Journal of Applied and Natural Science
15(1), 262 - 272 (2023)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Factors affecting the ecological habitat of Benthic macro-invertebrate assemblages in Asan wetland, Dehradun in Garhwal Himalaya

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Article Info
https://doi.org/10.31018/jans.v15i1.4222
Received: November 18, 2022
Revised: February 9, 2023
Accepted: February 17, 2023

How to Cite
Malik, D. S. *et al.* (2023). Factors affecting the ecological habitat of Benthic macro-invertebrate assemblages in Asan wetland, Dehradun in Garhwal Himalaya. *Journal of Applied and Natural Science*, 15(1), 262 - 272. https://doi.org/10.31018/jans.v15i1.4222

Abstract
The Himalayan region has several freshwater resources, such as rivers, lakes, and wetlands. These freshwater resources have been adversely affected by environmental factors. Freshwater biological systems are defenseless against outcomes of environmental changes that might prompt the irreversible disintegration of these natural surroundings. The present study aimed to investigate the effect of biotic and abiotic factors on the Benthic macro-invertebrate assemblages of the Asan wetland, Dehradun in Garhwal Himalaya. A determination of the physico-chemical health status of the Asan wetland viz., electrical conductivity (EC), total dissolved solids (TDS), biochemical oxygen demand (BOD), and nutrients parameters like nitrogen, potassium, and phosphorus were investigated during this study. Three sampling sites (Site 1, Site 2 and Site 3) of wetland were selected and the water samples were collected seasonally, i.e., summer, winter, and monsoon from April 2021-March 2022. Maximum values of EC(163.75 µS/cm), TDS (232.78 (mg/l), alkalinity (141.20 mg/l) and pH(7.8) were recorded in the monsoon season (June-September) and minimum values of EC(135.80µS/cm), TDS (196.80 (mg/l), alkalinity (119.80mg/l) and pH(7.2) were recorded in the winter season (November–February). An overall total of 18 macrobenthos genera belonging to four classes was identified. Maximum communities of macrobenthos were observed during the winter and minimum communities during the monsoon season. Canonical correspondence analysis (CCA) was used to determine whether microbenthic genera and habitat ecological parameters and showed a positive or negative correlation. Thus, the present study contributed to the status of various factors and their impacts on the Benthic macro-invertebrate structure of the Asan wetland.

Keywords: Asan wetland, Abundance, Canonical correspondence analysis, Diversity indices, Macroinvertebrate

INTRODUCTION

The wetlands are known for their dynamic nature on the surface of the earth, and their biodiversity is greatly affected by their genesis, topography, water regime and chemistry, dominant species, sediments, and soil characteristics. The role of wetlands is to regulate the hydrological cycle, maintain the water quality, move the nutrient cycles and support tropic food chains (Sarkar and Upadhyay, 2013; Pramod *et al.,* 2011; Malik *et al.,* 2020a). A diverse number of living organisms like animals, plants, and other organisms are present in wetlands, and their survival depends upon their habitat's existence. These wetlands are continuously polluted by undesirable pollutants released due to anthropogenic activities, industrial effluents, the influx of organic and inorganic nutrients, and recreational activities. Because these properties affect the habitat ecology of aquatic biota, it is important to understand better their physico-chemical properties (Kumar *et al.,* 2018).

Macroinvertebrates and water quality are interrelated, as they are sensitive and show quick responses to both anthropogenic and natural changes in the ecological characteristics of wetlands (Kumar *et al.,* 2018). Macroinvertebrates are essential to aquatic communities in lentic ecosystems. They are primary consumers of pollutants, dispersers, and secondary producers in aquatic ecosystems and play a crucial role in the aquatic food chain (Nautiyal, 2010; Amar *et al.,* 2011; Aswathy *et al.,* 2021) when the impact of contamination analyzed in nature the community assemblage structure is assessed at the point. For instance, macroinvertebrate gatherings' abundance, richness, and evenness have been regularly analyzed in water-quality examinations for a long time. Furthermore, underlying attributes and numerous practical methodologies that assess life-history qualities (species characteristics) are additionally utilized in biomonitoring (Carter *et al.,* 2017).

