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Macroinvertebrates Diversity and Seasonal Dynamics in the Streams of Southwest Bhutan: Preliminary Findings and Implications for Future Research

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Abstract

Traditionally, assessing stream and river health in the Hindu Kush-Himalayan (HKH) region has relied primarily on physical and chemical data, which offer limited insights into aquatic ecosystems. The recent *Assessment System to Evaluate the Ecological Status of Rivers in the Hindu Kush-Himalayan* region (ASSESS-HKH) project marks a significant advancement by developing robust bio-assessment tools. This initiative was crucial for addressing the region's unique ecological challenges, characterized by its rich biodiversity and essential freshwater resources. In Bhutan, however, the use of macroinvertebrates as bio-indicators for water quality assessment has been limited. This study aimed to enhance stream health evaluation in southwest Bhutan by utilizing macroinvertebrates. Two representative streams were sampled using detailed techniques, revealing a diverse range of macroinvertebrate families - 39 families in one stream and 34 in the other - with notable variations in abundance among key taxa. Seasonal changes in community composition reflected ecological dynamics influenced by factors such as water temperature, flow regime, and substrate composition. HKH biotic scores indicated minimal stream impairment. The study highlights the need for sustainable monitoring and management of stream health in southwest Bhutan. Future research should investigate the effects of monsoonal patterns on macroinvertebrate diversity, conduct long-term monitoring, and assess the impact of anthropogenic activities to further refine conservation strategies.

Keywords: Bio-assessment, Ecological dynamics, Freshwater, HKH biotic score, Macroinvertebrates, Sustainable stream management

Introduction

The biological assessment of stream and river health in the Hindu Kush Himalaya (HKH) region is not well-established (Shrestha et al., 2009; Korte et al., 2010; Dorji, 2016). Historically, water quality evaluations have relied primarily on physical and chemical data (Shrestha et al., 2009; Stubauer et al., 2010), offering only a limited perspective on aquatic ecosystem health (Hughes, 2009). However, recent advancements in ecological surveys of freshwater invertebrates have led to the development of a three-tier bioassessment methodology (HKHscreening, HKHbios, and HKHindex), providing a more comprehensive approach for assessing river and stream health. This initiative, part of the *Assessment System to Evaluate the Ecological Status of Rivers in the Hindu Kush-Himalayan Region* (ASSESS-HKH) project, brings together Eu-

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ropean and Asian scientific expertise to create scientifically grounded yet practical tools for assessing freshwater ecosystems across diverse ecoregions and environmental conditions in Bhutan, India, Nepal, Bangladesh, and Pakistan (Ofenböck et al., 2010; Dorji, 2016).

In Bhutan, the application of stream-dwelling macroinvertebrates as bioindicators for water quality assessment has been limited, and the ecology of species used in water quality indices remains insufficiently studied (Malicky et al., 2008; Dorji, 2016). This study aimed to address this gap by investigating the composition, abundance patterns, and temporal variations of stream-dwelling macroinvertebrates in typical streams of southwest Bhutan. By improving the understanding of macroinvertebrate ecology and their role as bioindicators of stream health, this research seeks to contribute to the sustainable management of Bhutan's vital water resources for future generations.

The primary goal of this study was to expand the understanding of how water quality indices based on macroinvertebrates can be applied to relatively undisturbed streams in southwest Bhutan. To achieve this, the study addressed three key components:

(i) Identifying the macroinvertebrate families present in two representative streams, spanning both low-lying and mountainous areas of Bhutan.

(ii) Investigating temporal variations in the abundance and composition of these macroinvertebrates between the post-monsoon (October to December) and pre-monsoon (January to February) periods.

(iii) Exploring the temporal distribution patterns of key macroinvertebrate taxa across different sampling months. Additionally, the study assesses the current water quality status of these streams using the HKH biotic score and examines how various physicochemical characteristics influence macroinvertebrate communities. Together, these objectives offered a comprehensive evaluation of water quality and the environmental factors shaping macroinvertebrate communities in the region.

Specific objectives of the study include:

1.**Documenting and Analyzing Macroinvertebrate Communities**: Identifying and cataloging macroinvertebrate families in representative streams of southwest Bhutan, with a focus on habitats ranging from low-lying to mountainous regions of the HKH area.

2.**Examining Temporal Variations in Abundance and Composition**: Investigating seasonal changes in the abundance and composition of macroinvertebrates between the post-monsoon (October to December) and pre-monsoon (January to February) periods in two streams.

3. Assessing Water Quality and Environmental Influences: Evaluating water quality in the two streams using the HKH biotic score, assessing ecological health, and analyzing the influence of environmental parameters such as depth, width, velocity, temperature, and pH on macroinvertebrate communities during the post-monsoon period.

Given the growing environmental stresses on freshwater ecosystems in Bhutan, it is essential to better understand stream processes and develop appropriate management strategies to mitigate these stresses. Scientific research should enhance knowledge regarding the biology of species used as key indicators of water quality and address specific anthropogenic disturbances that contribute to stream water quality deterioration.

