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ORIGINAL ARTICLE

Monitoring and assessment of anthropogenic impacts on water quality by estimating the BMWP and ASPT indices for a headwater stream in Doon Valley, India

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Abstract

The current study was conducted to evaluate the impact of anthropogenic stresses on physico-chemical attributes and the abundance of macroinvertebrates during a period of one year from November 2017 to October 2018. Two important sampling sites (reference site S1; impacted site S2) characterized by various human activities were identified along the river. Anthropogenic activities were common at the impacted site (S2). High concentrations of TDS, phosphates, nitrates, sodium, turbidity, and conductivity were recorded at site S2. Based on Pearson's correlation coefficient and canonical correspondence analysis, a few parameters including the dissolved oxygen, water velocity, TDS, turbidity, pH and nitrates shape the taxonomic order and species of macroinvertebrate in the Baldi River. The dominance of species under Ephemeroptera, Plecoptera, and Trichoptera orders at site S1 indicated the stress-free conditions, whereas an increase in the density of Oligochaeta and Diptera (Chrimonoids) at site S2 represented serious anthropogenic stress condition. Lower values of biotic indices (Shannon–Weiner diversity index, EPT %, BMWP, and ASPT) also indicated a disturbance at site S2. Degradation in water quality, decrease in the dominance of Ephemeroptera, Plecoptera, and Trichoptera, and an increase in Annelids and Chrimonoids are the key factors that reflect anthropogenic stress on the Baldi River.

Keywords Baldi river · BMWP · ASPT · EPT species · Biotic indices · Anthropogenic disturbances

Abbreviations

WT	Water temperature
WV	Water velocity
Trans	Transparency
Cond	Conductivity
TU	Turbidity
TDS	Total dissolved solids
DO	Dissolved oxygen
AL	Alkalinity
CA	Calcium
HAR	Hardness
MG	Magnesium
NI	Nitrates
PHOS	Phosphates
NA	Sodium
K	Potassium
SUL	Sulfates
CM	CPOM
FM	FPOM
E	Ephemeroptera
P	Plecoptera
T	Tricoptera
D	Diptera
C	Coleoptera
O	Odonata
G	Gastropoda
Oi	Oligochaeta

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Introduction

Anthropogenic disturbances are a serious problem for freshwater ecosystems (Gouide 2000; Søndergaard and Jeppesen 2007). A few common disturbances are agriculture, impoundment, mining, habitat destruction, and pollution (LaBonte et al 2001; Emmanuel et al. 2018) which lead to degradation and loss of biodiversity on the global scale (Vinson and Hawkins 1998; Mehari et al 2014). In the last few decades, the influence of human activities on aquatic bodies has increased dramatically in the southern part of Asia (Karn and Harada 2001; Kannel et al. 2007; Shah and Shah 2013). The freshwater ecosystem encompasses many communities; among them, benthic macroinvertebrates are ecologically important in running water ecosystems (Boulton 2003; Mehari et al. 2014; Hwang et al. 2014). Benthic macroinvertebrates are living organisms (> 500 µm in size) whose life cycles are nearly at the lower part of the water (Den Van Brink et al. 1994; Liang and Wang 1999). Benthic macroinvertebrates are key components of food webs in freshwater ecosystems (Wallace and Webster 1996; Grubh and Mitsch 2004; Enawgaw and Lemma, 2019) feeding on living or decaying organic matter and serving as food for other invertebrates (Moulton et al. 2010) and fish species (Copatti et al. 2012). Dispersion, density, and biomass of benthic macroinvertebrates rely upon the environmental attributes of water, nature of dregs or foundation, organic compounds like food, predation, and different variables (Gupta 2013; Wang et al. 2021).

Rivers, specifically, are generally described by a high level of spatio-temporal commutability (Elósegui and Pozo 1994; Liu et al., 2014). Variations in water quality and the physical structure of rivers are responsible for changes in the composition of the biotic community (biodiversity of an aquatic ecosystem) inhabiting the river (Maddock 1999). The number of inhabitants in benthic macroinvertebrate is exceptionally delicate to any natural annoyance and is profoundly affected by ecological changes or variations (Ishaq and Khan 2013a, 2013b; Clews et al. 2014). Bio-assessment of rivers gives more clear or accurate results about the health status of an aquatic ecosystem than the physico-chemical monitoring of running water (Shah and Shah 2013). Evaluation of physico-chemical parameters provides only a snapshot of a water body and not the overall health status (USEPA, 2005). Benthic macroinvertebrates are one of the most important bioindicators to assess the ecological health status of rivers (Hynes 1971; Reynoldson et al. 1989; Oliveira and Marcos 2010; Pan et al. 2012; Xuet al. 2013; Tampo et al. 2021). Biotic indices are mathematical articulations consolidating a quantitative proportion of species diversity with subjective data on the natural responsiveness of individual taxa (Czerniawska-Kusza 2005; Varnosfaderany et al. 2010; Yazdian et al. 2014). Biotic indices of macroinvertebrates for determining ecological health and water quality are particularly well established and are adopted worldwide for stream assessment (Rosenberg and Resh 1993; Clews et al. 2014).

The Biological Monitoring Working Party (BMWP) score framework that produced waterway contamination overviews in the UK (Armitage et al. 1983), has been effectively applied in different nations including Spain (Zamora-Munŏz et al. 1995), Italy (Solimini et al. 2000), Thailand (Mustow 2002; Payakka and Prommi 2014), Iran (Aazami et al. 2015), Poland (Czerniawska- Kusza 2005), Malaysia (Azrina et al. 2006), Hindu Kush–Himalaya region (Ofenböck et al. 2008), Iran (Varnosfaderany et al. 2010) Vietnam (Nguyen et al. 2014), Turkey (Arslan et al. 2016), Kano (Bawa et al. 2018) and India (Mophin-Kani and Murugesan 2014). However, no sincere attempt except by Ishaq and Khan (2013c) and Kadam et al. (2020) has been made so far to assess the ecological health status of a freshwater body located in the Doon Valley of India. Therefore, it is of paramount importance to undertake the current study about anthropogenic stress and its impact on the water quality and benthic macroinvertebrate diversity of headwater stream Baldi.

Materials and methods

Study area and sampling sites

Baldi River is a first-order headwater stream of Doon Valley. It is a significant feeder of the Song River streaming in the Doon Valley of Garhwal Himalaya in India. It is situated at latitude 30° 23′ N and longitude 78° 08′ E in the Raipur Block of Dehradun district of Uttarakhand state in India. The Baldi River meets the Song River at Maldevta (Dehradun) in the wake of covering a distance of 14 km. Depending on human interferences and a detailed survey of the entire catchment; two water sampling sites were identified (Fig. 1). The upstream site S1 (undisturbed site or reference site) was identified near Shera Chowki. No human activity was recorded at this site during the study period. Impacted site S2 (highly disturbed) was identified near to Sahasradhara tourist spot, about 2.5 km downstream of site S1. A number of hot water springs also join Baldi stream at the downstream site. This site is influenced by multiple human activities including bathing, washing, and discharge of sewage from hotels and restaurants. Regular monthly sampling was attempted during the early morning between 0800 and 1000 h at both the testing destinations from November 2017 to October 2018 spreading into three seasons—winter

