae	✓	✓
30	Coleoptera	Hydrophilidae	✓	✓
31	Coleoptera	Scirtidae	✓	✓
32	Coleoptera	Staphylinidae	✓	
33	Odonata	Coenagrionidae		✓
34	Odonata	Cordulegastridae	✓	
35	Odonata	Euphaeidae	✓	✓
36	Odonata	Gomphidae	✓	✓
37	Odonata	Libellulidae	✓	✓
38	Odonata	Macromiidae	✓	
39	Odonata	Protoneuridae	✓	✓
40	Hemiptera	Mesoveliidae	✓	
41	Hemiptera	Naucoridae		✓

42	Hemiptera	Gerridae		✓
43	Hemiptera	Micronectidae	✓	✓
44	Hemiptera	Nepidae		✓
45	Hemiptera	Veliidae	✓	
46	Lepidoptera	Pyralidae	✓	✓
47	Megaloptera	Corydalidae	✓	✓
48	Decapoda	Atyidae		✓
49	Decapoda	Palaemonidae		✓
50	Decapoda	Potamidae		✓
51	Haplotaxida	Tubificidae	✓	
52	Arhynchobdellida	Salifidae		✓
53	Architaenioglossa	Viviparidae		✓
54	Basommatophora	Planorbidae	✓	✓
55	Basommatophora	Lymnaeidae	✓	✓
56	Basommatophora	Planorbidae		✓
57	Sphaeriida	Sphaeriidae		✓
58	Unionida	Unionidae	✓	✓

Macroinvertebrates richness and abundance did not differ significantly between seasons ($p>0.05$). Richness, however, was higher for spring season compared to winter season while abundance was high in upstream river reaches (KM01-KM03) for winter season but high in downstream (KM04-KM08) river reaches for spring season (Fig. 3A).

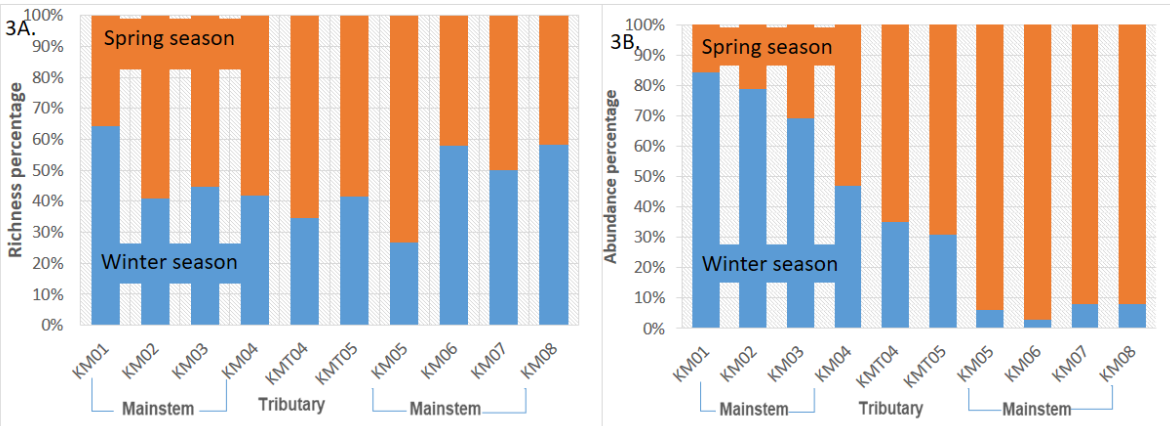

Figure 3. Proportion of macroinvertebrates richness (A) and macroinvertebrates abundance (B) in sites for winter and spring season along the Kamala River

SIMPER analysis indicated that *Baetis spp.*, *Torleya coheri*, *Caenis sp.* and *Cheumatopschye* contributed to dissimilarity between different seasons. NMDS revealed two clusters disentangling different macroinvertebrate community assemblages between two seasons (Fig. 4). Two axes cumulatively explained 68% variability in macroinvertebrate community structure between two seasons (stress= 0.2).