The abundance and distribution of macroinvertebrates vary greatly depending on their habitat characteristics and substratum since they are limited in mobility and live a near-sedentary lifestyle. Thus, understanding macroinvertebrate relationships is crucial to understanding aquatic community integrity, particularly in habitat degradation (Mishra and Nautiyal, 2016, Buss *et al.,* 2002). Consequently, understanding macroinvertebrate relationships is essential to understanding the integrity of aquatic communities in general and habitat degradation in particular. The density and diversity of the benthic organisms depend upon the physicochemical properties of water, soil, and the biological component of the ecosystem (Ramesh *et al.,* 2016). According to aquatic ecologists, wetland indicators include certain macroinvertebrates that respond to specific changes in water conditions. It is possible to determine the pollution level by analyzing macroinvertebrates using physico-chemical methods. Water quality in Indian wetlands is declining, which is a serious concern. It is particularly alarming when water quality changes occur in small water bodies such as lakes, tanks, and ponds because of agricultural runoff and sewage discharge from urban areas. As a result of urbanization and land use changes, wetlands absorb more nitrified, sedimented, and adsorbable pollutants, and then they can recycle through nitrification, sedimentation, and adsorption (Kumar *et al.,* 2018). Shah and Islam (2021) stated that the wetland is in danger primarily due to a number of anthropogenic stresses with the aid of growing population, encroachment, home and growing agricultural practices using nearby inhabitants. Besides, tourism intervention additionally leads to combined results that may provide additionally both advantages to the communities or degrade the ecosystem. Meleddu (2014) highlighted the fine and poor externalities of tourism on the freshwater ecosystem. Few reports on the benthic macro-invertebrate in Asan wetland are available. However, some scattered reports on the benthic macro-invertebrate in Asan wetland (Mishra and Nautiyal, 2016) are available and there is a need for an overall comprehensive study of macro-invertebrate assemblages of Asan wetland. Therefore, keeping this in view, the present study aimed to assess the factors affecting the ecological habitat of benthic macro-invertebrate assemblages of Asan wetland, Dehradun.

MATERIALS AND METHODS

Study area

Asan wetland, located on a major national highway (NH 72), is now known as the Asan conservation reserve. In 1967, a barrage was constructed at the confluence of the Asan River and the outlet channel of the Dhalipur power station to create the reservoir. Located in the Doon valley in the central Himalayas, the barrage is 287.5m long and falls at 30°25'26 N and 77°40'41 E. It has a net geographical area of 3.2 Sq. km. At the confluence of the Yamuna River and Asan River, the Asan wetland represented a typical wetland habitat. A dense Sal Forest of the Tamil Range surrounds the Asan wetland, along with cultivated and pastured land, Rampur Forest Block, mixed forests, and irrigation department land. The wetland is made up of both shallow and deep-water areas. On the western side of the wetland, there is a 287.5 m long barrage. The total catchment area of the wetland is Sq.1600 km, with the Asan River and Yamuna River contributing to its size. Asan wetland is one of the most important biodiversity hotspots in the Doon valley and sensitive ecological habitat. Fig. 1 illustrates selected sampling sites in the Asan wetland of Doon valley.

Sampling sites

Asan wetland was divided into three different sampling sites as shown in Table 1. Due to changes in the stagnant water quality of the wetland, seasonal sampling was done from all three sampling stations to analyze the physico-chemical parameters of the water samples and macroinvertebrates benthos. To analyze environmental variables, water samples were collected from the upper water surface using craft water sampling bottles on a seasonal basis (April 2021-March 2022). A centigrade thermometer was used to record water temperature (WT). The pH meter (HI98107) was used to determine the pH of the water. A Hanna Multi-Parameter Analyzer (HI1288) was used to measure the electrical conductivity (EC) and total dissolved solids (TDS) of samples. APHA (2012) and Trivedi and Goel (1996) provided standard methods for measuring alkalinity, dissolved oxygen (DO), biochemical oxygen demand (BOD), and chloride using titration techniques. The nitrogen (Kjeldahl method) using Systronics Spectrophotometer (118 UV-VIS), potassium (UV Spectrophotometric method), and phosphorus (Colorimetric) were measured. The correlation of physico-chemical parameters and benthos genera was calculated using MS Excel (2007). The hand nets were used and a sieve

Fig. 1. *Showing sampling zones of the study area of Asan wetland, Dehradun Source (Google map)*

with a mesh size of 250 m was used to collect benthos (macroinvertebrates) at different sites (Hauer and Lamberti, 1996). All macroinvertebrate samples were preserved in 10% formalin. A microscope from Olympus (CH 20i) was used to identify and count benthic macroinvertebrates (10X magnifying power of the lens of the microscope). Based on standard keys and a field guide, Wetzel and Likens (2000); Mandaeville (2002); Subramanian and Sivaramakrishanan (2007) and Picker *et al.* (2003) identified macroinvertebrates to genera level only. The abundance of invertebrates at each sampling site was recorded.

Benthos diversity indices

To estimate the composition of micro invertebrate benthos, taxa richness, and evenness of micro invertebrate benthos, five biological diversity indices were applied using Microsoft Excel (2007).

Using Berger-Parker's Index, the dominance of Benthos taxa was calculated

D= N max/N …….Eq. 1

Where N max= density of most dominant taxa,
N= density of all taxa.

The Shannon-Weiner's index of diversity was calculated according to the formula:

H'= (Σpi in pi) …... Eq. 2

Where, pi= n/N
n= No. of individual's taxa
N = total density of all micro invertebrate benthos organisms

Evenness was determined using the formula;

E1= H1/in S ….. Eq. 3

Where H1= species diversity; S= taxa richness

Statistical analysis

Karl Pearson's correlation

This study used Pearson's correlation coefficient to determine the relationship between habitat parameters and benthos groups in the Asan wetland. The correlation coefficient was calculated using Microsoft Excel (2013).