Materials and Methods

Study area

The study area is located at Norbugang (approximately 26°56'39.28"N, 89°2'25.70"E) in the southwest part of Bhutan (the Samtse District) (see Figure 1). The district covers an area of approximately 1,582 km^2 and its elevation ranges from 300 m to 3,800 meters above sea level. The study sites were located approximately 12 km from the district head quarters (Samtse) and experiences its annual mean temperature varying from 15° C to 30° C (Ministry of Agriculture, 1997). The climate is mainly subtropical and the region receives an annual rainfall of 1,500 mm to 4,000 mm (National Statistics Bureau, 2010). Generally, the region is distinguished by four seasons: spring (March – May), summer (June – August), autumn (September – November) and winter (December – February) with the wet monsoon starting by June and lasting until the middle or end of September (National Statistics Bureau, 2010).

Macroinvertebrates sampling

Two typical representative streams were scrutinized and selected for sampling the benthic-macroinvertebrates. In each stream, three sampling sites (down-stream, midstream and upstream) were selected as indicated in Figure 2. At each sampling site, the sample reach of about 100m length was used that included both riffle and pool sections of the stream. Three sampling units were performed in both riffle and pool sections of the stream, and sampling continued until 100 individual specimens were sampled per site. A 'sampling unit' is a stationary sampling performed by positioning the sampler net and disturbing the substrate in an area that equals the frame-size upstream of the net with the foot or scraping the underlying bed by hand. Samples were sorted on site and individual specimens were placed in containers labelled with stream name, site name, site code, sampling date and number of sample units for later identification in the laboratory.

Field sampling were performed on a monthly basis for the period of five months (October to February). A total of 30 samples were taken (5 months x 2 streams x 3 sites). All sampling sites were located at least a minimum of 100m upstream from any road or any disturbances to minimize its effect on stream velocity, depth and overall habitat quality. There were no major tributaries discharging to the stream in the study area.

The ASSESS-HKH multi-habitat sampling techniques were adapted and applied for sampling the stream macroinvertebrates (Ofenböck et al., 2010). Sampling started at the downstream end of the study reach and proceeded upstream to ensure the minimum disturbance during sampling. The following steps/ techniques were followed while performing the macroinvertebrate field sampling.

General sampling techniques

Stream Bed Disturbance: Sampling gear was placed on the stream bed, and upstream areas were disturbed by foot and hand to carry organisms downstream into the net.

Bedrock and Boulder Habitats: Surfaces were brushed in three positions (front, right, and left), sweeping organisms into the net.

Cobble and Stone Habitats: Surfaces were gently swept by hand to dislodge animals, and cobbles and larger stones were gently brushed to remove clinging organisms.

Smaller Substrates: Substrates were disturbed to a depth of 15-20 cm in a 0.25 x 0.25 m area upstream of the net.

Woody Debris and Leaf Litter: Samples were washed into the net, and animals were hand-recovered using fine forceps.

Macrophyte Habitats: All parts of macrophytes within a 25 x 25 cm area were removed and rinsed to separate organisms from plant material.

Field Sorting: Larger materials were removed, and samples were transferred to a shallow white tray for sorting; branches, sticks, and stones were thoroughly rinsed and checked.

Sample Preservation: All collected organisms were stored in containers with 70% ethanol, labeled with essential sampling information for later identification.

All collected samples were taken to the lab and kept in the refrigerator until lab sorting and identification begun.

Macroinvertebrates identification in the laboratory

Lab sorting

Samples collected from each sampling site were transferred onto white sorting tray, while the specimen container was rinsed thoroughly with water to remove all clung animals from the container. Hand lens and fine forceps were used to sort out morphologically similar or same animals, and this step was continued until all animals in the tray were sorted out.

Family level identification

Identification was performed with a binocular compound microscope with electric high quality light source in the laboratory. The macroinvertebrate samples were identified to operational taxonomic level i.e. down to family level using available HKH identification keys such as the HKH field key for selected Benthic Invertebrates from the HKH Region (Hartmann, 2007) and the key to the larval stages of common Odonata of Hindu Kush Himalaya (Nesemann et al., 2011). Where specimens are not recorded in the HKH keys, other appropriate keys were used (e.g. Dichotomous key for Macroinvertebrates –Pollution tolerance values for families of Stream Macroinvertebrates (Merritt & Cummins, *1996).*

According to literature, family level identification is sufficient for detecting perturbations on the freshwater macroinvertebrate community (Gabriels et al., 2005), with low cost and timely completion of the project. However a more detailed level of identification is required for ecological interpretation (Gabriels et al., 2005). The problems associated with the species level identification are expense, time requirements and availability of an appropriate laboratory and facilities. Therefore, due to lack of resources and expertise to identify each organism to species level, the operational taxonomic unit (OTU) approach was adapted to sort organisms of the same family into individuals that look the same (i.e. seem to be members of the same species). These groups of 'look-alikes' are called OTU species and can be used for calculation of species diversity.