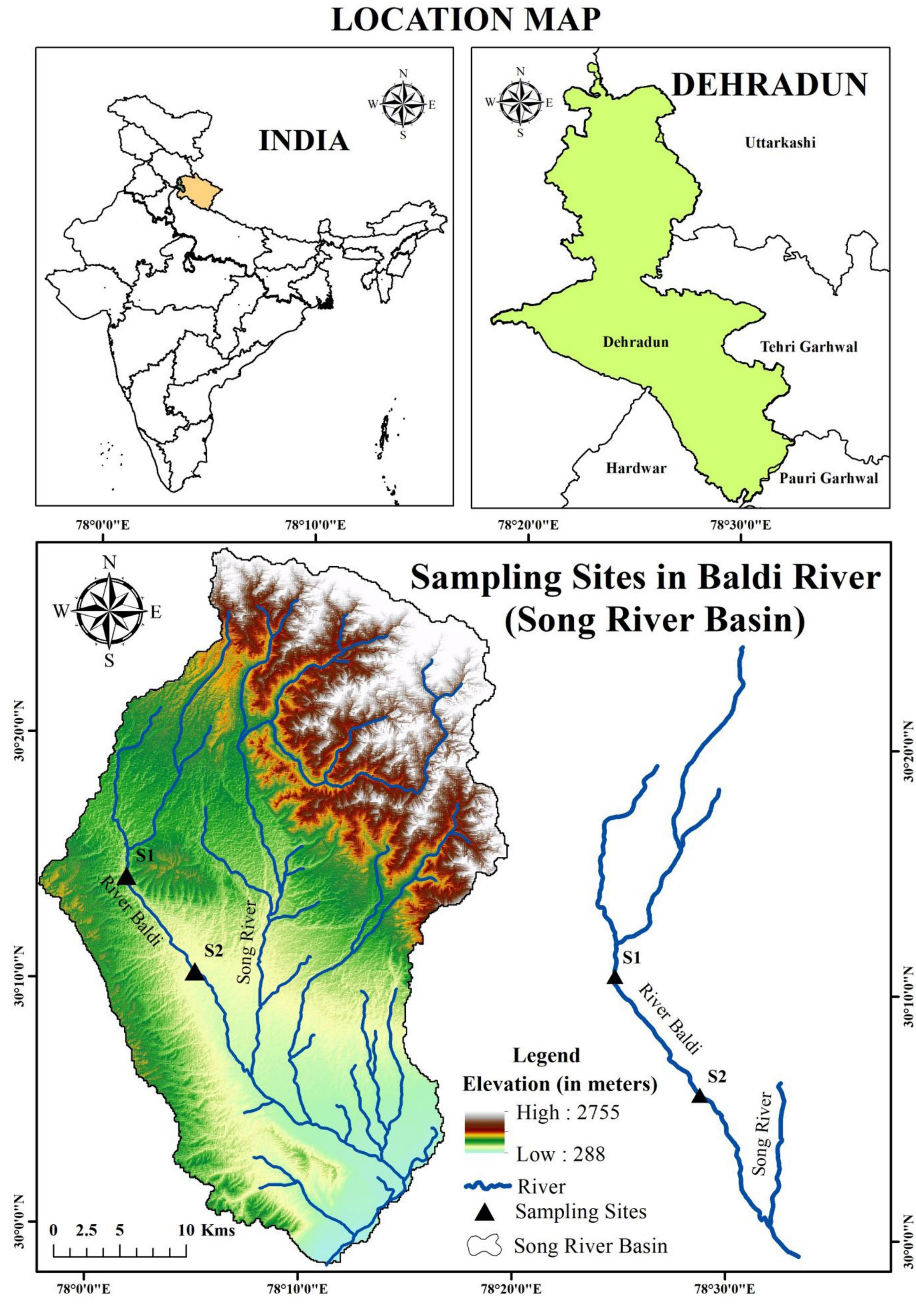

Fig. 1 Map of the study area showing locations of sampling sites on the Baldi River

season (from November to February); summer season (from March to June); and storm season (from July to October). Five repeats of tests were obtained for each parameter from both the sampling sites and later, the outcomes were incorporated and recorded.

Physico-chemical parameters

Water temperature was recorded using a digital thermometer having a temperature range of − 50 °C to + 300 °C whereas the turbidity was measured using the Metzer Digital Turbidity Meter (5D1M). The pH values of water samples were recorded using the Toshcon multi-parameter analyzer. The modified Winkler's method was used to estimate the concentration of dissolved oxygen in water (APHA, 2012). The concentrations of nitrates, phosphates, and sulfates were analyzed and recorded using the spectrophotometric methods given in APHA (2012). The concentrations of TDS, alkalinity, calcium, magnesium, and hardness were calculated using the titration method given in Wetzel and Likens (1991) and APHA (2012). The concentrations of sodium and potassium were analyzed using the Flame Photometer (EI-1381E). Coarse particulate organic matters (CPOM) and fine particulate organic matters (FPOM) were transferred to a container together with the sediment's interstitial water. The contents of the used container were then filtered through a 1 mm pore size sieve. CPOM (particles larger than 1 mm) and FPOM (particles smaller than 1 mm) were then determined by combustion for 5 h in a muffle furnace. Their values were expressed in g.L^{-1}.

Macroinvertebrate sampling

Benthic macroinvertebrates colonizing on the substrates (cobbles, pebbles, and gravel) were tested with the Surber sampler (0.5 mm network net) to a profundity of around 10 cm in a quadrant. Samples were preserved in a 4% formalin solution. At each testing destination, five replicates were taken. The collected diversity of macroinvertebrate was recognized to the conceivable most minimal ordered or taxonomic level. Identification of macroinvertebrate was made possible with the assistance help of Needham, and Needham (1962); Disney (1975); Hynes (1977); Kumar, and Khanna (1984); Elliott et al. (1988); Ward, and Whipple (1992); Edington, and Hilldrew (1995); Subbarao (1933), Biswas et al. (1995), Mitra (1999, 2003); Mitra et al. (2004); Rawat et al. (2019) and Kumar et al. (2021).

Statistical data analysis

The BMWP index [(rev. BWMP), Paisley et al. 2013) for each sampling site was monthly calculated by adding the individual scores of the families (Arslan et al. 2016; Walley and Hawkes 1996) whereas, the Average Score Per Taxon [(ASPT), Armitage et al. 1983)] index was calculated by the ratio of BMWP to the number of families. Simpson's diversity (D), Margalef's (R), and Shannon–Wiener diversity indices were calculated using PAleontological STatistics (PAST) software *ver*. 4.07 (Hammer et al. 2001) to determine the water quality. Physico-chemical parameters and macroinvertebrate assemblages were compared between stations by the Student's t test using Microsoft Excel 2013. The Karl Pearson's correlation coefficient was performed using SPSS *ver*.16.0 to determine the relationship between the various physico-chemical attributes and macroinvertebrate assemblages. Canonical correspondence analysis (CCA) was performed using the PAleontological STatistics (PAST) software *ver*. 4.07 (Hammer et al., 2001) to determine the relationship between dominant macroinvertebrate species and physico-chemical attributes. Results of the physico-chemical attributes were also classified according to values recommended by the WHO for surface water to demonstrate the water quality.

Results

Physico-chemical parameters

Data on bottom substrate composition and physico-chemical attributes recorded at both sampling sites across the Baldi River have been presented in Table 1. The bottom substrate in Baldi River was contributed by boulders, cobbles, pebbles, and sand that provide refuge to benthic macroinvertebrates. The reference site (S1) was dominated by boulders (45%), followed by cobbles (22%) and pebbles (15%), whereas the impacted site (S2) was dominated by sand (15%) and silt (10%). Thus, there is a distinct difference in the composition of bottom substrates at both the water sampling sites.