Conical correspondence analysis (CCA)

The influence of water quality variables on zooplankton taxon were determined by conical correspondence analysis using Microsoft XLstat and PAST version 3.06. As part of the canonical correspondence analysis (CCA), five environmental variables, WT, EC, DO, N and Cl were chosen to determine the relationship between benthos assemblages and water and water quality. P values (0.05) for graphic representation among benthos genera and physico-chemical charateristics of Asan wetland were considered for statistical significance.

RESULTS AND DISCUSSION

Physico-chemical characteristics of water

The mean values and standard deviations of different physico-chemical parameters of the Asan wetland are given in Table 2.

Aquatic biota suffers stress during high summer temperatures due to the inability of water to retain vital dissolved gases such as oxygen, resulting in massive plankton deaths. In the summer, the WT was highest (20.7±1.180c), while in the winter, it was lowest (16.5±1.96 ^{0}c). Across all selected sampling sites, a similar pattern was observed due to the ambient environmental conditions. This could be attributed to an increase in solar radiation, a lower water level, a clear atmosphere, and a high atmospheric temperature. A surrounding cold temperature and a shorter photoperiod led to the lowest water temperature. Bhat *et al.* (2017) also observed the same range of water temprature while working on the Asan wetland.

pH is one of the most important parameters as it governs most of the chemical reactions that take place in soil and water. High or low pH values may harm their health, and many living biotas may die. The pH of the collected water was revealed to be slightly alkaline at all the sites. Maximum pH (7.80±0.18) was recorded in the monsoon season and minimum (7.23±0.10) in the winter season. Thus, there was an insignificant change in the pH. Mishra *et al.* (2020) also observed maximum pH in the monsoon season in Suswa and Tawa streams in Doon valley river ecosystem.

As a measurement of total dissolved solids, electrical conductivity reached its highest value (163.75±6.70 µS/cm) during the monsoon season and its lowest value (135.80±12.45 µS/cm) was during the winter season. Similar patterns were observed at all sampling sites. EC was closely related to TDS. The more the value of TDS more was the value of EC. The more salt dissolved in water, the higher the EC value.The lowest value of TDS (196.80±14.88 mg/l) was in the winter season and monsoon was the year with the highest (232.78±6.33 mg/l) TDS. During the monsoon season, alkalinity was highest (141.20±3.26 mg/l), and during the winter season, it was lowest (119.80±14.88 mg/l). A similar seasonal pattern for the above parameters in the Tehri reservoir of the Garhwal region has been reported by Ayoade and Agarwal (2012) and Malik *et al.* (2021). The high value of TDS in wetland was runoff from the catchments basin and another is a heavy load of tourists in other seasons than in winter.

DO plays an important role in aquatic life. Its relationship with water bodies provides both direct and indirect information on bacterial activity, photosynthesis, nutrient availability and stratification (Premlata, 2009, Malik *et al.,* 2021). DO concentrations were found to be lowest (7.75±0.13 mg/l) during monsoons and maximum (9.23±0.51 mg/l) during the winter season. The higher concentration of dissolved oxygen was recorded during winter due to higher oxygen solubility at lower temperatures, favoring retention of oxygen reported by (Rani *et al.,* 2011; Malik *et al.,* 2020b). A similar pattern was observed in all selected sites. The highest value of BOD (2.6±0.18 mg/l) was observed in the monsoon season and the lowest value (1.4±0.49 mg/l) was observed in the winter season. An almost similar pattern of BOD during the previous years was observed at selected sampling sites by Bhat *et al.* (2017) in the Asan wetland.

Nitrogenous fertilizers are the main source of nitrate in the wetland, the maximum concentration of nitrogen (2.07±0.12 mg/l) was in the monsoon season at site 1 and the minimum concentration of nitrogen (1.37±0.17 mg/l) was in the winter season at site 2. Maximum potassium concentration (0.82±0.10 mg/l) was recorded in the monsoon season at site 1 and minimum (0.45±0.16 mg/l) in the winter season at site 2. The maximum concentration of phosphorous (0.62±0.05 mg/l) was in the monsoon season at site 1 and the minimum (0.41±0.03 mg/l) in the winter at site 2. The higher or lower chloride concentration might be attributed to its geographical origin. The values of chloride concentration in the present study were recorded to be maximum (0.93±0.04 mg/l) in the monsoon season and minimum (0.74±0.06 mg/l) in the winter season. A similar pattern was in all selected sampling sites. In many studies, water runoff from agricultural lands, forests, and pastures has significantly increased the concentrations of nutrients and organic matter in lotic ecosystems (Yang *et al.,* 2010; Steffen *et al.,* 2013, Sharma *et al.,* 2022). All parameters studied with the mean value of data with standard deviation are given in Table 2.