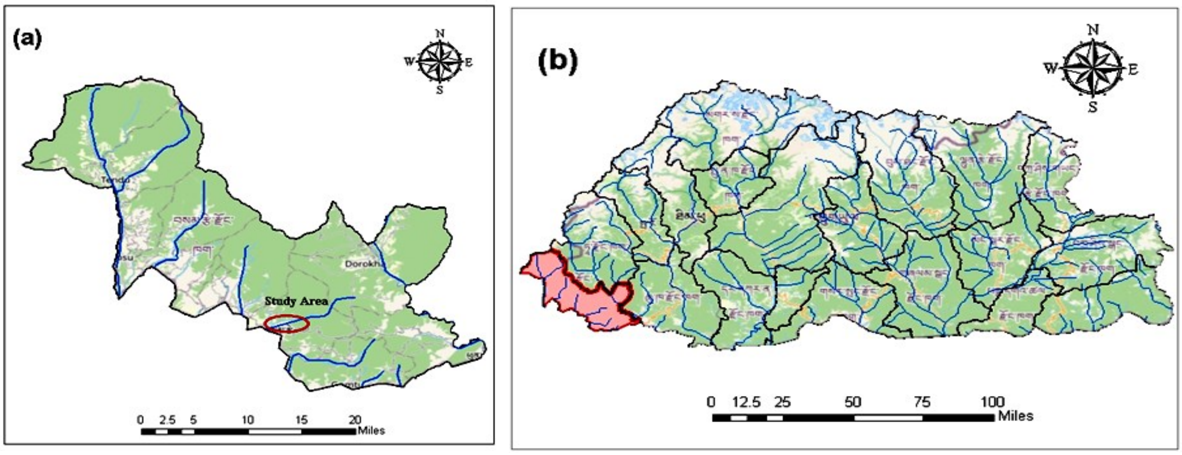


Figure 1: Map of (a) Samtse District and (b) Bhutan, Showing the Location of the Study Area

Measurements of stream physico-chemical parameters

The pH value and both air and water temperature were measured at each sampling site of each stream. Stream velocity, depth and width and substrate types were assessed in each habitat sampled. The surface current velocity was obtained by timing a ping pong ball over a stretch of 5 metres (the average of 3 times) at each sampling site, and average stream depth was calculated over 3 measurements in each sampling habitat with a meter ruler.

Data analysis

A more comprehensive score based biological condition were assessed by using the available HKHbios (Ofenböck et al., 2008) based on multiple habitats and reference sites. River quality classes and corresponding HKH Biotic score values (Table 1) adapted for streams in the Samtse region, Bhutan, reflecting local environmental conditions, including agricultural runoff and seasonal variations (Monsoonal influence).

Results and Discussion

Taxonomic composition and abundance patterns

In each of the 30 samples per stream, the first 100 individuals were selected for identification, resulting in 1,500 individuals analysed per stream. This standardised approach helped manage sampling effort and ensure representative diversity (Cao et al., 2001; Bailey et al., 2004). Analyzing a consistent subset of individuals has proven effective for capturing community composition, as macroinvertebrate diversity typically stabilises within the first 100 specimens (Resh & McElravy, 1993). However, rare species may be underrepresented in samples with high overall abundance.

The taxonomic composition of the sampled streams in southwest Bhutan displayed a rich assemblage, with 39 families identified in Stream 1 and 34 in Stream 2 (Table 2). Predominant families across both streams included *Ephemerellidae* (Ephemeroptera), *Baetidae, Heptageniidae, Psephenoidinae* (Coleoptera), *Hydropsychidae, and Philopotamidae* (Trichoptera). In contrast, many other families were represented by fewer than five individuals. This distribution pattern likely reflects ecological factors inherent to lotic ecosystems, such as resource availability and hydrological variability, which favour certain taxa (Dodds & Whiles, 2010).

Figure 2: Google map showing the sampling sites (down-stream, mid-stream & up-stream) of stream 1 & 2

Factors such as monsoonal fluctuations, agricultural runoff, and habitat fragmentation further shape community composition and species richness, impacting water quality and nutrient levels. The predominance of adaptable families suggests resilience to environmental variability and tolerance to organic matter, substrate diversity, and flow conditions (Wiggins, 1996). Conversely, lower-abundance families may have specific habitat needs or higher sensitivity to disturbances (Allan, 2004). Thus, the abundance distribution observed in this study mirrors the interplay of ecological preferences and environmental dynamics within the streams.

Table 1. *River Quality Classes (RQC) and corresponding HKH Biotic score values for the Samtse Area*

River quality class	Degree of impairments	HKH Biotic score values
I	None to very slight pollution	> 8.00
II	Moderate pollution	7.99–6.5
III	Critical pollution	6.49–4.8
IV	Heavy pollution	4.79–3.0
V	Very heavy to extreme pollution	< 3

Temporal Variation in Abundance and Composition

Monthly variations in the number of macroinvertebrate families across all samples from both streams were assessed, and species composition was compared between months using standard similarity and clustering methods (City Block measure of dissimilarity and between-groups clustering). Data from both streams revealed that species composition changed over time, particularly after the monsoon period. Notably, the families sampled in January and February (post-monsoon samples) showed the highest similarity to each other and were distinct from those collected in other months (Figure 3a & b).