Ephemeroptera, Trichoptera and Diptera were recorded in all sites between seasons (Figure 5A). Ephemeroptera was diverse order (winter- 6 ± 3; spring-6 ± 2) followed by Diptera (winter-5 ± 2; spring- 4 ± 1) and Trichoptera (winter-3 ± 2; spring-1 ± 0). However, only taxa richness of Plecoptera (winter- 0; spring- 1; $p<0.001$) and Mollusca (winter- 0; spring 2; $p<0.05$) differed between seasons.

In case of abundance, Ephemeroptera (winter- 219 ± 228 & spring-352 ± 363) was most abundant group followed by Trichoptera (winter- 126 ± 113 & spring-257 ± 282) and Diptera (winter- 109 ± 170 & spring-46± 59) in the sites of Kamala River (Figure 5B).

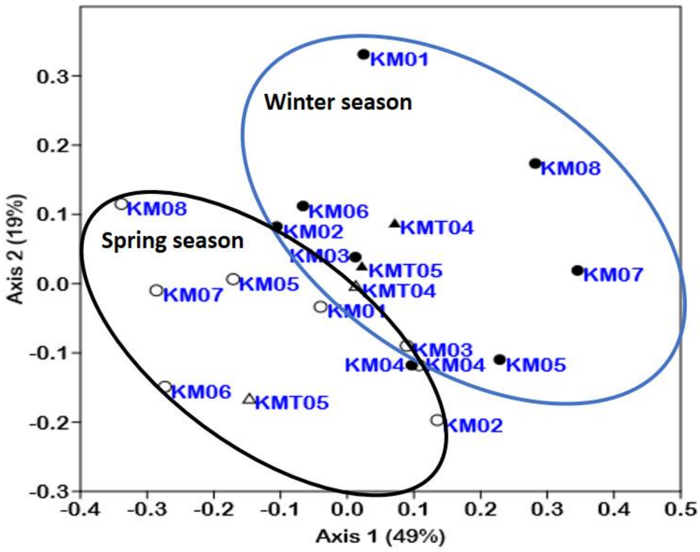

Figure 4. Two separate clusters of sites representing spring and winter seasons, from left and right, respectively. Unshaded circles and triangles indicate sites for spring season while shaded circle and triangles indicate sites for winter season

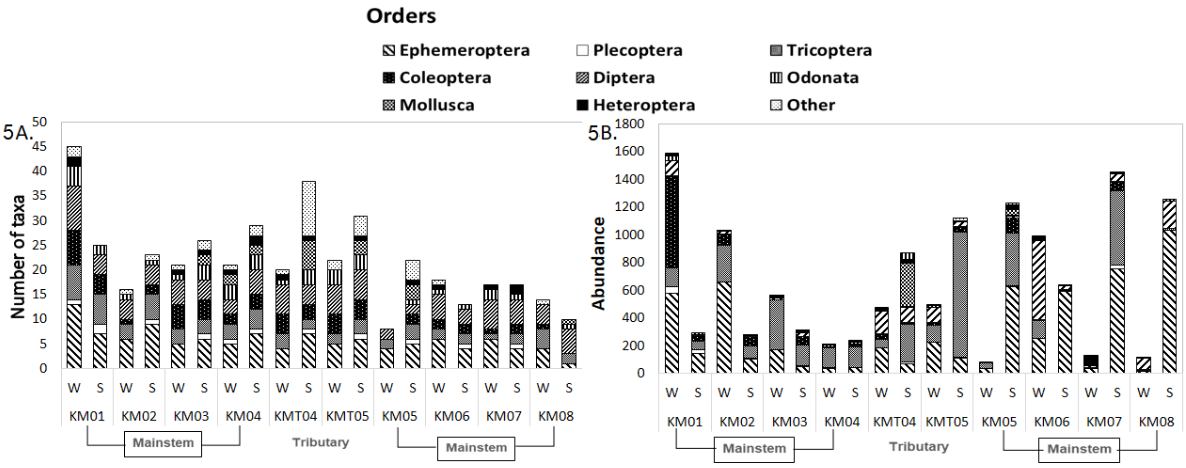

Figure 5. Number of macroinvertebrate taxa (A) and abundance (B) for each season in sites along Kamala River. Letter- "W" represents "winter" season and "S" represents "spring" season. The category- "Other" includes Lepidoptera, Megaloptera, Decapoda, Sphaeriida, Unionida, Architaenioglossa, Hemiptera and Annelids for winter and spring season

