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Assessment of the health of streams of Sukhia Pokhari, Darjeeling (West Bengal) using Aquatic Macroinvertebrates

Dawa Bhutia*

P.G. Department of Zoology, Darjeeling Government College, Darjeeling, West Bengal - 734101 (India)
*Corresponding Author: dbhutia16@gmail.com

Abstract

Sukhia Pokhari, like all other Himalayan areas, is conferred with a network of countless perennial streams that serve as a significant source of drinking water. These swell up during the rainy season but are reduced to narrow channels in summer. There have been concerns over the deterioration of these streams, especially those passing through human habitations. Benthic macroinvertebrates are sensitive to changes in different physicochemical and biological metrics, which make them ideal biomonitoring tools for assessing anthropogenic impacts. This study examines how benthic macroinvertebrate communities reflect stream health using the Hilsenhoff Biotic Index (HBI). 4 different drinking water sources of Sukhia Pokhri and its adjoining villages were studied. A total of 14 macroinvertebrate genera were caught. Temporal changes in the abundance of dominating species were also investigated, as well as their relationships with physicochemical factors like temperature, total dissolved solids, electrical conductivity, dissolved oxygen and total hardness. The findings indicate only a slight disturbance in the streams, indicating better ecological status of streams used for drinking. Seasonal fluctuations in physicochemical parameters and macroinvertebrate abundance were also observed, and the rainy monsoon season had a smaller population than the dry season.

Key words : Sukhia Pokhari, Darjeeling, macroinvertebrates, Hilsenhoff biotic index, stream health, dissolved oxygen.

Water is a basic necessity needed for all domestic uses; therefore, it is rightly described as the supporter of life. It is required for most human activities like drinking, cooking, bathing, crop irrigation, producing different goods, and recreational purposes; hence, it is considered a resource of multiple uses[1].

According to WHO[54], less than 50% of the population in India has access to safely managed drinking water. Historically, forests in the Himalayas have played a vital role in maintaining the area's environmental stability and ecological balance[34]. Due to rapid economic development, industrialisation, and urbanisation, the world's freshwater ecosystems are at serious risk. Over the past few decades, the forests have been under extreme pressure to meet the needs of an increasing human population[4,7]. In addition to these anthropogenic activities, the Himalayan ranges are under enormous pressure from various drivers of global change, including climate[35].

A significant relationship exists between physicochemical parameters and benthic macroinvertebrates[46]. Physical, chemical, and biological factors influence the distribution and seasonality of benthic macroinvertebrates in small streams[52]. Abiotic parameters like current speed, temperature, substratum, levels of oxygen, alkalinity, and hardness of the water are thought to be of prime importance in affecting the distribution of lotic macroinvertebrates[11]. Graca *et al.,*[9] demonstrated the importance of substrate type, particle size, organic content and habitat heterogeneity in the distribution of macroinvertebrates in freshwater streams. Wallace and Eggert[53] also considered riparian vegetation as one of the most critical factors that influenced community structure and productivity of freshwater lotic systems. Various anthropogenic changes, including deforestation, agricultural intensification, construction, waste disposal, bathing, washing clothes, etc., were often seen as responsible for reducing and eliminating certain pollution sensitive species and increasing the dominance of pollution tolerant species[48].

Many studies have been conducted on benthic macroinvertebrates and freshwater system in the Himalayan regions. Dutta and Malhotra[6] studied the seasonality of macrobenthic fauna of streams in Jammu and Kashmir. Sehgal[49] recorded structural adaptations in benthic organisms of the Himalayan torrential streams. Studies on the distributional pattern of benthic insects in a riffle in Himachal Pradesh were carried out by Julka *et al.,*[20]. Joshi *et al.,*[19] studied seasonal changes in the abundance of benthic macroinvertebrates in a freshwater stream of Garhwal region of Uttarakhand. Kahlon and Julka[11] related the distribution of benthic macroinvertebrates in different sections of a hill stream in Western Himalayas exposed to varying intensities of anthropogenic activities.

The health of a stream can be determined by using benthic macroinvertebrates since they are widely distributed have varying degrees of tolerance to pollution, are primarily sedentary, easy to collect and identify because of the availability of identification keys up to genera. Low sensitive taxonomic groups portrayed poor ecosystem health in urban waterways compared to local forested reference streams[46]. Recently, several studies were undertaken to assess the health of streams in India by utilising macroinvertebrates as bioindicators.