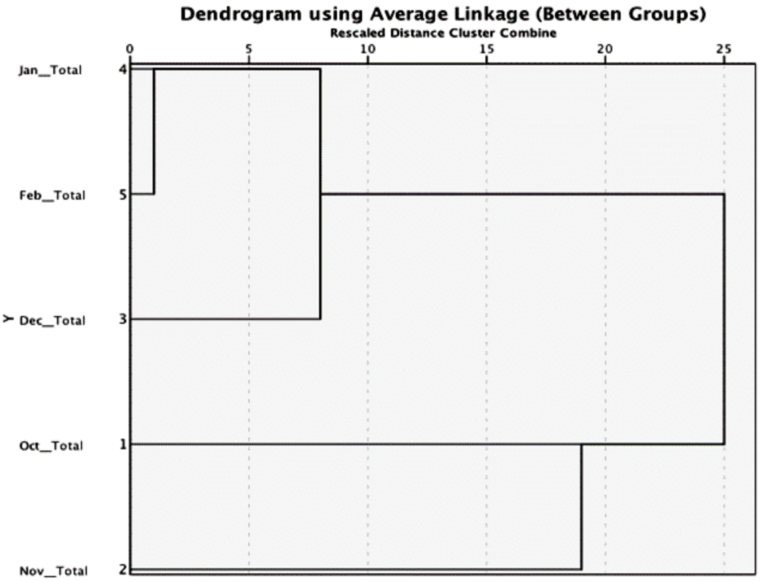


Figure 3a: Dendrogram showing the similarity in composition of families with month at Stream 1 (Diana)

These temporal changes in species composition align with post-monsoon recovery dynamics and the stabilisation of environmental conditions, as seen in other studies of aquatic ecosystems (Allan & Castillo, 2007; Lake, 2000; Jackson et al., 2020). The similarity of the January and February samples supports ecological theories of disturbance and succession, suggesting that the stability following the monsoon facilitates the reassembly of macroinvertebrate communities (Connell & Sousa, 1983; Boulton et al., 1992; Leigh et al., 2016). These findings highlight the role of seasonal fluctuations in shaping community structure and suggest avenues for future research to explore the specific mechanisms driving these patterns and the roles of individual taxa in community reassembly (Resh & Rosenberg, 1984; Tonkin

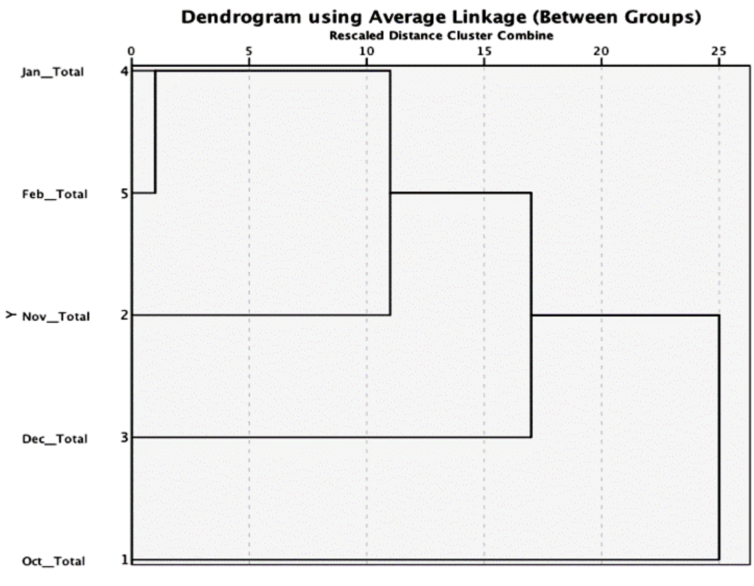


Figure 3b: Dendrogram showing the similarity in composition of families with month at Stream 2 (Dipijhora)

Table 2: Total number of families & individuals sampled from Stream 1 & 2 over 5 months (October to February)

