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Effect of water quality on macrobenthic fauna in Achenkovil River, Southern-Western Ghats, Kerala, India

Efeito da qualidade da água na fauna macrobentônica no rio Achenkovil, Southern-West Ghats, Kerala, Índia

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Abstract: Aim: The present study investigated the influence of environmental variables on macrobenthic fauna in the Achenkovil River, Southern Western Ghats, Kerala. The knowledge of aquatic ecosystems in many remote areas is very scanty and no one has yet made an attempt to study the macrobenthic fauna of Achenkovil river. Since, macrobenthos play an important role in the benthic community structure a better knowledge of their ecology and distributional patterns in remote freshwater ecosystems would be of great interest for a better understanding of their functioning. **Methods:** A bimonthly sampling was conducted from February 2019 to January 2020. Water samples for physicochemical analysis were carried to the laboratory in clean polyethylene bottles. The macrobenthic fauna was collected using Van Veen grab (0.025m^2). Multivariate statistical technique such as Principal Component Analysis was used to monitor the variation in environmental parameters. The diversity of macrobenthic fauna was studied using Simpson_1-D, Shannon_H, Evenness_e^H/S, and Margalef's indices. We analyzed the relationship between environmental variables and macrobenthic fauna, using Canonical Correlation Analysis and Pearson correlation. **Results:** A total of 3563 individuals belonging to 9 orders, 32 families, 32 genera, and 32 species were identified. The most dominant order was Ephemeroptera followed by Coleoptera and Trichoptera and the least dominant was Zygoptera. The maximum number of macrobenthic fauna was observed in station 1(S1), (1461 Ind/m2) and the least in station 9 (S9), (37 Ind/m^2). Station 1 (S1) is a pristine forest area, so this area is considered the reference site. The macrobenthic fauna in the pristine headwater forests (S1) was much more diverse than in the river mouth (S9) which is a highly impacted region. This region is facing various kinds of anthropogenic stress resulting in pollution and deterioration of water quality. The macrobenthic community structure in the Achenkovil River was significantly associated to the variations in water quality due to various natural as well as anthropogenic stresses. **Conclusions:** It can be concluded that Ephemeroptera, Coleoptera, and Trichoptera were the most dominant groups in the undisturbed habitats in the river during the study period. The predominance of Chironomidae species, especially from the *Chironomus* genus in the midstream and downstream segments of the river is possibly due to their ability to adapt to various environmental conditions or habitats and their tolerance to the low oxygen content in anoxic conditions of the bottom sediment. The lowest abundance of macrobenthos at all the studied stations was observed at station 9 (S9) during dry seasons. S9 is a highly impacted region, characterized by high temperature, turbidity, TDS, pH, conductivity, nitrate, and phosphate values. For this reason, anthropogenic stress and changing environmental conditions are the main factors affecting the distribution of the macrobenthic fauna of the Achenkovil River basin, Kerala.

Keywords: biodiversity indices; biological indicators; freshwater ecosystems; ephemeroptera; multivariate analysis.

Resumo: Objetivo: O presente estudo investigou a influência de variáveis ambientais na fauna macrobêntica no rio Achenkovil, Southern Western Ghats, Kerala. O conhecimento dos ecossistemas aquáticos em muitas áreas remotas é muito escasso e ninguém ainda fez uma tentativa de estudar a fauna macrobentônica do rio Achenkovil. Uma vez que os macrobenthos desempenham um papel importante na estrutura da comunidade bentônica, um melhor conhecimento de sua ecologia e padrões de distribuição em ecossistemas remotos de água doce seria de grande interesse para uma melhor compreensão de seu funcionamento. **Métodos:** Foram realizadas coletas bimensais de fevereiro de 2019 a janeiro de 2020. As amostras de água para análises físico-químicas foram levadas ao laboratório em frascos de polietileno limpos. A fauna macrobentônica foi coletada usando garrafa de Van Veen (0,025m2). A técnica estatística multivariada, como a Análise de Componentes Principais, foi utilizada para monitorar a variação dos parâmetros ambientais. A diversidade da fauna macrobêntica foi estudada usando os índices Simpson_1-D, Shannon_H, Evenness_e^H/S e Margalef. Analisou-se a relação entre as variáveis ambientais e a fauna macrobêntica, utilizando a Análise de Correlação Canônica e a Correlação de Pearson. **Resultados:** Foram identificados 3.563 indivíduos pertencentes a 9 ordens, 32 famílias, 32 gêneros e 32 espécies. A ordem mais dominante foi Ephemeroptera seguida por Coleoptera e Trichoptera e a menos dominante foi Zygoptera. O número máximo de fauna macrobentônica foi observado na estação 1(S1), (1461 Ind/m2) e o menor na estação 9 (S9), (37 Ind/m2). A Estação 1 (S1) é uma área de floresta intocada, portanto esta área é considerada o local de referência. A fauna macrobentônica nas florestas virgens da cabeceira (S1) foi muito mais diversa do que na foz do rio (S9), que é uma região altamente impactada. Esta região enfrenta vários tipos de estresse antropogênico, resultando em poluição e deterioração da qualidade da água. A estrutura da comunidade macrobentônica no rio Achenkovil foi significativamente associada às variações na qualidade da água devido a vários estresses naturais e antrópicos **Conclusões:** Pode-se concluir que Ephemeroptera, Coleoptera e Trichoptera foram os grupos mais dominantes nos habitats não perturbados no rio durante o período de estudo. A predominância de espécies de Chironomidae, principalmente do gênero *Chironomus* nos segmentos médio e jusante do rio, possivelmente se deve à sua capacidade de adaptação a diversas condições ambientais ou habitats e sua tolerância ao baixo teor de oxigênio em condições anóxicas do sedimento de fundo. A menor abundância de macrobentos em todas as estações estudadas foi observada na estação 9 (S9) durante as estações secas. S9 é uma região altamente impactada, caracterizada por alta temperatura, turbidez, TDS, pH, condutividade, nitratos e valores de fosfato. Por esta razão, o estresse antropogênico e a mudança das condições ambientais são os principais fatores que afetam a distribuição da fauna macrobentônica da bacia do rio Achenkovil, Kerala.