Functional Feeding Groups

Among functional feeding groups (FFGs), collector-gatherers, scrapers, collector-filterers and predators were recorded in all sites along Kamala River. Predators (winter- 8 ± 4.0 & spring-10 ± 3.0) was the most diverse groups followed by collector-gatherers (winter- 6 ± 2 & spring- 7± 3), scrapers (winter- 3 ± 2 & spring- 4 ± 3) and collector-filterers (winter- 3 ± 2 & spring- 2 ± 1) in the river (Fig. 6A; Fig. 6B).

Collector-gatherers (winter- 248 ± 288 & spring- 330 ± 361) was the most dominant functional feeding groups followed by collector-filterers (winter- 134 ± 114 & spring- 250 ± 288), predators (winter-106 ± 121 & spring-72 ± 57) and scrapers (winter- 85 ± 119& spring- 81 ± 99) in sites of Kamala River (Fig. 6). Though FFGs richness was relatively high for spring season, abundance of FFGs was high for winter season.

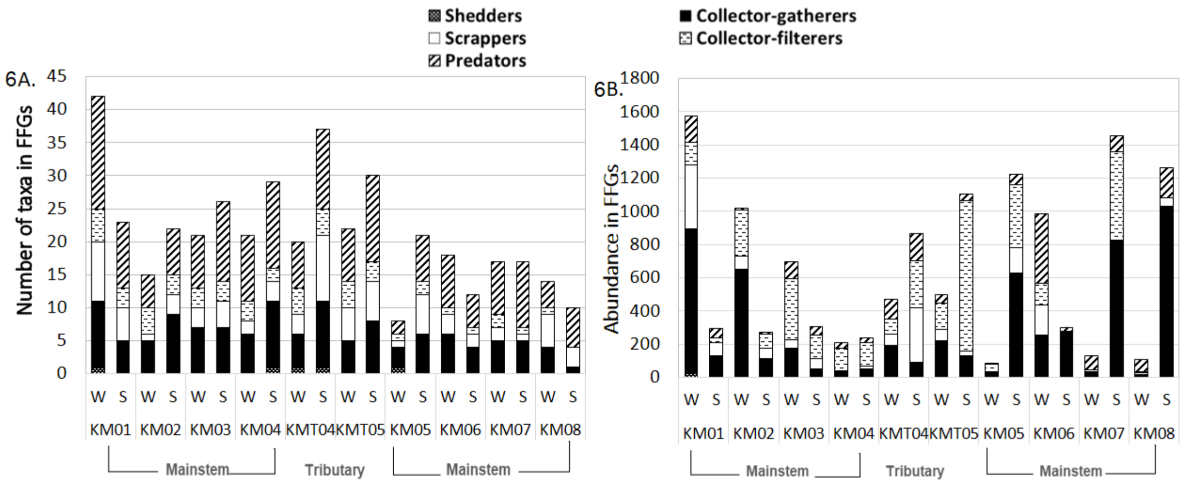

Figure 6. Functional feeding group richness (A) and abundance (B) across sites in Kamala River. Letter- "W" represents "winter" season and "S" represents "spring" season

Relative roles of environmental variables and catchment variables for community characterizations

CCA revealed that 55% of macroinvertebrates variability is explained together by the environmental and catchment variables, in particular dissolved oxygen, hardness, chloride, nitrate, phosphate and agricultural lands (Fig. 7). Many of the downstream sites located in agricultural land had higher concentrations of nutrients and other physico-chemical parameters for spring season (Table 3). These sites were colonized by moderately disturbance tolerant species such as *Baetis sp., Caenis sp.,* and *Torleya coheri* of Ephemroptera order and *Chematopsyche spp.* of Trichoptera order.