Taxonomic groups	Family	Total individuals (Stream 1)	Total individuals (Stream 2)
Coleoptera	*Dryopidae*	2	-
	Elmidae	2	2
	Eubrianacinae	4	-
	Euphaeidae	4	-
	Psepheninae	14	24
	Psephenoidinae	247	252
Crustacea	*Potamidae*	3	-
Diptera	*Blephariceridae*	4	10
	Chironomidae	20	6
	Tabanidae	18	20
	Tipulidae	14	24
Ephemeroptera	*Baetidae*	174	210
	Caenidae	33	12
	Ephemerellidae	166	120
	Ephemeridae	34	25
	Heptageniidae	241	114
	Leptophlebiidae	51	31
	Neoephemeridae	-	2
	Potamanthidae	13	-
Lepidoptera	-	-	6
Megaloptera	*Corydalidae*	1	-
Odonata	*Gomphidae*	3	10
Plecoptera	*Capniidae*	12	8
	Chloroperlidae	10	1
	Nemouridae	10	7
	Peltoperlidae	5	3
	Perlidae	37	44
	Perlodidae	14	30
	Taeniopterygidae	1	-
Tricladida	*Dugesiidae*	-	4
Trichoptera	*Brachycentridae*	12	44
	Glossosomatidae	8	7
	Goeridae	4	3
	Helicopsychidae	1	13
	Hydropsychidae	132	338
	Lepidostomatidae	1	1
	Leptoceridae	-	17
	Odontoceridae	2	-
	Philopotamidae	116	86
	Polycentropodidae	12	-
	Psychomyiidae	1	1
	Rhyacophilidae	33	22
	Stenopsychidae	41	3
	Total individuals	**1500**	**1500**
Total family in Stream 1 (Diana) = 39		**Total family in Stream 2 (Dipijhora) = 34**	

et al., 2018).

Temporal Distributions of Key Macroinvertebrate Taxa

The temporal distribution patterns of key macroinvertebrate taxa were assessed in the streams of southwest Bhutan, with a focus on Plecoptera (stonefly) families. Notable variations in their occurrence were observed across different sampling months. For instance, families such as *Nemouridae, Taeniopterygidae, Capniidae, Peltoperlidae, Perlodidae, Chloroperlidae,* and *Pteronarcyidae* were present in the early months of sampling but absent by December. In contrast, the *Perlidae* family reemerged in the January and February samples (Figure 4a & b). These temporal variations likely reflect ecological dynamics influenced by seasonal environmental factors, such as fluctuations in water temperature, flow regimes, and substrate composition. The absence of these families in December may be linked to environmental conditions that were unfavourable for their survival or reproductive activities. The reappearance of Perlidae in the

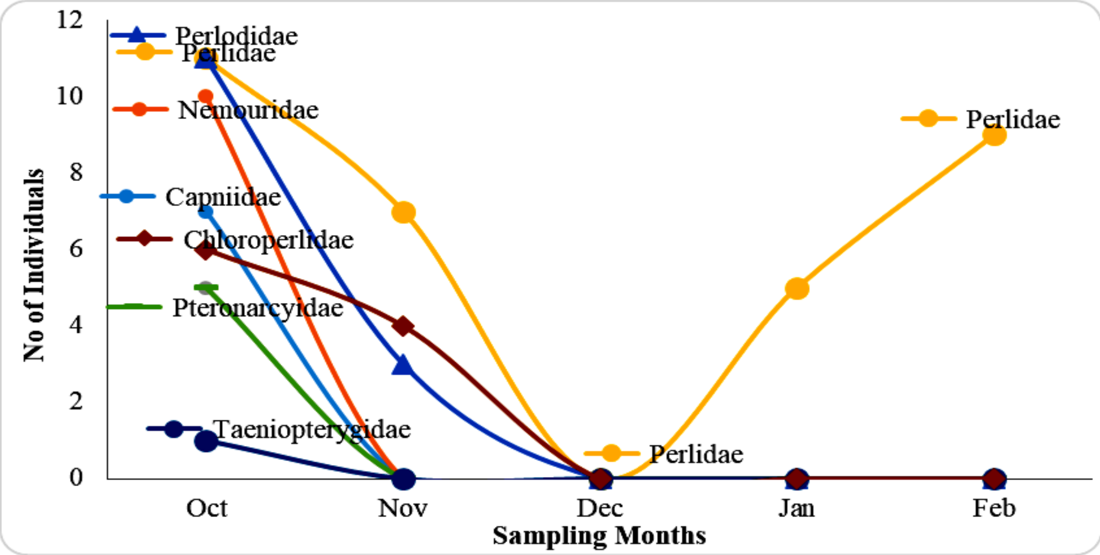


Figure 4a: The distribution of Plecopteran families (stonefly) across the sampling periods in stream 1 (Diana)