A considerable difference between the physico-chemical attributes of both the sampling sites has been recorded due to multiple anthropogenic activities at S2. A minor difference in the water temperature was recorded at S1 (13.36 ± 2.11 ˚C) and S2 (13.54 ± 2.11 ˚C). Higher transparency was recorded at site S1 (0.28 ± 0.11 m) than (0.18 ± 0.11 m) at S2 whereas, water velocity was also found higher (0.79 ± 0.13 ms^{-1}) at S1 in comparison to site S2 (0.52 ± 0.13 ms^{-1}). Conductivity was recorded higher (0.610 ± 0.03 mS cm^{-1}) at S2 and lower at S1 (0.400 ± 0.03 mS cm^{-1}). The highest amount of turbidity and TDS was recorded at site S2, whereas the lowest amount was at site S1. Depletion in the concentration of dissolved oxygen was recorded at S2 (7.09 ± 1.00 mg.L^{-1}) than S1 (8.56 ± 1.28 mg.L^{-1}). Alkalinity and Hardness were recorded higher at S1 than the values recorded

Table 1 Annual mean, t test, and WHO values for physico-chemical parameters during November 2017– October 2018

	Reference site (S_1) (Mean ± SD) (Range)	Impacted site (S_2) Mean ± SD (Range)	t test value	WHO limits
Boulders (> 256 mm)	45%	33%		
Cobbles (64–256 mm)	22%	20%		
Pebbles (16–64 mm)	15%	12%		
Gravel(2–16 mm)	15%	10%		
Sand (1–2 mm)	2%	15%		
Silt (> 1 mm)	1%	10%		
CPOM (g.L^{-1})	18.34 ± 7.17 (7.85–29.86)	23.04 ± 8.13 (10.43–34.50)		
FPOM (g.L^{-1})	10.04 ± 4.43 (4.57 –172.24)	14.73 ± 5.78 (6.82–23.51)		
Water Temperature (°C)	13.36 ± 2.11 (9.6–16)	13.54 ± 2.11 (9.8–16.2)	− 7.6072*	
Water velocity (m s^{-1})	0.79 ± 0.13 (0.63–1.02)	0.52 ± 0.13 (0.39–0.75)	34.3074*	–
Transparency (m)	0.29 ± 0.11 (0.12–0.42)	0.19 ± 0.12 (0.0–0.32)	24.9119*	–
Conductivity (mS cm^{-1})	0.400 ± 0.03 (0.372–0.463)	0.610 ± 0.03 (0.578–0.667)	− 452.681	1.5
Turbidity (NTU)	40.49 ± 33.15 (2–99)	52.48 ± 37.12 (8–115)	− 8.364*	–
Total Dissolved Solid (mg L^{-1})	106.38 ± 73.64 (30–236)	132.49 ± 81.03 (45–272)	− 9.356*	1000
pH	7.76 ± 0.07 (7.66–7.88)	7.69 ± 0.08 (7.58–7.84)	10.522*	6.5–8.5
Dissolved oxygen (mg.L^{-1})	8.56 ± 1.28 (6.68–10.32)	7.09 ± 1.00 (6.14–8.52)	14.9407*	5.0
Alkalinity (mg.L^{-1})	67.64 ± 18.54 (40–95)	60.19 ± 16.02 (38.5–84.6)	6.06744	200
Calcium (mg.L^{-1})	68.33 ± 13.85 (45–102)	64.92 ± 14.07 (35–97)	11.0952*	100
Hardness (mg.L^{-1})	165.33 ± 29.06 (135–198)	156.42 ± 29.31 (124–187)	7.22147*	100
Magnesium (mg.L^{-1})	45.08 ± 26.36 (15–52)	38.56 ± 26.33 (10–46)	3.98853	50
Nitrates (mg.L^{-1})	0.07 ± 0.01 (0.058–0.095)	0.09 ± 0.01 (0.072–0.115)	− 19.794	50
Phosphates (mg.L^{-1})	0.04 ± 0.02 (0.015–0.070)	0.05 ± 0.02 (0.028–0.080)	− 10.3807	1.5
Sodium (mg.L^{-1})	9.5 ± 0.88 (8.3–10.8)	10.36 ± 0.5 (9.4–11.3)	− 3.08914	200
Potassium (mg.L^{-1})	3.91 ± 0.4 (3.3–4.5)	3.98 ± 0.43 (3.34–4.55)	− 0.5123	12
Sulfates (mg.L^{-1})	1.62 ± 0.43 (1.12–2.32)	3.08 ± 0.44 (2.6–3.72)	− 81.7212*	250

at S2 (Table 1). Calcium and Magnesium were also found higher at S1 than S2. The concentrations of nitrates, phosphates, and sulfates were recorded highest at site S2 and the lowest at S1. Sodium concentration in water samples was recorded higher (10.36 ± 0.50 mg.L^{-1}) at S2 than S1 (9.15 ± 0.89 mg.L^{-1}). A similar trend was also found for Potassium. Student's t test was recorded significant ($p < 0.05$) for physico-chemical attributes between the two sites. Higher concentrations of turbidity, TDS, conductivity, nitrates, phosphates, sulfates, and lower concentrations of dissolved oxygen and transparency clearly reflect the impact of activities at the sampling site S2 (reflected site) (Table 2).

Table 2 Seasonal variations among the physico-chemical parameters (Using ANOVA)

Parameters/ Seasons	S_1 (Reference site)								S_2 (Impacted site)							
	Winter		Summer		Monsoon		*F*	*p*	Winter		Summer		Monsoon		*F*	*p*
	Mean	SD	Mean	SD	Mean	SD			Mean	SD	Mean	SD	Mean	SD		
Water Temperature (˚C)	10.95	1.3	14.5	1.47	14.63	0.84	11.48	0.003	11.1	1.26	14.73	1.44	14.8	0.85	12.27	0.0027
Water velocity (m s^{-1})	0.67	0.03	0.8	0.08	0.91	0.12	7.97	0.010	0.4	0.04	0.51	0.07	0.67	0.1	14.31	0.0016
Transparency (m)	0.39	0.03	0.27	0.1	0.21	0.1	4.51	0.044	0.29	0.03	0.17	0.12	0.11	0.12	3.62	0.07039
Conductivity (mS cm^{-1})	0.38	0	0.43	0.03	0.41	0.04	4.19	0.052	0.58	0	0.63	0.02	0.61	0.04	4.27	0.04976
Turbidity (NTU)	10	10.46	33.55	18.54	77.93	20.1	16.66	0.001	17	11.49	45.2	20.67	95.23	17.56	21.71	0.00036
TDS (mg.L^{-1})	45	13.52	81.38	41.39	192.75	46.76	17.42	0.001	63.75	14.1	106.98	53.5	226.75	44.71	16.91	0.00089
pH	7.69	0.03	7.77	0.05	7.83	0.05	8.71	0.008	7.63	0.05	7.7	0.05	7.75	0.09	3.78	0.06441
DO(mg.L^{-1})	9.83	0.48	8.48	0.98	7.37	0.87	9.38	0.006	8.02	0.42	7.15	0.61	6.12	0.81	9.10	0.0069
Alkalinity (mg.L^{-1})	51.23	11.51	67.18	16.65	84.53	10.54	6.39	0.019	46.08	7.75	61.75	15.63	72.75	12.54	4.67	0.04058
Calcium (mg.L^{-1})	76.5	8.06	66	10.33	50.5	8.7	8.30	0.009	72.25	6.95	62	9.93	45.5	9.68	9.09	0.00693
Hardness (mg.L^{-1})	171.25	10.31	151.25	12.31	110.5	16.82	21.68	0.0004	160.25	9.32	143.5	12.48	109.5	16.76	22.56	0.00031
Magnesium (mg.L^{-1})	44.75	4.43	35.25	2.22	28	9.83	31.95	0.0001	40	4	31.5	5	24	8.45	34.80	0.00005
Nitrate (mg.L^{-1})	0.06	0.004	0.076	0.009	0.083	0.013	6.13	0.021	0.076	0.003	0.095	0.01	0.1	0.013	6.89	0.0153
Phosphate (mg.L^{-1})	0.026	0.008	0.046	0.018	0.059	0.013	5.89	0.023	0.040	0.01	0.054	0.018	0.068	0.012	3.99	0.0575
Sodium (mg.L^{-1})	10.28	0.39	8.68	0.52	9.55	0.86	6.67	0.017	10.64	0.52	10.6	0.07	9.85	0.34	6.11	0.0211
Potassium (mg.L^{-1})	3.5	0.22	4.13	0.45	4.12	0.09	5.99	0.022	3.69	0.36	3.86	0.41	4.4	0.14	5.18	0.0318
Sulfate (mg.L^{-1})	1.21	0.08	1.67	0.38	2	0.34	7.10	0.014	2.64	0.11	3.14	0.4	3.46	0.3	7.83	0.0107