Macroinvertebrates react speedily to any environmental perturbations[27]. They are, therefore, used to study both temporal and spatial changes in various aquatic environments and paved their path for water quality assessment as they are cheaper than chemical assessment[2]. Hilsenhoff[13] developed a biotic index, commonly known as Hilsenhoff's Biotic Index (HBI), to evaluate the general status of organic pollution in water bodies. HBI was based on the tolerance values of different families of macroinvertebrates to various levels of organic pollution. The wide distribution of ranked organisms allowed this index to be applied in many locations with minimal modification.

In the present study, various parameters of the water samples from 4 different sites of Sukhia Pokhari were analysed biweekly for 6 months, following the standard methods, and compared with standard values to determine the water quality. The study aimed to determine the health of the streams by an indexing system called Hilsenhoff's Biotic Index, and analyse and correlate the biological and physicochemical parameters like temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), and total hardness (TH) of water samples.

Study area :

The study was conducted in 4 important perennial streams of Sukhia Pokhari (latitude: 26° 59' 54.222"N and longitude: 88° 10' 1.0128"E) located 20 km from Darjeeling, at an elevation of 2194m asl in the mountain ranges of the Eastern Himalayas adjoining Jorepokhri Salamander Wildlife Sanctuary. The four study sites, *i.e.* Maneybhanjang Road Water Source (Site 1), Simana Road Water Source (Site 2), Parment Water Source (Site 3) and Debrepani Water Source (Site 4), serve as a source of drinking water for the town of Sukhia Pokhari and its adjoining villages throughout the year. The climate of the study area is warm and humid, with mild summers (maximum temperatures seldom exceeding 25^{o}C). Monsoon showers lashing the towns characterise the monsoon season (June to September). The region is frequently shrouded in mist and fog during the monsoon and winter seasons.

Macroinvertebrate sampling :

Benthic macroinvertebrates were sampled biweekly over 6 months (June 2023 to November 2023). Quantitative samples

Figure. 1. Map of study area showing respective sites of study.

were taken using the Kick-Net method. The D-frame net (500 µm mesh) was placed downstream of the stony riffles. The sediment and stones were disturbed upstream of the net by rubbing and stirring using one foot so that the animals beneath the stones and gravels dislodged and were swept into the net. This procedure was continued for at least 5 minutes. After the collection, the macroinvertebrates were transferred into the sorting trays with the help of a plastic spoon. The similar groups of insects were placed together and counted thoroughly. From each group, one or two insects were picked with the help of forceps and transferred into the sample vials containing 4% formalin for preservation. These collected samples were then taken to the laboratory and stored in the refrigerator for further identification.

The specimens were viewed under dissecting microscopes for detailed identification. For the identification, taxonomic keys provided by CT Department of Energy and Environmental Protection[5], Riffle Bioassessment by Volunteers Program (Macroinvertebrates Field Identification Card) were referred.

Calculation of Hilsenhoff Biotic Index (HBI) :

The Hilsenhoff Biotic Index (HBI) estimates the overall tolerance of the community in a sampled area, weighted by the relative abundance of each taxonomic group (family, genus, etc.). Organisms are assigned a predetermined tolerance value from 0 to 10 pertaining to that group's known sensitivity to organic pollutants, 0 being the most sensitive, 10 being the most tolerant.

HBI values range from 0 to 10. Low HBI values reflect a higher abundance of sensitive groups and, thus, a lower pollution level. The results were interpreted from the chart provided for the family biotic index provided by Hilsenhoff,[13] (Table-1). The HBI was calculated by using the formula:

$$\text{HBI} = \frac{\Sigma niai}{N}$$

Where, ni = number of specimens in taxa i
ai = tolerance value of taxa i
N = total number of specimens in the sample

Water sample collection :

Water samples were analysed for physicochemical parameters following the

Table-1. Water Quality ratings based on family-level biotic index values for result interpretation (adapted from Hilsenhoff, 1988)

Biotic Index	Water Quality	Degree of organic pollution
0.00-3.50	Excellent	No apparent organic pollution
3.51-4.50	Very Good	Possible slight organic pollution
4.51-5.50	Good	Some organic pollution
5.51-6.50	Fair	Fairly significant organic pollution
6.51-7.50	Fairly Poor	Significant organic pollution
7.51-8.50	Poor	Very significant organic pollution
8.51-10.0	Very Poor	Severe organic pollution

standard methods of Gupta,[10]. Water sampling was carried out on a biweekly basis throughout the study period. The water samples were collected in clean 2-litre polyethene cans that were sterilised and pre-rinsed with distilled water. After sampling, the bottles were sealed, labelled and immediately transferred to the laboratory for analysis. The temperature, EC, and TDS values were measured using a portable field thermometer, EC, and TDS meter. Estimation of DO and total hardness were conducted titrimetrically.