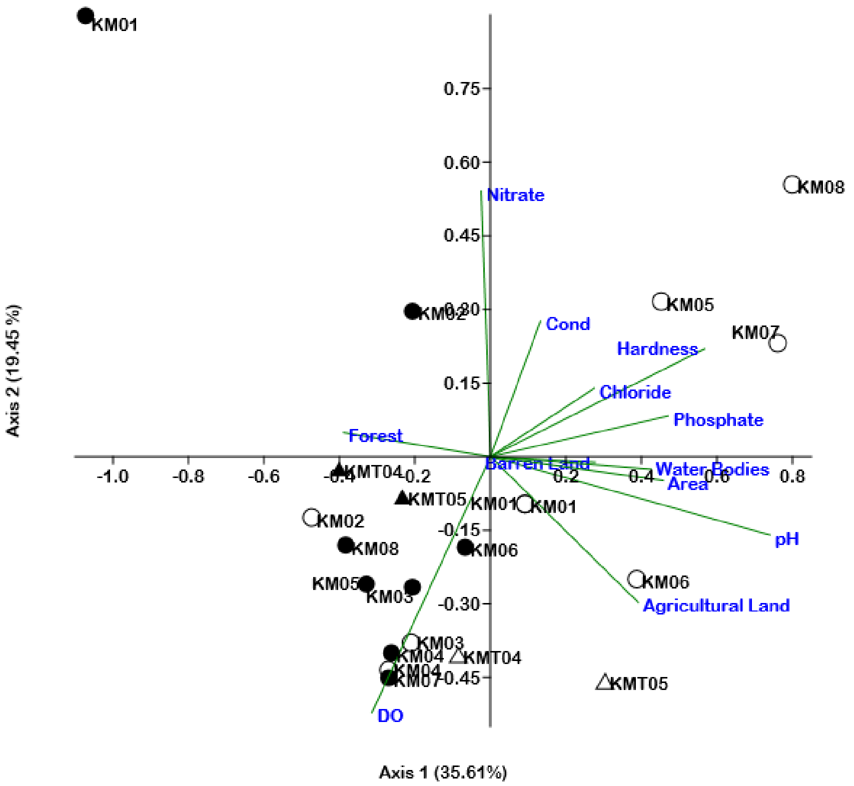

Figure 7. CCA biplot for Kamala River. Unshaded circle and triangle symbols indicate mainstem sites and tributary sites, respectively for spring season while shaded circle and triangle symbols represent sites of mainstem and tributaries, respectively for winter season

DISCUSSION

Macroinvertebrate diversity and community composition

Macroinvertebrates spend most of their life on the bottom of aquatic ecosystems and therefore water chemistry, hydrological parameters and substrate are important for governing diverse types of macroinvertebrates. Within natural river-environment, seasonal changes in flow regimes, substrate modification and physico-chemical parameters are minimal to significantly alter macroinvertebrate community composition between seasons in a year (Tachamo-Shah *et al.*, 2020b). However, in case of highly hydro-morphologically modified rivers (see Tachamo Shah *et al.*, 2020a) and polluted rivers (Tachamo-Shah & Shah, 2013), changes in river discharge might have significantly altered physico-chemical parameters leading to different community composition between seasons as revealed in the current study. Kamala River is one of the highly hydro-morphologically degraded rivers. Large river substrates have already been removed from entire river stretches except in reference sites (Table 1). Only small-size river substrates such as stone, gravel and pebbles dominated in downstream stretches of the river. Therefore, most of water quality parameters elevated in sites during low-flow spring season (Fig. 7). Relatively high-water temperature and increased nutrient concentrations accompanied by low river discharge in spring season increased abundance of warm water and pollution tolerant macroinvertebrates: mollusks, *Caenis* sp., Chironomidae in the river. It is not surprising to observe no net loss in taxa richness and overall abundance of macroinvertebrates in the sites as disappearance of sensitive taxa occurred in winter season is replaced by the appearance of warm water and pollution adopted macroinvertebrates (Table 3).