Benthic community of Asan wetland

The density and diversity of macroinvertebrate taxa are summarized in Table. 3. The composition of benthic macroinvertebrates varied seasonally. The benthic fauna consisted of 18 invertebrate taxa. Clitellata was the group with the highest species richness, represented by 9 taxa followed by Gastropoda, which included 4 taxa, Bivalvia included 2 taxa, and Insecta included 3 taxa. Thus, the Clitellata was the dominant class among them in all seasons. The seasonal variation in the percentage composition of the benthos group is shown in

Table 1. Selected sampling zones with their geo-coordinates

S. No.	Sampling sites	Description	Geo- coordinates	Elevation
1.	Site 1	Confluence of reservoir and Yamuna canal	30º26’09.34” N 77º40’28.68” E	402 m
2.	Site 2	Asan Barrage bird sanctuary	30º26’09.85” N 77º39’56.50” E	398 m
3.	Site 3	GMVN Asan conservation resort	30º26’22.30” N 77º40’08.68” E	403 m

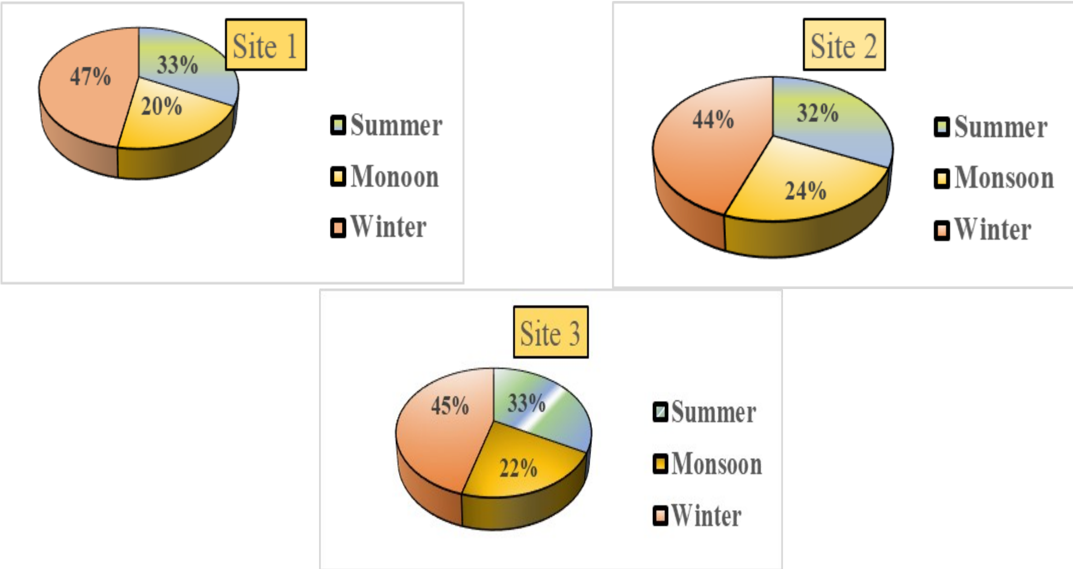

Fig. 2. *Percentage composition of macro benthic community in different seasons at selected sampling sites during 2021-2022*