Macroinvertebrate assemblages and spatio-temporal variations

During the period of study, a total of 29 species of macroinvertebrate from 18 families representing 8 orders were recorded at both the sampling sites across the Baldi River. The orders Ephemeroptera and Plecoptera were represented by five species each, whereas Trichoptera was represented by six species. Diptera and Odonata were represented by four species each, while Coleoptera was represented by two species. Gastropoda was represented by two species; while, Oligochaeta was represented by one species. Maximum density of macroinvertebrate (276 ind. m^{-2}) was observed at site S1 which reduced to 207 ind. m^{-2} at site S2 (Fig. 2; Table 3). The order Ephemeroptera was dominant at S1. While, the members of orders Odonata, Diptera, and Oligochaeta were found dominant at S2. These orders have tolerance capability against water pollution. Overall, the maximum density of macroinvertebrates was recorded during the winter season and the minimum density during the monsoon period at both the sampling sites. During monsoon season, the Baldi River was flooded resulting in a lower density of macroinvertebrates. A significant difference in the macroinvertebrate assemblages was observed between S1 and S2 ($p < 0.05$) (Table 4). A low density of EPT species and a high density of Odonata and Diptera at S2 indicated anthropogenic stress at this stretch of the fluvial ecosystem.

Diversity, similarity, evenness, dominance indices, BMWP and ASPT scores

Biological indices including taxa, number of individuals, Shannon–Weiner diversity index, Simpson diversity index, Margalef's richness index, BMWP, and ASPT scores calculated for both the sampling sites (Reference site: S1 and Impacted site: S2) are given in Table 5. The maximum number of taxa (20) was recorded at S1. Shannon-Weiner Diversity Index was recorded as the highest (2.836) at S1 and the lowest (2.599) at S2. Margalef's index was recorded as the highest (3.327) at S1 and the lowest (2.802) at S2. The percentage of EPT recorded the highest at S1 (52.11%) and the lowest (47.91%) at S2. The BMWP score was found to be the maximum (78.08) at S1 and the minimum (65.33) at S2 whereas, the ASPT scores were recorded as maximum (6.04) at S1 and minimum (5.85) at S2. The minimum values of biotic indices indicate the stress of anthropogenic activities at site S2.

Statistical correlation between macroinvertebrate composition and physico-chemical parameters

Data on Pearson's correlation coefficient calculated between the macroinvertebrates abundance and physico-chemical attributes have been given in Table 6. Ephemeroptera, Plecoptera, Trichoptera, Diptera, Odonata, Coleoptera, Gastropoda and Oligochaeta showed a significant

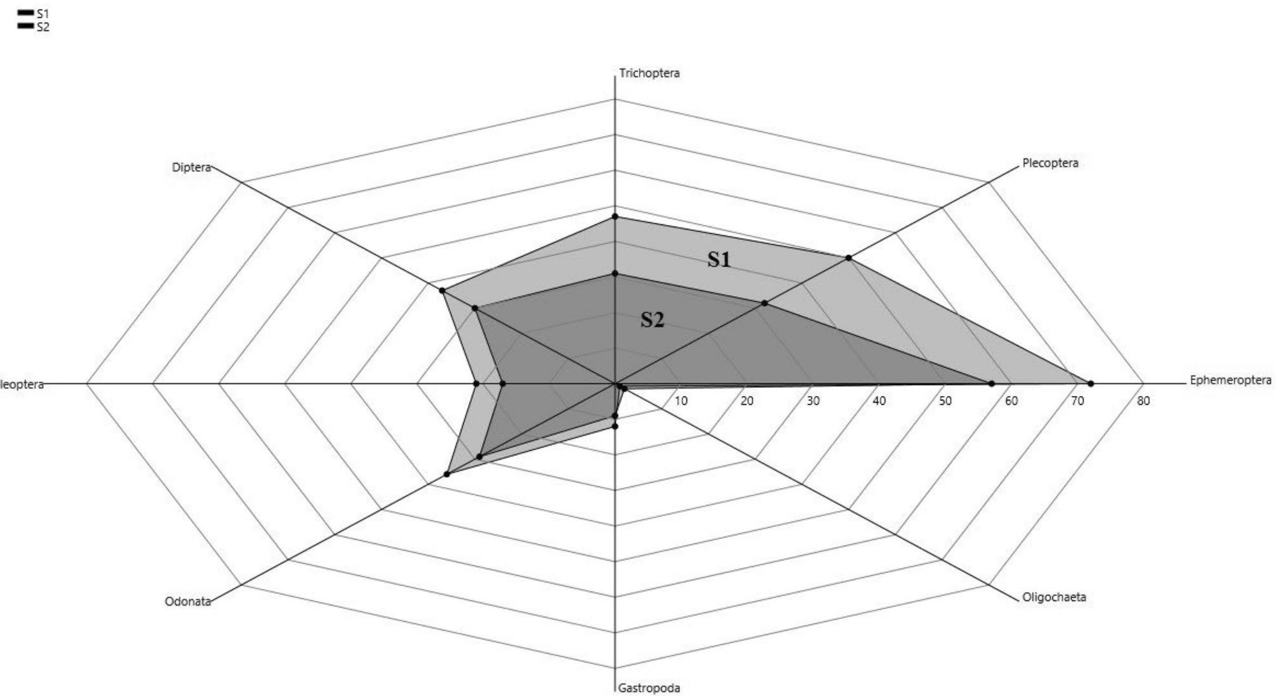

Fig. 2 Macroinvertebrate composition (ind.m.$^{-2}$) at the reference (S1) and the impacted (S2) sites of the Baldi River

Table 3 BMWP score and density of macroinvertebrate composition (ind.m.$^{-2}$) in the Baldi River during November 2017–October 2018

Order	Family	BMWP* Score	Taxon	Code	S_1	S_2
Ephemeroptera (E)	Baetidae	4	*Baetis niger*	BA	6	3
	Ephemerellidae	10	*Ephemerella ignita*	EI	18	16
	Heptageniidae	10	*Ecdyonurus* sp	Ec	5	3
			Heptagenia lateralis	HL	22	17
			Rhithrogena sp.	RHI	21	18
	Perlodidae	10	*Isoperla* sp.	Iso	3	3
		10	*Perla* sp.	P	18	15
Plecoptera (P)	Perlidae		*Claassenia* sp.	CL	12	5
			Neoperla sp.	NEO	7	1
	Taeniopterygidae	10	*Taeniopteryx* sp.	TA	10	8
Trichoptera (T)	Rhyacophilidae	7	*Rhyacophila* sp.	RHY	13	9
	Hydroptilidae	6	*Hydroptila* sp.	HYD	4	11
	Limnephilidae	7	*Limnephilus* sp.	LIM	11	0
	Molannidae	10	*Molanna* sp.	MOL	13	4
	Uenoidae	10	*Neophylax* sp.	NEO	6	5
	Phryganeidae	10	*Ptilostomis*sp.	PTIL	0	2
Diptera (D)	Chironomidae	2	*Chironomus* sp.	CHIR	10	18
			Tendipes tentans	TEN	10	8
	Tipulidae	5	*Megistocera* sp.	MEGI	1	0
	Simuliidae	5	*Simulium* sp.	SIM	16	4
Coleoptera (C)	Dytiscidae	5	*Hydaticus fabricii*	HF	8	9
			Hydaticus vittatus	HV	13	8
Odonata (O)	Coenagrionidae	6	*Ceriagrion coromandelianum*	CC	11	7
			Enallagma parvum	EP	12	11
			Ischnura aurora	IA	11	8
			Onychogomphus bistrigatus	OB	2	3
Gastropoda (G)	Planorbidae	3	*Gyraulus convexiusculus*	GC	10	6
	Lymnaeidae	3	*Lymnaea acuminata*	LA	2	3
Oligochaeta (Oi)	Tubificidae	1	*Tubifex tubifex*	TT	1	2
Total density (ind.m^{-2})					276	207