In hilly river systems, Ephemeroptera, Plecoptera and Trichoptera are the most dominant groups (Tachamo-Shah *et al.*, 2020b). Since, Kamala River originates in mountain range and flows through Churia range and the Plains, EPT richness ranged from 27% to 24% for winter and spring seasons, respectively.

The studied environmental variables captured most of the variation (55%) in macroinvertebrates composition for Kamala River (Fig. 7). Majority of physico-chemical parameters ($p<0.05$) and river discharge ($p<0.01$) between seasons might have governed the community structure in the river (Regmi *et al.*, 2021). Grazing snails were absent during the winter season and mainly occurred during the spring season. The types and distribution of river substrates favour macroinvertebrates to reside in or on the sediments (Beauger *et al.*, 2006). According to Bhandari *et al.* (2018), cobbles and stones are suitable substrates for majority of macroinvertebrates taxa as the spaces between the substrates provide suitable habitats, food and adequate oxygen required to the organisms. Fine mineral substrates such as silt or sand is suitable for only those species with burrowing habits and filter feeders such as some mollusks and pollution tolerate insects such as Chironomidae (Gao *et al.*, 2006) . The results of this study showed that the silty bottom (KM08) had the highest number of macroinvertebrates taxa, particularly Chironomidae. This was probably attributed to the rich organic matter that provides a variety of food in a suitable environment (Longing *et al.*, 2010). The river ecosystems of Churia range are highly fragile due to vulnerable geology. Strict regulation in riverbed extraction and river water diversion for agriculture practices could improve the ecological integrity of the Kamala River.

CONCLUSIONS

In this study, macroinvertebrate community assemblage was studied in the Kamala River. Richness and abundance of insects was found high for winter and spring seasons. Ephemeroptera- *Baetis* sp., *Caenis* sp., and *Torleya coheri* and Trichoptera- *Chematopsyche* spp. were found to be the major taxa that significantly alter community composition across sites between seasons.

ACKNOWLEDGEMENTS

The study was supported by CSIRO.

AUTHOR CONTRIBUTIONS

RDTS, DNS, TD and SC conceptualized the study. RDTS, DNS, AP and JM carried out sampling and analysis. RDTS and DNS wrote the manuscript. RDTS and JM performed statistical analysis. All authors wrote and revised the manuscript.

CONFLICT OF INTEREST

No conflicts of interest exist in relation to the research work presented in this study.

DATA AVAILABILITY STATEMENT

Data will be made available on request with a suitable reason.

REFERENCES

Allen, P.M., Arnold, J.G., & Skipwith, W. (2008). Prediction of channel degradation rates in urbanizing watersheds. *Hydrological Sciences Journal, 53*(5), 1013-1029. https://doi.org/10.1623/hysj.53.5.1013

Álvarez-Cabria, M., Barquín, J., & Antonio, J.J. (2010). Spatial and seasonal variability of macroinvertebrate metrics: Do macroinvertebrate communities track river health? *Ecological Indicators*, *10*(2), 370–379. https://doi.org/10.1016/j.ecolind.2009.06.018

APHA. (2005). Standard methods for the examination of water and wastewater, 21st Edn. American Public Health Association, Washington, United Book Press.