The HBI was calculated manually using MS Excel, 2010 and the correlation analysis was calculated and interpreted with the help of PAST statistical software.

Hilsenhoff Biotic index (HBI) :

The macroinvertebrate assemblage in the streams under study was dominated by insect taxa, consistent with other mountain streams worldwide. A total of 14 genera belonging to different taxonomic groups were caught (Table-2). The values of HBI at 4 sampling sites of the stream for June to November, 2023 are provided in Figure 3. The values ranged from 3.63- 4.96, indicating that the stream in all the sites was mainly in the "very good" to "good" quality water range, showing only slight levels of organic pollution, reinforcing the clean status of the streams. This result was expected since the sampling sites were less impacted and had intact riparian vegetation. It is useful to use the HBI to assess the overall level of organic pollution in streams within a watershed in order to determine which streams or watersheds require additional research[13].

The most common macroinvertebrates were members belonging to the Order Ephemeroptera (Mayfly larva), Plecoptera (Stonefly larva) and Trichoptera (Caddisfly larva). The other groups caught belong to the order Diptera, Coleoptera, Odonata and members from the Class Oligochaeta and Hirudinea of Phylum Annelida. The members of these groups have been known to predominate streams in different parts of the tropics[16]. According to Nautiyal *et al.,*[33], the streams across the western Himalayas are typically rich in Ephemeroptera, Trichoptera and Diptera, as also elsewhere in other mountainous streams in the world[15,56]. Although the larvae of Ephemeroptera, Plecoptera, and Trichoptera may survive in various aquatic environments, cool waters exhibit the most diversity. Improved aquatic conditions with respect to pollution and physicochemical matrices in flowing rivers are the main cause of these species' higher relative abundance[11,14]. Higher densities of Diptera are attributed to their adaptation to tolerate a wide range of environmental variations and great diversity[52]. The Plecoptera, a high pollution intolerant group, have been recognised as the first EPT taxa to disappear when pollution begins to occur[8]. The population of macro-invertebrates was influenced by seasonal environmental variations, with higher abundance during the dry season compared to the wet season (monsoon months of July to September). Similar seasonal fluctuations in the density of macroinvertebrates were also observed in streams of the Himalayan region[20] and other parts of the world[54].

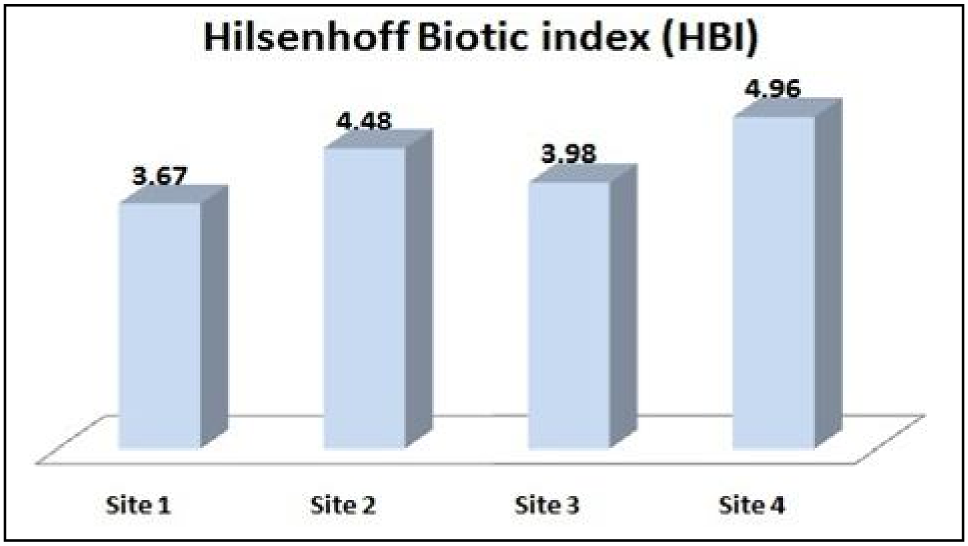

Fig. 3. Value of HBI observed at 4 sampling sites during June -November, 2023.
Site 1: Maneybhanjang Road Water Source; Site 2: Simana Road Water Source;
Site 3: Parment Water Source; Site 4: Debrepani Water Source