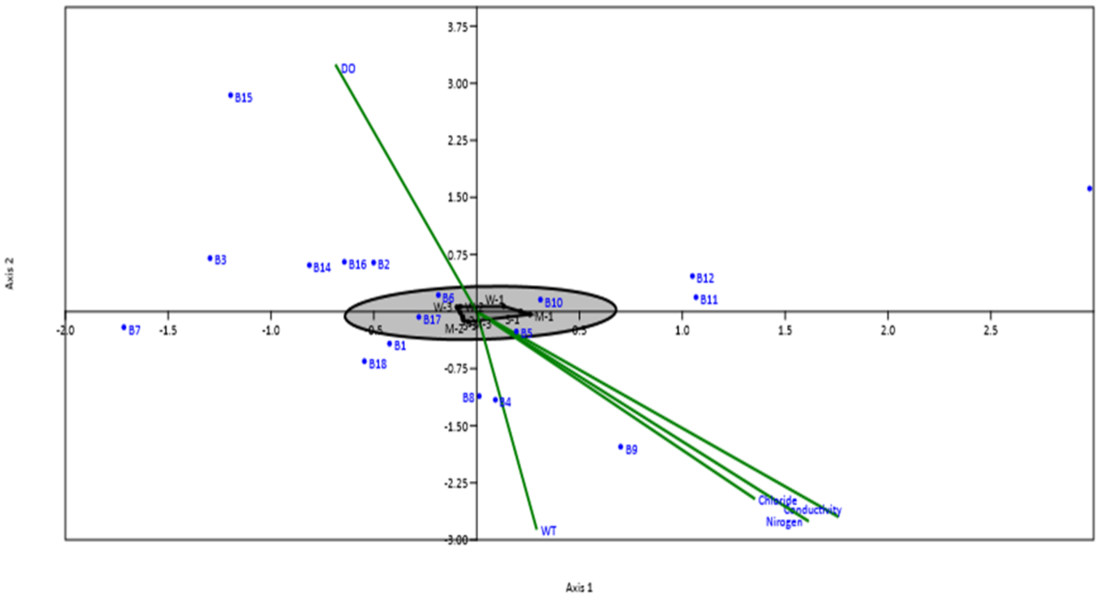

Fig. 3. *CCA biplot showing the seasonal variation between benthos genera and Physicochemical parameters at Asan wetland (B1: Amynthas sp; B2: Metaphire sp; B3: Perionyx sp; B4: Tubifex sp; B5: Limnodrillus sp; B6: Poecilobdella sp; B7: Poecilobdella sp; B8: Helobdella sp; B9: Hirudineria sp; B10: Bellamya sp; B11: Gabbia sp; B12: Lymnaea sp; B13: Gyraulus sp; B14: Parreysia sp; B15: Sphaerium sp; B16: Dineutes sp; B17: Hydaticus sp; B18: Cybister sp.*

Fig. 2. The maximum density (492 ind/m^2) was in the winter season at site 2, and the minimum density (170 ind/m^2) in the monsoon season at site 1. Bhat *et al.* (2017) also observed the maximum density of macroinvertebrates in the winter while working on Asan wetland. Malik *et al.* (2020a) have also noted the maximum diversity of macroinvertebrates during the studies in the river Ganga and its tributaries.

Statistical and indices analysis

Diversity indices

An ecosystem's diversity is measured using Simpson's diversity index, which takes into account the number of species present in a particular habitat region. According to the benthos diversity indices shown in Table 4, site 2 had the highest number of individuals, followed by site 3 and then site 1. At site 2, the Simpson index reached its maximum value (0.943) during the winter and its minimum value (0.935) during the monsoon season. The analysis of the Shannon index was done as per the classification scheme of Fernando *et al.* (1998). These diversity index values in Asan wetland ranged from 2.802 in the monsoon to 2.865 in the winter. As per the results shown in Table 9 and Table 4, the values of the index indicate that Asan wetland supported moderate to high benthic diversity. (Table 9). The higher value of the Shannon-wiener index (H') indicated a greater diversity of species. This means a more extensive food chain and greater inter-specific interactions, which can be controlled by negative feedback decreasing oscillations and improving community stability (Ludwick and Reynold 1998). Mishra *et al.* (2020) have also reported the moderate to high value of Shannon index while studying the Suswa and Tawa streams in Doon valley river ecosystem.

Karl pearson's correlation coefficient

A degree of co-relationship between the habitat ecology characteristics of water and benthos in Asan wetland was calculated and presented in (Tables 5 to 7). At site 1, the relationship between WT and DO (-0.906), Oligochaeta (-0.851), Hirudinea (-0.844), Gastropoda (-0.846), Bivalvia (-0.886), Insect (-0.857) was significantly negative and showed an increase or decrease in values of WT. The values of DO and benthic groups also exhibited a decrease or increase in their values and showed a significant positive correlation with BOD (0.940) and other parameters. pH showed a significant negative correlation with DO (-0.971), Oligochaeta (-0.992), Hirudinea (-0.994), Gastropoda (-0.993), Bivalvia (-0981), Insecta (-0.990) and positive correlation with BOD (0.946), TDS (0.954) and with all nutrients. EC showed a negative correlation with DO (-0.970), Oligochaeta (0.992), Hirudinea (-0.994), Gastropoda (-0.993), Bivalvia (-0.980), Insect (-0.990) and positive correlation with TDS (0.954), BOD (0.945) and with all nutrients. TDS showed a significant negative correlation with DO (-0.854), Oligochaeta (-0.909), Hirudinea (-0.914), Gastropoda (-0.913), Bivalvia (-0.877), Insect (-0.904). DO showed a negative correlation BOD (-0.996) and with all nutrients and a positive correlation with Oligochaeta (0.993), Hirudinea (0.992), Gastropoda (0.992), Bivalvia (0.999) and Insect (0.995). BOD showed a negative correlation with Oligochaeta (-0.979), Hirudinea (-0.976), Gastropoda (-0.977), Bivalvia (-0.991) and Insecta (0.981). All nutrients showed a negative correlation with the benthic group and all the benthic groups showed a positive correlation with each other. The same pattern of correlation coefficients was among all the selected sampling sites. Kamboj *et al.* (2022) reported Karl pearson's correlation in their studies and observed both positive and negative correlations between different parameters while working on the river Ganga whereas, Khichi (2022) also observed similar results while working on the Narmada river.