Armonies, W., & Reise, K. (2003). Empty habitat in coastal sediments for populations of macrozoobenthos. *Helgoland Marine Research, 56*(4), 279–287. https://doi.org/10.1007/s10152-002-0129-8

Beauger, A., Lair, N., Reyes-Marchant, P., & Peiry, J.L. (2006). The distribution of macroinvertebrate assemblages in a reach of the River Allier (France), in relation to riverbed characteristics. *Hydrobiologia, 571*, 63-76. https://doi.org/10.1007/s10750-006-0217-x

Bhandari B., Tachamo-Shah R.D., & Sharma S. (2018). Status, distribution and habitat specificity of benthic macro-invertebrates: a case study in five tributaries of Buddhiganga river in western Nepal. *Journal of Institute of Science and Technology 23(1)*, 69-75. https://doi.org/10.3126/jist.v23i1.22198

Bonada, N., Prat, N., Resh, V.H., & Statzner, B. (2006). Developments in aquatic insect biomonitoring: Comparative analysis of recent approaches. *Annual review of entomology, 51(1),* 495–523. https://doi.org/10.1146/annurev.ento.51.110104.151124

Chi, S., Li, S., Chen, S., Chen, M., Zheng, J., & Hu J. (2017). Temporal variations in macroinvertebrate communities from the tributaries in the Three Gorges Reservoir Catchment, China. *Revista Chilena de Historia Natural, 90,* 6. https://doi.org/10.1186/s40693-017-0069-y.

Clarke, K.R. (1993) Non-parametric multivariate analyses of changes in community structure. *Austral Ecology, 18,* 117-143. https://doi.org/10.1111/j.1442-9993.1993.tb00438.x

Feld, C.K. (2004). Identification and measure of hydromorphological degradation in Central European lowland streams. *Hydrobiologia*, *516*, 69–90. https://doi.org/10.1023/B:HYDR.0000025259.01054.f2

Gao, A., Chen, Q., & Zeng, J. (2006). Ecological characteristics of the marine benthic organisms in the muddy intertidal zone of Cangnan. *Marine Sciences-Qingdao-Chinese Edition, 30*(5), 92-96.

Irvine, K. (2004). Classifying ecological status under the European Water Framework Directive: the need for monitoring to account for natural variability. *Aquatic Conservation: Marine and Freshwater Ecosystems, 14*(2), 107–112. https://doi.org/10.1002/aqc.622

Jacobsen, D., & Encalada, A. (1998).The macroinvertebrate fauna of Ecuadorian highland streams in the wet and dry season. *Archiv fur Hydrobiologie, 142*, 53-70. https://doi.org/10.1127/archiv-hydrobiol/142/1998/53

Joshi, N.M., & Shrestha, P.M. (2008). Regional co-operation for flood disaster mitigation in the Ganges and Brahmaputra River Basin in South Asia. *Jalasrot Vikas Sasntha`/Nepal Water Partnership Anamnagar, Kathmandu, Nepal* [online]. Available From: https://jvs-nwp.org.np/wp-content/uploads/2018/07/Number-46.pdf

Kaiser, M. J., Broad, G., & Hall, S. J. (2001). Disturbance of intertidals of-sediment benthic communities by cockle hand raking, *Journal of Sea Research, 45*(2)*,*119–130. https://doi.org/10.1016/S1385-1101(01)00052-1

Kennen, J.G. (1999). Relation of macroinvertebrate com-munity impairment to catchment characteristics inNew Jersey streams. *Journal of the American Water Resources Association*, *35*(4), 939–954. https://doi.org/10.1111/j.1752-1688.1999.tb04186.x

Leunda, P.M., Oscoz, J., Miranda, R., & Arino, A.H. (2009). Longitudinal and seasonal variation of the benthic macroinvertebrate community and biotic indices in an undisturbed Pyrenean River. *Ecological Indicators,* 9(1*),* 52-63. https://doi.org/10.1016/j.ecolind.2008.01.009

Longing, S.D., Voshell, J.R. Dollof, C.A. & Roghair, C.N. (2010). Relationships of sedimentation and benthic macroinvertebrate assemblages in headwater streams using systematic longitudinal sampling at the reach scale. *Environmental Modeling and Assessment, 161,* 517–530. https://doi.org/10.1007/s10661-009-0765-4

Morse, J.C., Yang, L., & Tian, L. (1994). Aquatic insects of China useful for monitoring water quality. Hohai University Press, Nanjing, pp XII+570 ISBN 7–5630–0240–5.