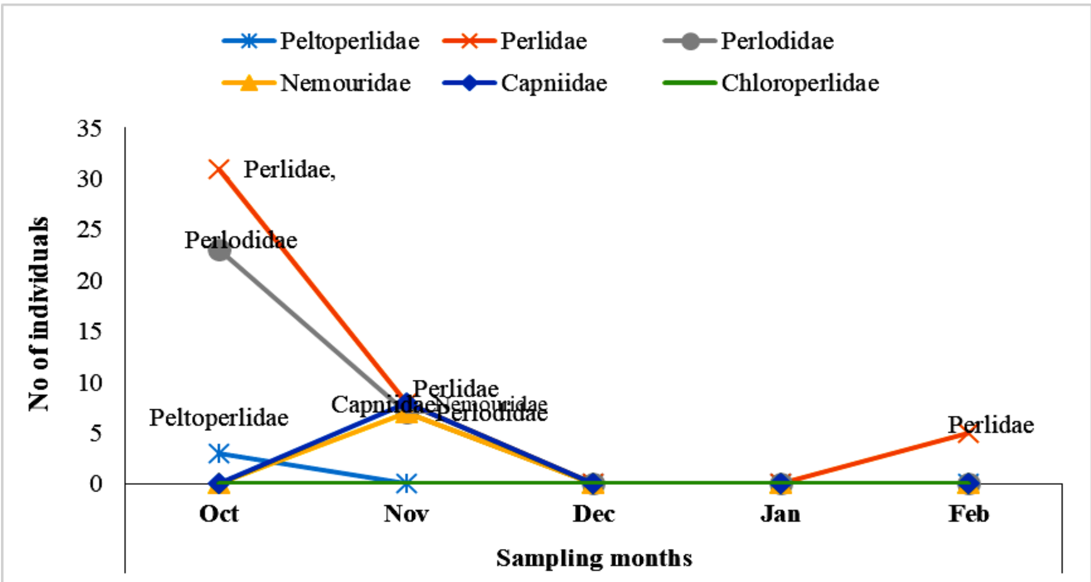
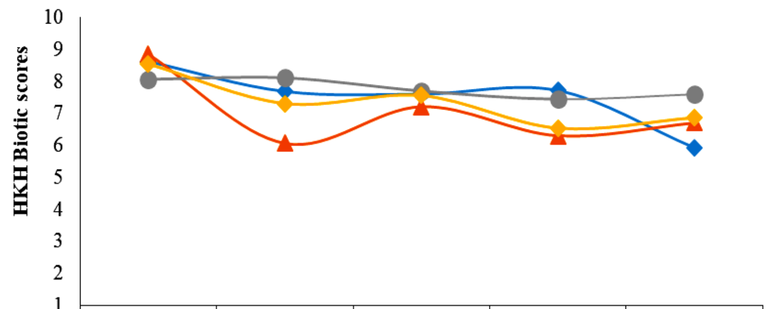


Figure 4b: The distribution of Plecopteran families (stonefly) across the sampling periods in stream 2 (Dipijhora).



	October	November	December	January	February
Down	8.64	7.70	7.62	7.73	5.93
Mid	8.87	6.07	7.22	6.31	6.71
Up	8.08	8.13	7.71	7.45	7.61
Total	8.56	7.32	7.57	6.55	6.88

Figure 5a: Monthly HKH biotic scores of water quality in stream 1 (Diana)

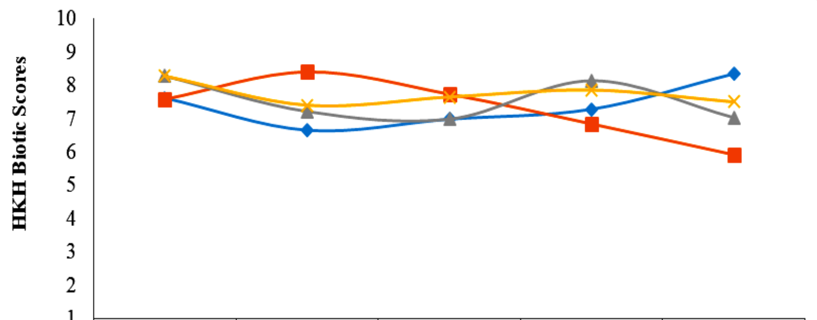
subsequent months suggests that they may be more adaptable to the changing habitat conditions or that these months offer more favourable conditions for their presence. Biological factors, such as life cycle differences and inter-species interactions, may also contribute to these observed patterns.

The disappearance of certain Plecoptera families during the dry season, coupled with the re-emergence of *Perlidae*, underscores the significant role that seasonal environmental factors play in shaping the composition of macroinvertebrate communities. While this study did not directly observe the effects during the monsoon period, it is likely that the increased precipitation and altered flow regimes during this time provide critical resources and habitats that support the survival of these taxa (Sundar & Muralidharan, 2017). Additionally, human activities, such as agriculture and land use changes, may exacerbate the effects of the dry season by further disrupting stream habitats and contributing to the disappearance of key taxa (Allan, 2004). Alterations to water flow, quality, and habitat structure can severely impact the resilience of macroinvertebrate communities, especially during environmental stressors like the dry season (Hedrick et al., 2010).

To gain a fuller understanding of these dynamics, future studies should focus on year-round monitoring to capture the complete seasonal variability. This approach will help elucidate the mechanisms driving the disappearance of key taxa during the dry season and assess the combined impacts of natural and anthropogenic factors on stream ecosystems. Such comprehensive data is essential for informing adaptive management strategies aimed at conserving freshwater resources in the region.