Palavras-chave: índices de biodiversidade; indicadores biológicos; ecossistemas de água doce; ephemeroptera; análise multivariada.

1. Introduction

Rivers are highly dynamic ecosystems. The hydrology, connectivity, and geomorphology create heterogenous environments in rivers resulting in different microhabitats that influence the migration and dispersion of aquatic organisms (Poff & Allan, 1995; Picapedra et al., 2022). The ability of macrobenthic invertebrates to respond to different ecological conditions varies from species to species and therefore can be used as bioindicators for water quality assessments in highly disturbed ecosystems (Sharma et al., 2006). Macrobenthos plays a key role in the functioning of an ecosystem and is considered a potent bioturbator (Chakraborty et al., 2022). The multiple roles played by these ecosystem engineers through bioturbation facilitate the freshwater as a self-sustaining and self–stabilizing system (Chakraborty et al., 2022).

The omnipresence and sedentary nature of the macrobenthic fauna helps to monitor spatial analysis of pollutants in the water body or they are differentially sensitive to many biotic and abiotic factors in their environment (Yorulmaz & Ertaş, 2021). The community structure of macrobenthic fauna is significantly influenced by the variations in water quality due to various natural as well as anthropogenic stresses. Therefore, the community structure has commonly been used as an indicator of the condition of an aquatic system (Yorulmaz & Ertaş, 2021).

An increase in population growth rate, industrialization, urbanization, inappropriate use of fertilizers for agricultural purposes, etc. fastens habitat degradation that finally results in the global decline of biodiversity and ecological functionality of freshwater ecosystems (Deborde et al. 2016). Nowadays water quality monitoring programs are implemented to assess the biological status of freshwater ecosystems and to sustain the human and ecological needs of freshwater.

Traditional methods for assessing water quality are based on physicochemical parameters alone, and that is insufficient in providing better results. Therefore, combining physicochemical parameters with biological monitoring can provide a comprehensive evaluation of the overall condition of freshwater ecosystems (Heatherly II et al., 2007).

To conserve the biodiversity of freshwater ecosystems it is important to determine how the macrobenthic fauna are influenced by abiotic and biotic factors, Medupin (2020). This study attempts to determine the effect of environmental parameters such as water temperature (WT), Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), turbidity, TDS, conductivity, pH, nitrate, phosphate, and silicate on macrobenthic fauna in the Achenkovil River basin, Kerala. Since there are no published data on the macrobenthic fauna of the Achenkovil River, this study serves as an initial baseline data for the development of a biotic index for freshwater rivers.

Macrobenthic invertebrates are employed for ecological river assessment studies in different parts of the world. But the use of macrobenthic fauna in India is still in its infancy. In Kerala the knowledge of riverine biodiversity is scanty, and biomonitoring and conservation of rivers are not well developed. However, the assessment methods based on Macrobenthic invertebrates serve as efficient tools for water quality monitoring programs (Korte et al., 2010), due to the increase in pollution and anthropogenic impacts in waterbodies, which are well reflected by the benthic communities.