NDRI, & CSIRO. (2016). Kamala Basin [online]. Nepal Development Research Institute (NDRI) in collaboration with Commonwealth Scientific and Industrial Research Organization (CSIRO). Available From: http://www.ndri.org.np/wp-content/uploads/2017/11/2_Kamala-Basin_Final-Report-19th-Feb.pdf

Nesemann, H., Shah, R.D.T., & Shah, D.N. (2011). Key to the larval stages of common Odonata of Hindu Kush Himalaya, with short notes on habitats and ecology. *Journal of threatened Taxa* , 3, 2045-2060. https://doi.org/10.11609/JoTT.o2759.2045-60

Rantz, S.E. (1982). *Measurement and Computation of Streamflow*: Volume 1. Measurement of Stage and Discharge. United States Geological Survey Water-Supply Paper 2175. *In Library of Congress Cataloging, Washington DC.*

Regmi, T., Shah, D.N., Doody, T.M., Cuddy, S.M., & Shah, R.D.T. (2021). Hydrological alteration induced changes on macrophyte community composition in sub-tropical floodplain wetlands of Nepal. *Aquatic Botany*, *173*, 103413. https://doi.org/10.1016/j.aquabot.2021.103413

Rampel, L.L., Richardson, J.S. & Healey M.C. (2000). Macroinvertebrate community structure along gradients of hydraulic and sedimentary conditions in a large gravel bed river. *Freshwater Biology 45(1)*, 57–73. https://doi.org/10.1046/j.1365-2427.2000.00617.x

Rosenberg, D.M., & Resh, V.H. (1993). Introduction to freshwater biomonitoring and benthic macroinvertebrates; In: *Freshwater biomonitoring and benthic macroinvertebrates (eds) Rosenberg D M and Resh V H (New York: Chapman and Hall*), 1–9.

Shrestha, M. (2016) cited in NDRI & CSIRO (2016) *Kamala basin: Water and Energy Commission Secretariat, Kathmandu, Nepal.* (Unpublished Report).

Shrestha, S., Tachamo Shah, R.D., Doody, T.M., Cuddy, S., & Shah, D.N. (2021). Establishing the relationship between benthic macroinvertebrates and water level fluctuation in subtropical shallow wetlands. *Environmental Monitoring and Assessment*, *193*(8), 534. https://doi.org/10.1007/s10661-021-09225-5

Tachamo-Shah, R.D., Shah, D.N., & Sharma, S. (2020c). *Rivers handbook- A guide to the health of rivers in the Hindu-Kush Himalaya.* Aquatic Ecology Centre, School of Science, Katmandu University.

Tachamo-Shah, R.D., Sharma, S., Haase, P., Jähnig, S., & Pauls, S. (2015). The climate sensitive zone along an altitudinal gradient in central Himalayan rivers: a useful concept to monitor climate change impacts in mountain regions. *Climatic Change, 132*, 265-278. https://doi.org/10.1007/s10584-015-1417-z

Tachamo-Shah, R.D., & Shah, D.N. (2013). Evaluation of benthic macroinvertebrate assemblage for disturbance zonation in urban rivers using multivariate analysis: Implications for river management. *Journal of Earth System Science, 122*(4), 1125-1139. https://doi.org/10.1007/s12040-013-0317-8

Tachamo-Shah, R.D., Sharma, S., & Bharati, L. (2020a). Water diversion induced changes in aquatic biodiversity in monsoon-dominated rivers of Western Himalayas in Nepal: Implications for environmental flows. *Ecological Indicators, 108,* 105735. https://doi.org/10.1016/j.ecolind.2019.105735

Tachamo-Shah, R.D., Sharma, S., Shah, D.N., & Rijal, D. (2020b). Structure of benthic macroinvertebrate communities in the rivers of western Himalaya, Nepal. *Geosciences, 10* 4), 150. https://doi.org/10.3390/geosciences10040150