*Walley and Hawkes 1996

correlation with physico-chemical attributes. Macroinvertebrates have negative correlation with water temperature, water velocity, conductivity, turbidity and TDS ($p < 0.01$). Ephemeroptera has a strong positive correlation with DO ($r = 0.932$, $p < 0.01$) transparency ($r = 0.808$, $p < 0.01$), hardness ($r = 0.923$, $p < 0.01$) and calcium ($r = 0.927$, $p < 0.01$). However, it has a strong negative correlation with pH ($r = -0.855$, $p < 0.01$), alkalinity ($r = -0.899$, $p < 0.01$), TDS, nitrates and phosphates ($p < 0.01$). Plecoptera showed a negative correlation with water temperature ($r = -0.617$, $p < 0.05$), water velocity ($r = -0.629$, $p < 0.05$), conductivity ($r = -0.848$, $p < 0.01$) and positive correlation with transparency ($r = 0.722$, $p < 0.01$), and dissolved oxygen ($r = 0.609$, $p < 0.05$). The Gastropods did not show any significant correlation with physico-chemical attributes. The Diptera has a strong negative correlation with turbidity ($r = -0.935$, $p < 0.01$), while the Coleoptera has a strong negative correlation with nitrates ($r = -0.948$, $p < 0.01$).

The Canonical Correspondence Analysis (CCA) method was used to determine the relationships between the macroinvertebrate species and physico-chemical environmental variables. From biotic and abiotic factors, CCA extracts gradients and the explanatory variables are quantitatively represented by arrows in a graphical biplot (Muylaert et al. 2000; Liu et al 2010). The arrow length indicates the importance of variables and shows positive or negative correlations with the axis (Abrantes et al. 2006, Liu et al. 2010). Percentage of variance and Eigenvalues of each site on axis 1 were found maximum than on axis 2 (Table 7). A similar finding was reported by Liu et al. (2010). For axis 1 and axis 2, the correlation between physico-chemical parameters and dominant macroinvertebrate species was found to be the maximum at

Table 4 Seasonal variations in macroinvertebrate community at the reference (S_1) and the impacted (S_2) sites of the Baldi River during November 2017–October 2018

	S_1	S_2		S_1 (Reference site)					S_2 (Impacted site)				
				Winter	Summer	Monsoon			Winter	Summer	Monson		
	Mean ± SD	Mean ± SD	t -stat value	Mean ± SD	Mean ± SD	Mean ± SD	F	p	Mean ± SD	Mean ± SD	Mean ± SD	F	p
E	71.50 ± 8.21	56.67 ± 36.14	5.703	106.75 ± 13.84	71.5 ± 27.74	37.25 ± 27.86	8.34	0.009	87.25 ± 9.78	62.75 ± 32.51	20 ± 3.41	8.17	0.009
P	50.00 ± 5.61	31.83 ± 12.37	4.762	57.25 ± 3.2	41.25 ± 13.96	46.5 ± 12.77	2.17	0.170	36 ± 13.09	29.5 ± 4.65	30 ± 18.26	0.30	0.749
T	47.00 ± 5.34	30.58 ± 17.42	3.388	70.5 ± 7.59	41 ± 18.02	27 ± 22.42	6.69	0.017	47 ± 14.35	27.25 ± 13.3	17.5 ± 11.12	5.35	0.030
D	37.00 ± 6.18	30.17 ± 15.91	2.044	59 ± 10.89	36.5 ± 16.9	14.75 ± 3.86	14.01	0.002	42.75 ± 8.58	32.25 ± 17.8	15.5 ± 5.8	5.34	0.030
C	21.00 ± 3.54	17.17 ± 8.09	2.787	30.75 ± 2.99	18.5 ± 8.5	16 ± 13.64	2.80	0.114	24.75 ± 4.5	16 ± 2.0	10.75 ± 9.07	5.66	0.026
O	36.00 ± 4.69	30.08 ± 17.68	1.479	40.25 ± 14.41	33.75 ± 19.75	33.75 ± 11.09	0.23	0.796	42.75 ± 19.5	23 ± 18.78	24.5 ± 9.54	1.76	0.226
G	12.00 ± 5.66	8.00 ± 3.81	6.200	13.25 ± 1.5	15.5 ± 1.73	10.75 ± 2.99	4.78	0.038	11 ± 3.83	9 ± 1.83	4 ± 0.82	8.36	0.009
Oi	1.00 ± 0.79	2.33 ± 1.87	− 1.959	1.5 ± 0.58	1 ± 1.15	1.75 ± 0.5	0.91	0.435	4 ± 0.0	1.5 ± 1.91	1.5 ± 1.91	3.41	0.079
GT	276 ± 40.02	207 ± 113.29		379 ± 55	259 ± 107.75	188 ± 94.63			296 ± 73.63	201 ± 92.78	128 ± 59.93		

Table 5 Biotic indices and scores of the sampling sites at the Baldi River

Biotic indices	Reference site (S_1)	Impacted site (S_2)
Number of taxa	19.500 ± 2.844	15.833 ± 4.260
Number of individuals	276.250 ± 105.206	206.833 ± 94.735
Dominance	0.064 ± 0.009	0.084 ± 0.023
Simpson diversity index	0.936 ± 0.009	0.916 ± 0.023
Shannon-Weiner diversity index	2.836 ± 0.137	2.599 ± 0.277
Evenness	0.884 ± 0.036	0.874 ± 0.034
Margalef richness index	3.327 ± 0.333	2.802 ± 0.592
EPT%	52.11 ± 5.091	47.913 ± 6.610
BMWP	78.08 ± 2.81	65.33 ± 15.35
ASPT	6.04 ± 0.49	5.85 ± 0.22

both the sampling sites. At site S2, conductivity, TDS, and turbidity were the important factors that govern macroinvertebrates distribution at the impacted site (Fig. 4). Higher values of conductivity, TDS, and turbidity indicate anthropogenic disturbances at site S2.