Assessment of Stream Water Quality Using the HKH Biotic Score

The current status of stream water quality in southwest Bhutan was assessed using the HKH Eco-data management Tool (ECODAT) and the corresponding HKH Biotic score. The analysis of two representative streams based on the River Quality Classes (RQC) and HKH Biotic scores revealed predominantly minimal to very slight pollution levels in both Stream 1 (Figures 5a, 6a) and Stream 2 (Figures 5b, 6b).



	October	November	December	January	February
Down	7.64	6.67	7.00	7.30	8.36
Mid	7.60	8.42	7.75	6.86	5.93
Up	8.29	7.23	7.00	8.15	7.05
Total	8.29	7.42	7.67	7.88	7.52

Figure 5b: Monthly HKH biotic scores of water quality in stream 2 (Dipijhora)

Table 3: *Monthly physical and chemical characteristics of downstream, midstream and upstream sections of Stream 1 (Diana) and stream 2 (Dipijhora)*

Months	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
Sites	**Stream 1 (downstream)**					**Stream 2 (downstream)**				
Air temp (^{0}C)	28.3	28	24	26.5	27	28	29.5	25	21	28
Water temp. (^{0}C)	26.5	24	19	18	19	26.3	25	21	20	20
Stream depth (cm)	60	30	40	43	38	42	28	30	19	14
Stream width (m)	16.5	18	20	20	15	8.5	4.62	2.5	2	3.5
Velocity (m/s)	1.8m/s	1.8m/s	1.4m/s	1.4m/s	1.2m/s	2.4m/s	1.4m/s	1.6m/s	3.6m/s	3m/s
pH value	7.2	7.5	7.2	7.5	7.8	7.6	8.3	7.8	7.9	9.1
Sites	**Stream 1 (midstream)**					**Stream 2 (midstream)**				
Air temp (^{0}C)	29	26	21	26	28	29	29	24.5	25	27.5
Water temp. (^{0}C)	26	21	18	17.8	20	26	23	20	20	20.5
Stream depth (cm)	62	52	43	42	30	30	50	28	23	10
Stream width (m)	12.5	12.77	12	16	15	6	4.56	3	5	4
Velocity (m/s)	1.4m/s	1.7m/s	1.6m/s	1.6m/s	2m/s	1.4m/s	1.6m/s	3.2m/s	2m/s	2m/s
pH value		7.6	7.4	7.5	7.8	7.6	7.9	7.4	8.4	8.8
Sites	**Stream 1 (upstream)**					**Stream 2 (upstream)**				
Air temp (^{0}C)	27.5	23	19	21	28	27.5	28	24	27	25
Water temp (^{0}C)	25.8	19	16	17	20	25.8	23	20	21	20
Stream depth (cm)	45	88	51	41	36	24	31	21	32	14
Stream width (m)	14	5.5	6	11	7	5.4	11.67	3	3.5	1.2
Velocity (m/s)	1.2m/s	1.26m/s	0.8m/s	1.6m/s	2.2m/s	1.2m/s	1.52m/s	1.8m/s	2.2m/s	2.8m/s
pH value	7.1	7.5	7.1	7.6	7.7	7.3	8.3	7.6	8.1	8.4

The majority of HKH Biotic score values exceeded the threshold of 7.60, indicating minimal impairment. However, occasional deviations into the moderate pollution category (RQC II) were noted, particularly in Stream 1 during February and Stream 2 in November and January. These fluctuations suggest transient increases in pollution levels, likely influenced by seasonal variations or localised anthropogenic activities.

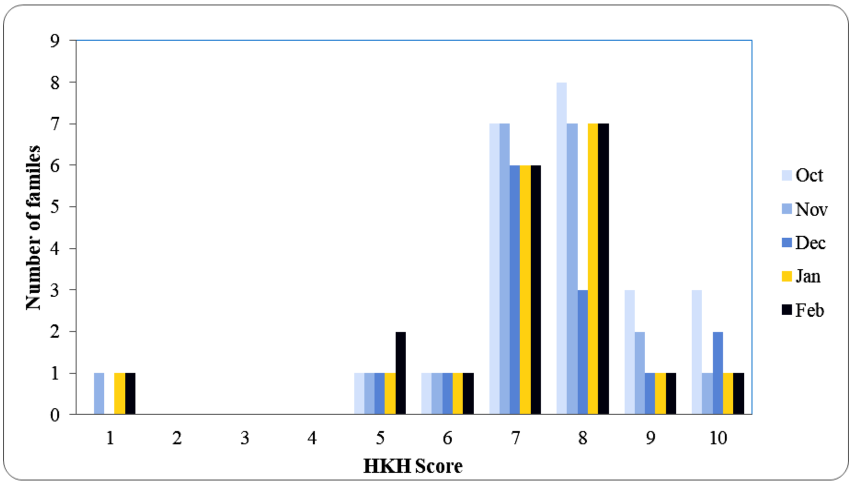


Figure 6a: Monthly HKH scores distribution for the families caught in stream 1 (Diana)

This pattern reflects a generally favourable stream water quality, but the occasional shifts into moderate pollution highlight the importance of ongoing monitoring and management. The geographic characteristics of the study area, including topography and hydrology, likely contribute to the high water quality in pristine mountainous regions, with natural filtration processes from vegetation and soil mitigating pollution (Hartmann et al., 2007). Conversely, variations in land use practices within the catchment areas such as agricultural, urban, or industrial activities - are likely contributors to the observed fluctuations in water quality. While areas with minimal human disturbance maintain healthy stream ecosystems, regions with higher anthropogenic pressures can experience increased pollutant loads, leading to periodic shifts into moderate pollution (Menetrey et al., 2008).