Canonical correspondence analysis (CCA)

The Canonical Correspondence Analysis (CCA) shows the correlation between biotic and abiotic factors by

Table 2. Seasonal variation of physicochemical parameters in Asan wetland during 2021-2022

Parameters	Site 1			Site 2			Site 3		
	S	M	W	S	M	W	S	M	W
WT °C	20.2±1.14	19.9±1.06	16.5±1.96	20.5±1.12	20.1±1.13	16.7±1.92	20.7±1.18	20.3±1.26	16.9±1.88
pH	7.3±0.10	7.5±0.17	7.2±0.10	7.4±0.10	7.6±0.19	7.3±0.08	7.6±0.13	7.8±0.18	7.4±0.01
Conductivity µS/cm	151.50±7.93	163.75±6.70	142.35±11.11	142.85±4.79	153.78±4.16	135.80±12.45	147.93±6.52	160.03±6.17	138.33±12.03
TDS (mg/l)	210.65±8.53	232.78±6.33	206.83±16.09	198.70±4.54	222.78±7.48	196.80±14.88	201.50±5.97	228.03±6.50	201.65±15.12
Alkalinity (mg/l)	129.98±5.19	141.20±3.26	128.53±7.78	121.38±4.77	132.78±2.23	119.80±14.88	124.70±4.71	136.60±1.28	121.00±9.79
DO (mg/l)	8.3±0.22	7.8±0.17	9.1±0.51	8.4±0.22	8.00±0.18	9.2±0.51	8.2±0.22	7.7±0.13	9.00±0.48
BOD (mg/l)	2.3±0.17	2.6±0.18	1.6±0.49	2.1±0.17	2.4±0.18	1.4±0.49	2.2±0.17	2.5±0.18	1.5±0.49
N (mg/l)	1.75±0.20	2.07±0.12	1.55±0.23	1.55±0.20	1.92±10.17	1.37±0.17	1.65±0.20	1.97±0.12	1.45±0.23
K (mg/l)	0.64±0.11	0.82±0.10	0.51±0.16	0.62±0.11	0.76±0.10	0.45±0.16	0.63±0.07	0.80±0.07	0.48±0.16
P (mg/l)	0.51±0.03	0.62±0.05	0.44±0.04	0.43±0.02	0.52±0.01	0.41±0.03	0.46±0.02	0.52±0.09	0.42±0.03
Cl (mg/l)	0.80±0.03	0.93±04	0.78±0.08	0.74±0.03	0.89±0.03	0.73±0.06	0.76±0.02	0.92±0.04	0.76±0.06

S-Summer(March-June) ; W-Winter (November-February); M-Monsoon(July-October)

Table 3. Distribution and Abundance of benthos (ind./m^2) in sediments of shallow shoreline of Asan reservoir during March 2021 to Feb 2022

Codes	Genera/Taxa	Site 1			Site 2			Site 3		
		S	**M**	**W**	**S**	**M**	**W**	**S**	**M**	**W**
	Class Clitellata									
B1	*Amynthas* sp.	15	11	21	23	16	31	19	13	27
B2	*Metaphire* sp.	18	9	28	25	18	38	21	14	31
B3	*Perionyx* sp.	8	6	16	19	11	26	15	9	23
B4	*Tubiflex* sp.	19	12	24	18	24	33	23	15	28
B5	*Limnodrillus* sp.	24	15	31	29	19	38	27	17	35
B6	*Poecilobdella* sp.	18	9	28	23	19	33	19	14	29
B7	*Glossiphonia* sp.	8	6	16	23	15	29	18	11	25
B8	*Helobdella* sp.	19	12	24	25	19	29	21	15	28
B9	*Hirudinaria* sp.	24	15	31	27	23	31	26	19	25
	Total	**153**	**95**	**219**	**212**	**164**	**288**	**189**	**127**	**251**
	Class Gastropoda									
B10	*Bellamya* sp.	17	12	23	21	13	29	17	11	24
B11	*Gabbia* sp.	14	9	21	15	11	19	11	8	16
B12	*Lymnaea* sp.	19	12	24	19	11	25	15	9	21
B13	*Gyraulus* sp.	23	16	32	14	9	23	11	7	18
	Total	**73**	**49**	**100**	**69**	**44**	**96**	**54**	**35**	**79**
	Class Bivallvia									
B14	*Parreysia* sp.	7	4	11	12	8	16	9	5	14
B15	*Sphaerium* sp.	8	3	16	13	9	24	11	5	21
	Total	**15**	**7**	**27**	**25**	**17**	**40**	**20**	**10**	**35**
	Class Insecta									
B16	*Dineutes* sp.	11	5	16	15	11	23	13	8	19
B17	*Hydaticus* sp.	14	9	19	19	13	27	16	11	23
B18	*Cybister* sp.	8	5	15	15	11	18	11	9	14
	Total	**33**	**19**	**50**	**49**	**35**	**68**	**40**	**28**	**56**
	Grand total	**274**	**170**	**396**	**355**	**260**	**492**	**303**	**200**	**421**

S-Summer (March-June); W-Winter (November-February); M-Monsoon (July-October)

Table 4. Seasonal variation in diversity indices of benthos in Asan wetland during 2021-2022

Indices	Site 1			Site 2			Site 3		
	S	**M**	**W**	**S**	**M**	**W**	**S**	**M**	**W**
Individuals	274	170	396	355	260	492	303	200	421
Simpson_1-D	0.936	0.935	0.940	0.940	0.938	0.943	0.939	0.937	0.941
Shannon_H	2.818	2.802	2.851	2.859	2.838	2.865	2.842	2.828	2.860
Eveness_e^H/S	0.930	0.915	0.961	0.969	0.948	0.974	0.953	0.939	0.970