Discussion

Physico-chemical attributes

In the riverine ecosystem, water temperature influences the life cycle of aquatic organisms (Ward and Stanford 1979). The water temperature of the Baldi River was recorded within a range from 10.6 to 25.1 °C. The concentration of dissolved oxygen is an important parameter that plays a key role in the existence of life in an aquatic ecosystem (Ahmed 2004; Kumar et al. 2020; Rawat et al. 2020). Its concentration in the Baldi River was recorded within a range of 6.14 mg.L^{-1} to 10.32 mg.L^{-1} was more than the value (5 mg/L^{-1}) recommended by WHO for the surface water. This amount of dissolved oxygen is a must for the survival of aquatic organisms. Variations in other parameters including turbidity, transparency, TDS, and temperature may cause fluctuation in the concentration of dissolved oxygen (Ahmed 2004; Sharma and Kumar 2017; Kumar et al. 2018). At the infected site (S2), anthropogenic or human disturbances were common resulting in a lower concentration of dissolved oxygen. The highest concentrations of TDS (272 mg.L^{-1}) and turbidity (115 mg.L^{-1}) were reported at site S2 whereas, their lowest concentrations were found (TDS: 30 mg.L^{-1}; Turbidity: 2 mg.L^{-1}) at site S1 in the Baldi River. Transparency in rivers indicates their productivity (Shinde et al. 2011). More clear is the water, more is the productivity. The higher transparency (0.42 m) was recorded at site S1

Table 6 Statistical correlation computed between macroinvertebrate orders and physico-chemical parameters

Order/ Parameter	WT	WV	TRAN	CON	TU	TDS	pH	DO	ALK	CL	CA	HAR	MG	NI	PHOS	NA	K	SUL	CM	FM
Ephemeroptera	– 0.756**	– 0.926**	0.868**	– 0.558	– 0.928**	– 0.924**	– 0.855**	0.932**	– 0.899**	– 0.749**	0.927**	0.923**	0.860**	– 0.904**	– 0.889**	0.735**	– 0.769**	– 0.947**	– 0.909**	– 0.975**
Plecoptera	– 0.617*	– 0.629*	0.722**	– 0.848**	– 0.470	– 0.506	– 0.635*	0.609*	– 0.603*	– 0.655*	0.510	0.401	0.281	– 0.848**	– 0.622*	0.860**	– 0.232	– 0.718**	– 0.608*	– 0.635*
Trichoptera	– 0.798**	– 0.944**	0.929**	– 0– 0681*	– 0.894**	– 0.885**	– 0.878**	0.953**	– 0.922**	– 0.845**	0.899**	0.863**	0.776**	– 0.928**	– 0.921**	0.836**	– 0.715**	– 0.960**	– 0.891**	– 0.925**
Diptera	– 0.782**	– 0.881**	0.850**	– 0.564	– 0.935**	– 0.915**	– 0.875**	0.908**	– 0.922**	– 0.812**	0.934**	0.893**	0.800**	– 0.803**	– 0.878**	0.694*	– 0.833**	– 0.923**	– 0.863**	– 0.859**
Coleoptera	– 0.751**	– 0.906**	0.880**	– 0.676*	– 0.808**	– 0.787**	– 0.881**	0.883**	– 0.825**	– 0.750**	0.822**	0.780**	0.694*	– 0.948**	– 0.844**	0.880**	– 0.586*	– 0.882**	– 0.882**	– 0.918**
Odonata	– 0.731**	– 0.697*	0.695*	– 0.658*	– 0.607*	– 0.556	– 0.749**	0.758**	– 0.811**	– 0.722**	0.697*	0.536	0.363	– 0.654*	– 0.853**	0.623*	– 0.710**	– 0.687*	– 0.567	– 0.629*
Gastropoda	– 0.302	– 0.505	0.390	0.145	– 0.672*	– 0.652*	– 0.439	0.519	– 0.503	– 0.318	0.611*	0.699*	0.729**	– 0.208	– 0.443	0.057	– 0.584*	– 0.410	– 0.454	v.430
Oligochaeta	– 0.657*	– 0.671*	0.774**	– 0.818**	– 0.563	– 0.552	– 0.720**	0.696*	– 0.729**	– 0.721**	0.629*	0.476	0.315	– 0.807**	– 0.735**	0.837**	– 0.477	– 0.800**	– 0.630*	– 0.672*

**. Correlation is significant at the 0.01 level (2-tailed)

*. Correlation is significant at the 0.05 level (2-tailed)

Table 7 CCA biplot scores between physico-chemical parameters and macroinvertebrate species

Parameters	Reference site (S_1)		Impacted site (S_2)	
	Axis1	Axis2	Axis1	Axis2
WT	0.639	0.465	0.401	0.533
TR	– 0.865	– 0.088	– 0.575	– 0.461
WV	0.868	0.129	0.591	0.667
CON	0.507	0.437	– 0.040	0.258
TUR	0.888	0.114	0.629	0.706
TDS	0.918	0.015	0.625	0.635
pH	0.797	0.298	0.492	0.697
DO	– 0.840	– 0.263	– 0.586	– 0.672
ALK	0.825	0.312	0.499	0.634
CL	0.643	0.551	0.301	0.538
CA	– 0.856	– 0.227	– 0.643	– 0.705
MG	– 0.836	– 0.019	– 0.638	– 0.692
HA	– 0.875	– 0.123	– 0.669	– 0.729
NI	0.848	0.157	0.414	0.469
PHO	0.851	0.193	0.447	0.703
SUL	0.903	0.190	0.491	0.522
Na	0.844	0.243	0.557	0.671
K	0.828	0.173	0.461	0.872
CM	0.855	0.179	0.449	0.623
FM	0.884	0.088	0.584	0.628
Eigenvalue	0.120	0.085	0.163	0.116
Percentage of Variance	32.950	23.400	28.360	20.080
p value	0.521	0.398	28.360	20.080

whereas the lowest transparency (0 m) was recorded at site S2.

Conductivity expresses the ability of water to carry electric current (Shinde et al. 2011). It is straightforwardly connected with turbidity and all-out broken down solids (TDS). More of the value of dissolved solids will be particles or ions in water (Bhatt et al. 1999; Sharma et al. 2018; Bisht et al. 2018; Kumar and Sharma 2019). The highest conductivity (0.667 mS cm^{-1}) was recorded at site S_2 whereas the lowest conductivity (0.372 mS cm^{-1}) was recorded at site S_1. The conductivity was found within the range from 0.372 mS. cm^{-1} to 0.667 mS cm^{-1}. A similar range of conductivity was reported by Rani et al. (2011) for the rivers of the middle Gangetic plains of India. Higher values of Calcium and hardness were recorded in the Baldi River due to the presence of a high amount of calcareous rocks. The overall high calcium hardness values are a direct attribute of calcium-rich rocks (Hynes 1971). As compared to the concentration of calcium, a low concentration of magnesium was recorded in the Baldi River. A similar observation was reported by Jafari et al. (2011) in the Haraz River of Iran and Rawat et al. (2018) in the Garhwal Himalayan river of India. The water of the Baldi River was alkaline in nature during the period of study. This kind of alkaline nature of water was also reported by Ali (2010) in the Greater Zab River of Iraq. This might be because of the presence of a great measure of calcareous rocks in the Baldi River. Regular water is generally basic with high pH because of the presence of carbonate rocks in high amounts (Ormerod et al.1990; Todd 1995).

Higher values of CPOM (23.04 g.L^{-1}) and FPOM (14.73 g.L^{-1}) were recorded at site S2 than at site S1. High nitrates and phosphates were also recorded at site S2. It may be because of anthropogenic or human exercises at the location. High concentrations of nitrates and phosphates showed the negative or harmful impacts of human activities and surface or agricultural runoffs (Kannel et al. 2007). Potassium and sodium showed sporadic conveyance in the Baldi River. The presence of high concentrations of potassium and sodium in the Himalayan Rivers has been reported due to weathering of rocks (Seth et al. 2016). A higher concentration of sulfates was also recorded at site S2 at the Baldi River. It may be due to the presence of a huge amount of sulfur compounds, the geology of the river bed, and several anthropogenic activities (Shinde et al. 2011).