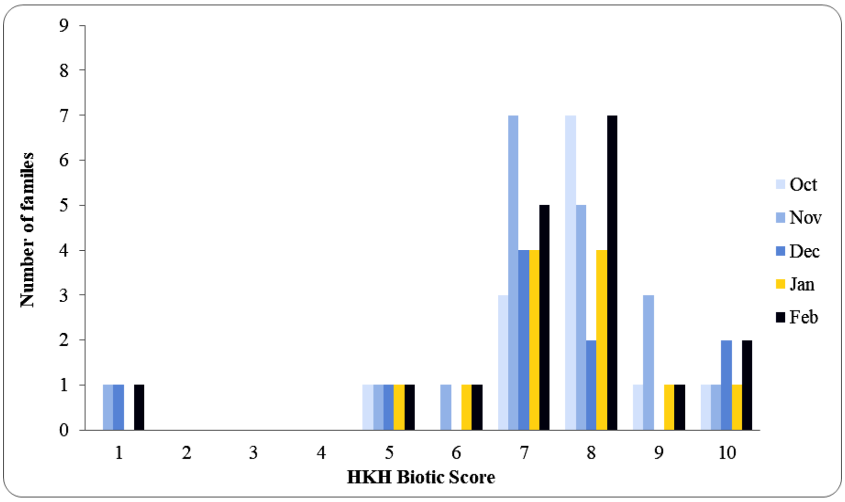


Figure 6b: Monthly HKH scores distribution for the families caught in stream 2 (Dipijhora)

Moreover, seasonal and climatic factors also influence water quality. Post-monsoon periods often see increased sedimentation and nutrient runoff, which can affect water quality and biotic score assessments (Barbour et al., 1999). Overall, the application of the HKH biotic score provides valuable insights into stream health, demonstrating the resilience of less disturbed environments and highlighting the vulnerabilities of regions subjected to human pressures. These findings emphasise the need for strategic conservation and ongoing management to ensure the sustainability of water resources in the region.

Streams' Physical and Chemical Characteristics and Influences

The analysis of two typical streams in southwest Bhutan revealed both similarities and differences in their physical and chemical characteristics (Table 3). Both streams exhibited higher temperatures and velocities downstream, with variations in parameters such as depth, width, and pH values.

These differences are likely influenced by both environmental factors and human activities. While key parameters, including air and water temperatures, stream depth, width, velocity, and pH values, generally show consistent patterns across different sampling sites and months, some minor fluctuations exist. These similarities suggest that both streams share similar environmental conditions, shaped by a combination of natural processes and human influences. The slight variations in pH levels and stream velocities are relatively minor compared to the overall consistency in stream health between the two streams.

The complex interaction of physical and chemical parameters underscores the need for effective water resource management. Natural factors such as geographical and climatic conditions, coupled with human activities like agriculture, urbanisation, and industrialisation, contribute to these dynamics. Variations in depth, width, and temperature are influenced by landscape features and seasonal weather patterns, while pH levels and stream velocities are likely affected by both natural processes and anthropogenic influences. Additionally, changes in land use and hydrological dynamics can alter sedimentation rates, nutrient loads, and pollutant concentrations, further impacting water quality.

These findings align with previous research, highlighting the interconnectedness of natural and human-induced factors in shaping stream ecosystems (Hedrick et al., 2010). The observed coherence in the physical and chemical characteristics of the streams in southwest Bhutan emphasises the importance of holistic conservation and management strategies. By addressing shared environmental challenges and promoting sustainable stream health, these strategies can ensure the continued resilience of stream ecosystems across the region. Monitoring and managing these parameters are crucial for maintaining water quality and supporting both human and wildlife needs.

Conclusion

This study on the streams of southwest Bhutan highlights the complex interplay between natural and anthropogenic factors influencing stream ecosystems. The findings revealed that both streams exhibited generally favourable water quality, with minimal pollution levels and consistent physical and chemical characteristics across sampling sites. However, occasional deviations into moderate pollution levels underscore the importance of continuous monitoring. Temporal variations in macroinvertebrate communities, particularly in relation to seasonal changes, further emphasise the dynamic nature of these ecosystems. The analysis of key taxa and water quality using the HKH biotic score illustrates the resilience of pristine environments, while also highlighting the vulnerabilities of areas affected by human activities. The study underscores the need for integrated conservation and management strategies that account for both natural processes and anthropogenic pressures, ensuring the sustainability of water resources and the health of stream ecosystems in the region.

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