Table-2. Macroinvertebrates as an Indicator species caught in the 4 study sites

Common Name	Family	Tolerance value	No. of Individuals			
			Site 1	Site 2	Site 3	Site 4
Flathead mayfly larva	Heptageniidae	0	8	7	5	3
Minnow mayfly larva	Isonychidae	2	22	16	18	12
Body-Builder Mayfly	Ephemerellidae	0	12	4	8	1
Common Stonefly larva	Perlidae	1	18	15	21	8
Green Stonefly larva	Chloroperlidae	1	12	6	7	10
Plant casemaker caddisfly larva	Lepidostomatidae	1	4	3	8	2
Netspinner Caddisfly larva	Hydropsychidae	4	9	18	16	16
Fingernet Caddisfly larva	Philopotamidae	3	17	16	21	12
Predaceous diving beetle	Dytiscidae	5	13	23	18	19
Broad Winged Damselfly larva	Calopterygidae	5	7	8	11	13
Black fly larva	Simuliidae	6	19	26	21	28
Non-biting midge larva	Chironimidae	6	16	22	26	19
Aquatic Worm	Class- Oligochaeta	8	9	13	8	11
Leech	Class-Hirudinea	10	10	13	10	18
		Total	**176**	**190**	**198**	**172**

Site 1: Maneybhanjang Road Water Source; Site 2: Simana Road Water Source;
Site 3: Parment Water Source; and Site 4: Debrepani Water Source

Physicochemical characterisation :

The primary goal of studying water's physicochemical features is to assess its potability[41]. The physicochemical properties of water samples from 4 study sites were uniform, as presented in Table-3.

Temperature :

Water temperature is one of the most essential factors in an aquatic environment, regulating various physicoche-mical and biological activities[41]. The water temperature showed a minimum of 7.4°C in November 2023 and a maximum of 24.4°C in June 2023 (Table-3). Temperature was based on seasons and showed monthly variations. Fluctuations in air and water temperature may be due to the influence of season, location and difference in the time of collection[18]. High temperature is thought to alter the concentration of dissolved oxygen and other gases and may also change microbial colonies' activities[23].

Electrical conductivity (EC):

The ability of a solution to conduct an electrical current is determined by solution migration and is affected by the nature and amount of ionic species present. It is a helpful tool for assessing the purity of water. The electrical conductivity of water samples collected from 4 sites had EC values ranging from 50 to 182 $\mu S\ cm^{-1}$ (Table-3). The permissible limit[3] for electrical conductivity is 300 $\mu S\ cm^{-1}$, indicating that electrical conductivity values were lesser than the permissible limits. Seasonal variations in conductance and dissolved solids are mainly due to water's ionic composition; therefore, factors like rainfall and biota cause changes in conductivity and dissolved solids[43].

Total dissolved solids (TDS):

The electrical conductivity of water samples correlates with the concentration of dissolved minerals, also known as the total dissolved salts of water samples. Table-3 shows that the TDS of the analysed water samples ranged from 25 to 92 ppm, which was lower than the acceptable TDS range (500 mg/L). The increase in TDS is due to the rise in salts containing carbonates, bicarbonates and chlorides and may lead to undesirable taste, corrosion or incrustation[38]. Densely populated areas, polluted sewage water, and industrial effluents may also be some of the reasons. A high concentration of TDS is known to produce distress in cattle and livestock. Plants are also adversely affected by the higher contents of solids in irrigation water, which increases the salinity of the soil[32].

Dissolved oxygen (DO):

DO recorded during the study ranged from 4.97 to 9.79 mg/L. DO showed little variation among the 4 different study sites, although the highest concentration was during the monsoon season (Table-3). The results of the present study are per the works of Prasannakumari *et al.,*[40] in River Neyyar of Kerala and Sivakumari *et al.,*[51], who studied the hydrographic factors of Adyar estuary. According to Singh and Gupta[50], DO determines the nature of an entire aquatic ecosystem to a great extent, while Kalwale and Savale[22] referred to it as one of the essential parameters in assessing water quality and understanding the physical and biological processes prevailing in it. It is also necessary for protecting and supporting biological life in water and for the decomposition and decay of organic waste[50]. Hence, DO is the prime critical factor in natural waters both as a regulator of metabolic processes of biotic community and indicator of aquatic health[28]. The high dissolved oxygen level during monsoon season could be due to the mixing of rainwater rich in oxygen[44]. On the other hand, low DO values may be due to low flow rate and enhanced utilisation by microorganisms in the decomposition of organic matter[26,29].