Macroinvertebrate abundance and composition

Macroinvertebrate assemblages vary with the types of substrate. For example, the biodiversity of the macroinvertebrate is found to be the minimum in fluid mud and sand and the maximum in stable cobble and gravel beds (Beauger et al. 2006). Therefore, substrate stability plays a major role in the presence of the maximum diversity and abundance of species (Hynes 1971; Scarsbrook and Townsend 1993; Death and Winterbourn 1995). During the study period, the maximum macroinvertebrate density (276 ind.m^{-2}) was recorded at site S1 whereas, it was recorded as minimum (207 ind.m^{-2}) at site S2. The presence of stable cobbles and gravels bed at site S1 may be the reason for higher macroinvertebrate density at the site. Multiple anthropogenic activities at site S2 also led to habitat destruction of macroinvertebrates. In the current study, minimum densities of macroinvertebrate were recorded during the monsoon period due to maximum anthropogenic disturbances. Similar observations were also reported by Negi and Mamgain (2013) for the Tons River in the Doon Valley of Uttarakhand in India. The Baldi River is flooded during the monsoon season and is disturbed highly due to high loads of debris from the riparian zone coming into the river by runoff. The order Ephemeroptera is considered an important representative of macroinvertebrates in the fluvial ecosystem. The presence of the members of Ephemeroptera plays a crucial role in assessing the health of the aquatic biodiversity of rivers (Dolisy and Dohet 2003). The abundance of Ephemeroptera was found to be dominant at site S1 in the present study. The presence of species of Ephemeroptera at a particular site is considered to be a relatively cleaner site because they are sensitive to environmental stresses (Merritt and Cummins 1978).

Macroinvertebrates show the cumulative impact of pollution and help with the study of habitat loss in an aquatic ecosystem. Macroinvertebrates act as cleansers as well as nutrient recyclers in a food web of a stream. They decompose organic matter and make the nutrients available for living organisms available in an aquatic ecosystem at different trophic levels. In the Baldi River, macroinvertebrates performed various activities including their use as bioindicators to represent the health status of a water body.

We studied the density and diversity of macroinvertebrates along with various biotic indices to generate baseline information for the Baldi River. Density and diversity help in the determination of variation among the macroinvertebrates, whereas calculation of biotic indices helps in the water quality assessment. During the current study, the standard methodology outlined in Needham and Needham (1962); Kumar, and Khanna (1984); Elliott et al. (1988); APHA (2012); and Kumar et al. (2021) were followed. CCA plots and Pearson correlation coefficient between the concentration of physico-chemical parameters and macroinvertebrates showed how biotic and abiotic factors affect each other.

Diversity indices

Diversity indices are considered to be a good indicator of pollution levels in an aquatic ecosystem (Chughtai et al. 2011). Shannon–Wiener diversity index value greater than 3 indicates clean water. A value within the range of 1–3 indicates moderately polluted water conditions whereas, a value that is less than 1 indicates heavily polluted water conditions (Wilhm and Dorris 1968; Masson1998; Chughtai et al. 2011). The Shannon–Wiener diversity index has been calculated as the lowest (2.599) for site S2, whereas it has been calculated as the highest (2.836) for site S1 indicating the anthropogenic impacts at site S2. Simpson diversity index ranged between 0 and 1, where values close to 0 indicate the least evenly distributed communities and values close to 1 show the most evenly distributed communities indicating less pollution levels (Thakur et al. 2013). Simpson diversity index in Baldi River was recorded between 0.936 and 0.916 indicating less pollution in Baldi River. If the recorded value of the Margalef index is more than 3 then it indicates clean water and if the recorded values are less than 3 then it indicates polluted water (Margalef 1958; Thakur et al. 2013). The Lower Margalef index value (2.802) calculated at site S2 reflected pollution at the impacted site. Higher values of diversity indices at site S1 and lower values at site S2 clearly indicated the various anthropogenic disturbances at site S2 that contributed to the degradation of water quality.

The percentage of EPT was found higher at site S1 (52.11%) than at site S2 (47.91%). Moskova (2008) stated that high values of EPT scores are indicators of good water quality, its lower values are indicators of poor or deterioration in water quality. According to Czerniawska-Kusza (2005), the BMWP scores vary from undisturbed to highly disturbed sites. The BMWP score calculated for both the sampling sites varied. It was recorded the maximum (78.08) at site S1 and a minimum (65.33) at site S2. These values also indicate anthropogenic disturbances at site S2. A similar kind of observation was also reported by Varnosfaderany et al. (2010) for the Zayandeh-Rud River of Iran. A higher ASPT score was found at site S1 than at site S2 in the Baldi River which is a clear indication of anthropogenic disturbances at site S2.

Statistical correlation between macroinvertebrate and physico-chemical attributes

The CCA biplots showed a significant relationship between macroinvertebrates species and physico-chemical parameters recorded at both the sampling sites [(S1: Fig. 3); (S2: Fig. 4)]. *Hydroptila* sp., *Perla* sp., *Limnephilus* sp., and *Baetis niger* were found to have a positive correlation with axis 1 at site S1. *Gyraulus convexiusculus* distribution was affected by turbidity, TDS, pH, and alkalinity. Conductivity and water temperature affected the distribution of *Hydaticus fabricii*. The distribution of *Onychogomphus bistrigatus* was affected by hardness, calcium, and magnesium at site S2. Conductivity also affected the distribution of *Ceriagrion coromandelianum* and *Perla* sp. Chironomids were influenced by dissolved oxygen and turbidity. *Taeniopteryx* sp. showed a strong influence against the physico-chemical parameters at site S2. Macroinvertebrate density has a negative correlation with water velocity and turbidity. A similar relationship was reported by Semwal and Akolkar (2006) for the Dhauliganga River of Uttarakhand in India. Macroinvertebrate density has a positive correlation ($p < 0.01$) with dissolved oxygen and transparency. Similar findings were reported from the Tons River, Doon Valley (Negi and Mamgain, 2013). ETP species have a positive correlation with transparency, dissolved oxygen, hardness, and sodium ($p < 0.01$). The same relationship was reported in River Yamuna (Ishaq and Khan 2013b).

Physico-chemical attributes have significantly influenced the distribution and density of macroinvertebrates at site S2. The anthropogenic pressure at site S2 resulted in the reduction of water quality and diversity of macroinvertebrate species. A similar finding was reported by Shrestha et al. (2008) for downstream sites of the Bagmati River in Nepal. During the current study, densities of Rhyacophilidae, Heptageniidae, and Baetidae were recorded higher at site S1