Table 5. Pearson correlation coefficient among physico-chemical parameters, nutrients and macro benthic parameters at site 1 during 2021-22

Parameters	WT	pH	Conductivity	TDS	DO	BOD	N	K	P	Cl	Oligo-chaeta	Hirudinea	Gastropoda	Bivalvia	insect
WT	1.000														
pH	0.778	1.000													
Conductivity	0.778	1.000	1.000												
TDS	0.554	0.954	0.954	1.000											
DO	-0.906	-0.971	-0.970	-0.854	1.000										
BOD	0.940	0.946	0.945	0.805	-0.996	1.000									
N	0.746	0.999	0.999	0.968	-0.957	0.928	1.000								
K	0.772	1.000	1.000	0.957	-0.968	0.942	0.999	1.000							
P	0.749	0.999	0.999	0.967	-0.959	0.930	1.000	0.999	1.000						
Cl	0.543	0.950	0.950	1.000	-0.847	0.797	0.964	0.953	0.963	1.000					
Oligochaeta	-0.851	-0.992	-0.992	-0.909	0.993	-0.979	-0.985	-0.991	-0.985	-0.903	1.000				
Hirudinea	-0.844	-0.994	-0.994	-0.914	0.992	-0.976	-0.987	-0.992	-0.988	-0.909	1.000	1.000			
Gastropoda	-0.846	-0.993	-0.993	-0.913	0.992	-0.977	-0.986	-0.992	-0.987	-0.907	1.000	1.000	1.000		
Bivalvia	-0.886	-0.981	-0.980	-0.877	0.999	-0.991	-0.970	-0.978	-0.971	-0.870	0.997	0.996	0.997	1.000	
Insect	-0.857	-0.990	-0.990	-0.904	0.995	-0.981	-0.982	-0.989	-0.983	-0.898	1.000	1.000	1.000	0.998	1.000

Table 6. Pearson correlation coefficient among physico-chemical parameters, nutrients and macro benthic parameters at site 2 during 2021-22

Parameters	WT	pH	Conduc-tivity	TDS	DO	BOD	Nitrogen	Potassi-um	Phospho-rus	Chloride	Oligo-chaeta	Hirudinea	Gastropoda	Bivalvia	insect
WT	**1.000**														
pH	0.783	1.000													
Conductivity	0.736	0.997	1.000												
TDS	0.474	0.919	0.945	1.000											
DO	-0.902	-0.975	-0.957	-0.808	1.000										
BOD	0.932	0.955	0.931	0.760	-0.997	1.000									
N	0.685	0.990	0.997	0.966	-0.933	0.902	1.000								
K	0.845	0.994	0.984	0.871	-0.993	0.981	0.968	1.000							
P	0.564	0.955	0.974	0.994	-0.866	0.825	0.988	0.918	1.000						
Cl	0.415	0.891	0.921	0.998	-0.768	0.716	0.947	0.837	0.985	1.000					
Oligochaeta	-0.909	-0.971	-0.951	-0.797	1.000	-0.998	-0.926	-0.991	-0.857	-0.756	1.000				
Hirudinea	-0.828	-0.997	-0.989	-0.886	0.989	-0.975	-0.975	-1.000	-0.930	-0.853	0.986	1.000			
Gastropoda	-0.827	-0.997	-0.989	-0.887	0.989	-0.974	-0.976	-0.999	-0.931	-0.855	0.986	1.000	1.000		
Bivalvia	-0.902	-0.974	-0.956	-0.807	1.000	-0.997	-0.932	-0.993	-0.865	-0.766	1.000	0.989	0.989	1.000	
Insect	-0.862	-0.990	-0.978	-0.855	0.996	-0.987	-0.960	-1.000	-0.905	-0.819	0.995	0.998	0.998	0.996	1.000

Table 7. Pearson correlation coefficient among physico-chemical parameters, nutrients and macro benthic parameters at site 3 during 2021-22