Total hardness (TH):

The hardness of water is mainly due to the presence of calcium and magnesium ions and is vital in indicating the toxic effects of poisonous elements[25]. The 4 study sites recorded TH ranging from 11.6 mg/L to 27.4 mg/L (Table-3). Total hardness was high in the monsoon and low in post-monsoon seasons, similar to the investigation carried out by Raymahashay[45] in river water and Pondhe *et al.,*[37] in dam water. TH is due to the natural accumulation of salts from contact with soil and geological formations, or it may be caused by direct pollution by human activities[31]. It indicates hydrogeology and the aesthetic quality of water[30]. Though total hardness has no known effects on human health, if present above the permissible limit (600 mg/L) it can lead to health hazards and become unfit for industrial and domestic use[42]. Patil *et al.,*[36] have demonstrated that concentrations of more than 300 mg/L may cause heart and kidney problems. An increase in hardness is known to cause scale formation and interfere with the lathering activity of soap[24]. According to Jain *et al.,*[17], hard water is also unsuitable for cooking, washing and cleaning.

Correlation analysis :

A correlation statistical matrix was prepared taking an average value of all parameters to find the relation between 5 different physiochemical parameters and HBI (Table-4). Positive correlations indicated that the variables moved/influenced each other in the same direction. In contrast, negative or

Table-3. Minimum and maximum values of the physicochemical parameters of 4 different Sukhia Pokhari area water sources with safe limits prescribed by BIS[3].

Parameters		Site:1	Site:2	Site:3	Site:4	Limit
Temp. (^oC)	Min.	7.6	7.4	8.5	9.3	6^oC-
	Max.	21.2	21.3	24.4	23.8	30^oC
EC ($\mu S\ cm^{-1}$)	Min.	50	54	58	62	300
	Max.	147	129	182	135	
TDS (ppm)	Min.	25	27	29	31	600
	Max.	74	65	91	68	
TH (mg/L)	Min.	16.02	15.41	16.76	16.23	500
	Max.	17.65	17.44	18.56	18.72	
DO (mg/L)	Min.	5.94	5.14	5.99	4.97	>6
	Max.	8.79	8.68	'9.79	8.95	

Site 1: Maneybhanjang Road Water Source; Site 2: Simana Road Water Source;
Site 3: Parment Water Source; and Site 4: Debrepani Water Source

Table-4. Pearson Correlation Matrix of 5 different physicochemical parameters and Hilsenhoff Biotic Index.

	HBI	Temp.	EC	TDS	TH	DO
HBI	1					
Temp.	0.3359	1				
EC	-0.2539	0.7741	1			
TDS	-0.2486	0.7786	0.9999	1		
TH	-0.0530	0.9220	0.9117	0.9145	1	
DO	-0.8264	0.2272	0.7542	0.7507	0.5720	1

inverse correlation meant that the variables moved/influenced each other in the opposite direction). The highest positive correlation was observed between TDS and EC, followed by TH's positive correlation with temperature, TDS, and electrical conductivity. However, a high negative correlation was also observed between HBI and DO, indicating that water sources with lower HBI scores have better ecological status than higher HBI scores[12].

Good quality drinking water is of elemental significance for the functioning of human bodily processes, and the sustenance of life depends on its accessibility. The present study mainly considered evaluating the streams' overall health. The natural waters harbour a diverse range of benthic macroinvertebrate organisms which serve as good indicators of pollution and can be utilised for monitoring the quality of water because these organisms respond differently to various abiotic factors whose condition may prove deleterious or promotional to their growth and reproduction. Seasonal environmental variations affect the population of macroinvertebrates with higher abundance during the dry season compared to the wet season. Various physicochemical variables, often interrelated, influenced temporal changes in their abundance. The preponderance of tolerant taxa and the absence of sensitive species indicates the stream's degradation and the presence of pollution in the water.

In the present study, the results of the physicochemical characterisation of all drinking water samples from 4 different sites revealed that the levels of all of the parameters analysed were within the safe limits prescribed by BIS[3]. Variations observed in most parameters could be due to seasonal changes, including temperature fluctuations, rainfall, humidity, time of collection and various other abiotic factors. Since water quality is critical in disease prevalence, the streams should be protected and regularly monitored to formulate action plans to prevent disease epidemics. Several purification processes and proper water treatment along with a good drainage facility must be integrated with other aspects of development such as sanitation and education which has to be implemented to minimise this problem of water pollution to a large extent.

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