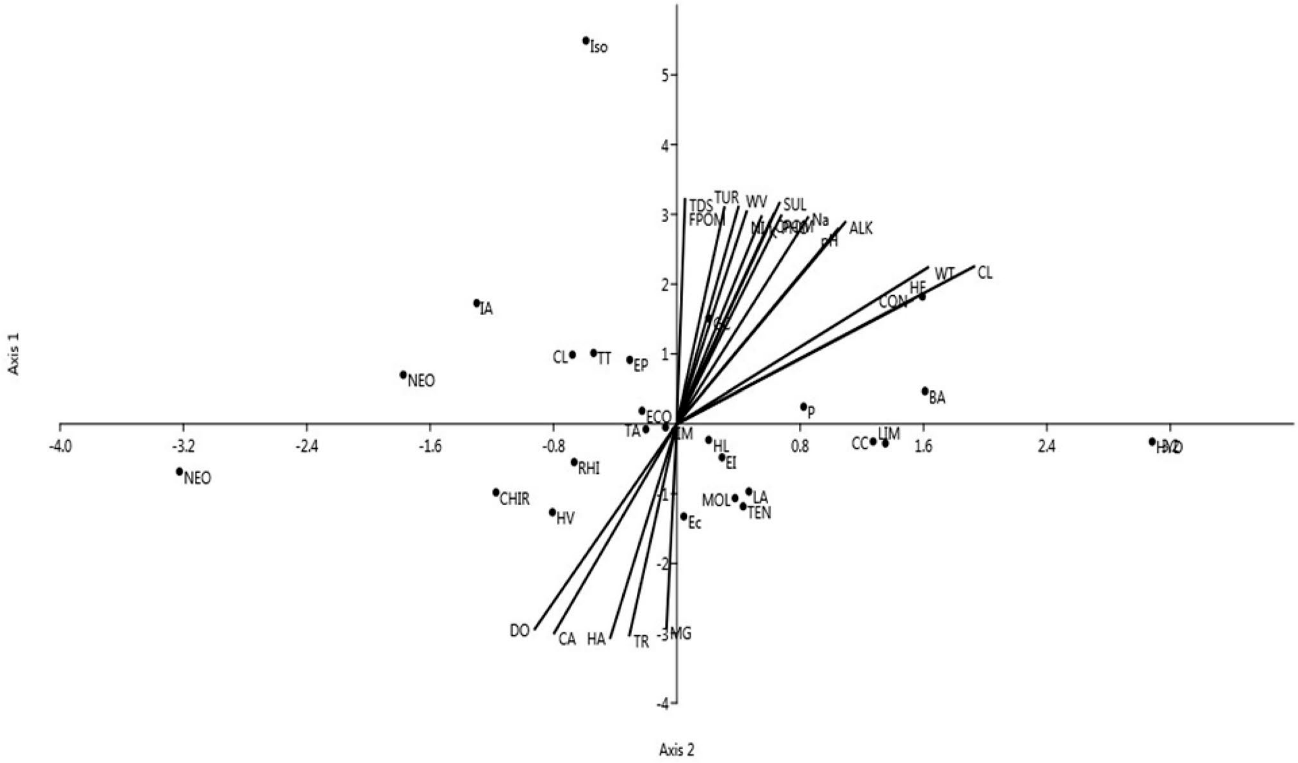

Fig. 3 Canonical correspondence analysis (CCA) biplot between physico-chemical attributes and macroinvertebrate species at reference site (S1)

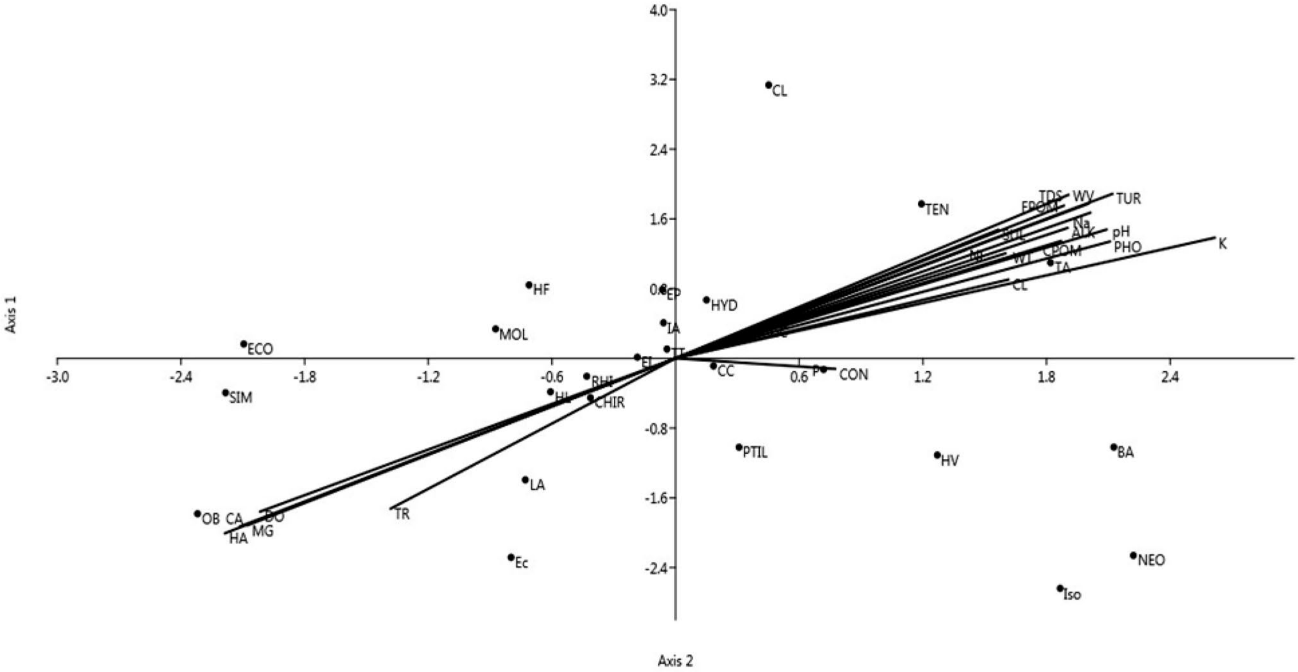

Fig. 4 Canonical correspondence analysis (CCA) biplot between physico-chemical attributes and macroinvertebrate species at impacted site (S2)

as compared to site S2. A higher density of Chironomidae was recorded at site S2. This may be due to the fact that Rhyacophilidae, Hepatageniidae, and Baetidae prefer rocky bottom substratum like boulders and cobbles; whereas Chironomidae prefers silt and clay (Aagoard et al. 2004). River Baldi is the only source of water for the people to fulfill their daily needs including cooking, bathing, drinking, and various other activities. Therefore, anthropogenic pressure is considerably at site S2. The macroinvertebrate population in streams and rivers helps the researchers and various other authorities to assess the overall health of an aquatic body (Carlisle and Meador 2007). The current study on the Baldi River clearly revealed that the upstream site (S1) was in good health condition as compared to the downstream site (S2). Various anthropogenic stresses result in the degradation of water quality and depletion of the density of EPT at site S2.

Future outlook

The present research work will provide baseline information about the ecological diversity for the biomonitoring of the Baldi River. It will also help in the proper management of the ecosystem. The recorded observations would also help in the identification of potential keystone species and also support the determination of the nutrient cycle as well as the energy flow within the Baldi River. The current study observed an interrelationship between biotic and abiotic factors that may help in the reduction of anthropogenic pressure along with the fluvial ecosystem of the Baldi River. The current study has some key limitations including the tough sampling procedure of macroinvertebrates during the monsoon period (rainy season). It was hard to sample because of heavy runoff and increased macroinvertebrate drift. It is very challenging to find out a specific keystone species during the study period. It is because the macroinvertebrates perform in groups to maintain the functionality of a fluvial ecosystem.

Conclusion

The macroinvertebrate community of headwater stream Baldi was highly diverse in nature and greatly influenced by physico-chemical attributes. 29 genera from 8 orders of macroinvertebrate were recorded during the study period. Diversity indices also reflected the diverse nature of macroinvertebrates. Some of the stretches of the Baldi River are highly disturbed due to anthropogenic stress. Therefore, the impact of this stress was assessed. The water quality of Baldi River at reference site (S1) was found good in condition with the dominance of EPT species whereas, the impacted site (S2) was degraded with a low percentage of EPT. Biotic indices also revealed that site S2 was disturbed and polluted as compared to site S1. The BMWP and ASPT scores supported this assessment. Anthropogenic activities result in the degradation of water quality and depletion of the population of macroinvertebrates. The current study provides an assessment of the health of the fluvial ecosystem of the River Baldi through the assessment of macroinvertebrates. It can further be used for biomonitoring of the river that can help the responsible authorities in its management and conservation.

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Declarations

Conflict of interest The authors have declared that no competing interests exist.

Consent to participate All authors voluntarily agree to participate in this research study.

Consent to publish All authors voluntarily approved the publication of this research study.

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