Parameters	WT	pH	Conductivity	TDS	DO	BOD	Nitrogen	Potassium	Phosphorus	Chloride	Oligochaeta	Hirudinea	Gastropoda	Bivalvia	insect
WT	1.000														
pH	0.889	1.000													
Conductivity	0.774	0.978	1.000												
TDS	0.410	0.783	0.895	1.000											
DO	-0.884	-1.000	-0.980	-0.789	1.000										
BOD	0.932	0.994	0.951	0.713	-0.993	1.000									
N	0.730	0.962	0.998	0.923	-0.965	0.928	1.000								
K	0.793	0.984	1.000	0.881	-0.986	0.960	0.995	1.000							
P	-0.581	-0.143	0.066	0.504	0.133	-0.246	0.132	0.036	1.000						
Cl	0.415	0.786	0.897	1.000	-0.792	0.716	0.924	0.883	0.500	1.000					
Oligochaeta	-0.823	-0.992	-0.997	-0.856	0.993	-0.973	-0.989	-0.999	0.015	-0.858	1.000				
Hirudinea	-0.800	-0.986	-0.999	-0.875	0.988	-0.963	-0.994	-1.000	-0.024	-0.878	0.999	1.000			
Gastropoda	-0.857	-0.998	-0.990	-0.821	0.999	-0.986	-0.978	-0.993	0.078	-0.824	0.998	0.995	1.000		
Bivalvia	-0.875	-1.000	-0.984	-0.800	1.000	-0.991	-0.970	-0.989	0.115	-0.803	0.995	0.990	0.999	1.000	
Insect	-0.859	-0.998	-0.989	-0.819	0.999	-0.986	-0.977	-0.993	0.082	-0.822	0.998	0.994	1.000	0.999	1.000

Table 8. CCA biplot physico-chemical parameters and macro benthic species

Codes	Axis 1	Axis 2
B1	-0.424	-0.421
B2	-0.501	0.644
B3	-1.297	0.702
B4	0.091	-1.159
B5	0.193	-0.261
B6	-0.186	0.218
B7	-1.716	-0.206
B8	0.012	-1.110
B9	0.700	-1.776
B10	0.310	0.157
B11	1.067	0.189
B12	1.049	0.467
B13	2.981	1.617
B14	-0.813	0.610
B15	-1.196	2.845
B16	-0.643	0.654
B17	-0.281	-0.071
B18	-0.546	-0.652
S-1	0.214	0.002
M-1	0.259	-0.037
W-1	0.131	0.070
S-2	-0.080	-0.010
M-2	-0.066	-0.107
W-2	-0.080	0.065
S-3	-0.068	-0.067
M-3	-0.043	-0.135
W-3	-0.096	0.058
WT	0.083	-0.813
EC	0.501	-0.768
DO	-0.195	0.923
N	0.460	-0.785
Cl	0.385	-0.701
Eigen value	0.0125	0.0042
%	69.89	23.89
P	0.066	0.016

illustrating positive or negative values associated with the variables using the arrow length to measure each variable's importance (Abrantes *et al.,* 2006; Liu *et al.,* 2010). The analysis of the CCA indicates the significance of a given variable by its vector length. For analysis, five environmental variables, such as WT, EC, DO, N and Cl were examined with the eighteen genera for establishing the relationship of each genera with the selected physico-chemical parameters; the results obtained from the two axes are shown in Fig. 3.

As shown in Table 8, eigenvalues 0.0125 and 0.0042 for axis 1 explained 69.89% and 23.89% of the correlation between physicochemical parameters and the benthos group in Asan wetland. For axis 1, WT, EC, N and Cl were positively correlated and showed positive with *Hirudineria* sp., *Gabbia* sp., *Lymnaea* sp. and *Gyraulus*

Table 9. Classification schemefor the Shannon Diversity index (Fernando *et al., 199*8)

Relative Values	Shannon Index(H') values
Very High	3.50 and Above
High	3.00-3.49
Moderate	2.50-2.99
Low	2.00-2.49
Very Low	1.99 and below

sp. DO showed a positive correlation with *Amynthas* sp., *Metaphire* sp., *Perionyx* sp., *Poecilobdella* sp., *Parreysia* sp., *Sphaeriun* sp., *Sphaeriun* sp., *Dineutes* sp., *Dineutes* sp. For axis 2, WT, EC, N and Cl were positively correlated and showed positive relationship with *Amynthas* sp., *Tubifex* sp., *Helobdella* sp., *Hirudineria* sp. and *Cybister* sp. DO also showed a positive correlation with *Metaphire* sp. and *Dineutes* sp. Nautiyal *et al.* (2015) have also reported the correlation between physicochemical parameters and benthos group while studying spatial distribution of benthic macroinvertebrate fauna in Alaknanda and Mandakini river of Uttarakhand, India.

Conclusion

The present study concluded that physicochemical parameters like WT, EC, DO, BOD, pH, TDS moderately influenced the wetland ecosystem. During the study period, 18 macroinvertebrates genera were recorded. *Limnodrillus* sp. constituted the highest number of macroinvertebrates species in all the winter seasons, while *Sphaerium* sp. constituted the lowest number of the species in the Asan wetland. The correlation between macroinvertebrates and physicochemical parameters showed that macroinvertebrates were negatively correlated with WT, pH, EC and TDS, while positively correlated with DO. Thus, the overall study gives a decent framework of seasonal dynamics relationship between large-scale macroinvertebrates and environmental factors. The study uncovers that the progressions in the physico-chemical attributes of the Asan wetland prompt quantitative and subjective changes in the large-scale invertebrate community. The water quality variables influencing the water quality of Asan wetland will be a reference for future aqutic biodiversity bio-monitoring and its management.

Conflict of interest

The authors declare that they have no potential conflict of interest.

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