2. Materials and Methods

2.1. Study area

The Achenkovil River originates in the Southern tip of the peninsula by the confluence of the Rishimala, Pasukidamettu, and Ramakkalteri rivers from Devarmalai of Western Ghats (9°19’0” N 76°28’0” E), Kerala, India (Figure 1). The length of this river is 120 km, the basin size is 1,484 km^2 and the average water flow is 2287 million cubic meters. Based on the Strahler method of stream ordering, Strahler (1957) the Achenkovil River is considered as a seventh-order stream with two sixth order tributaries, 10 fifth order tributaries and 41 fourth order tributaries, Dhanya (2014). The river drains through highly varied geological formulations and covers the highland, midland, and lowland physiographic provinces of the state. About 60% of the highland is occupied by dense forest, 5% by degraded forest and 10% is agricultural land (Prasad & Ramanathan, 2005).

Figure 1. Map showing the study sites in the Achenkovil river basin, Kerala.

Forty percent of the Midland region is under double-crop paddy cultivation. The lowland region is a narrow strip of land along the West Coast and is occupied by 80% agricultural land (mixed agricultural/horticultural plantation) and 10% under double crop paddy cultivation. The rest of the area was occupied by water bodies. The study area experiences a semiarid tropical climate. The area is influenced by the Southwest Monsoon (June – September) and Northwest Monsoon (October – December), with an annual rainfall of 2000-5000 mm (Prasad & Ramanathan, 2005).

2.2. Sampling methods and biological data

Samples were collected bimonthly, and early in the morning hours (06.00 - 11.30 h) throughout the study period (2019-2020). The entire river body is divided into three segments- upstream stations (S1, S2, S3) with 9°07'39.53'N and 77°07'58.56'E with an elevation of 870 ft a.m.s.l, midstream stations (S4, S5, S6)- 9°13'59.37'N and 76°40'38.4'E with an elevation of 66 ft a.m.s.l, and downstream stations (S7, S8, S9) with 9°19'29.07'N and 76°26' 54.31'E with an elevation of 6 ft a.m.s.l - with three stations in each segment of the river (Figure 1), (total 9 sampling sites along the entire stretch of the river).

Station 1 (S1), located in the deepest part of the Western Ghats, the river is flanked by a reserve forest with thick vegetation. As it is a pristine forest region with no anthropogenic impacts it is considered the reference site. The mean depth of this site was recorded as 0.9m. Station 2 (S2), a major stream that flows into the Achenkovil originates here with a mean depth of 1.32m. A sizeable portion of this remote village falls within Konni Reserve Forest. Stations 3 to 9 (S3 to S9), are severely under anthropogenic impacts. The mean depth of these stations was 2.43m (S3), 3.49m (S4), 4.11m (S5), 3.19m (S6), 3.85m (S7), 3.15m (S8), 2.08m (S9). During the pre-monsoon season, the water level decreases and the water flow gets obstructed (the flow velocity decreases or the water remains flowless) in this river. Stations S8 and S9 face saline intrusion from the nearby Kayamkulam Lake during this period.

Macrobenthic fauna was collected using Van Veen grab in triplicates (0.025m^2). The grab samples collected were sieved through a series of mesh sieves- 3000μm (3mm), 2000 μm (2mm), 1000 μm (1mm), and 500μm (0.5mm) mesh, and the sediments retained in the 0.5mm sieve was washed, and the samples were carefully transferred to a white plastic tray and sorted out. All the collected macrobenthic fauna were preserved in 80% ethanol for subsequent analysis. In the laboratory, the preserved sample was examined using a stereomicroscope (Magnus MSZ- BI LED) and identified up to genus as well as to species level using standard taxonomic literature (Covich et al., 1999; Dudgeon, 1999; Yule & Sen, 2004; Thorp & Rogers, 2015; Selvakumar et al., 2019)

2.3. Environmental variables

The temperature was recorded immediately after collection at the field itself with a mercury thermometer (with ± 0.1°C accuracies). The samples for Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD) were fixed with alkaline potassium iodide and manganous sulphate at the site itself. The water samples were then carried immediately to the laboratory for further analysis. The DO (mg/l) and BOD (mg/l) were analyzed using Winkler's method, pH (pH meter), turbidity (NTU) by Nephelometric method, conductivity (μS/cm) using Systronics water analyzer 371, TDS (mg/l) by gravimetric method, nitrate (mg/l), phosphate (mg/l), and silicate were carried out using spectrophotometric method, APHA (2017).

2.4. Statistical analysis

The variation of environmental parameters and the relationship of environmental variables with the macrobenthic fauna was analyzed using the multivariate statistical techniques, Principal Component Analysis (PCA), and Canonical Correlation Analysis (CCA), respectively. Pearson's correlation was also conducted to quantify the association between the studied physicochemical parameters and the macrobenthic fauna. Principal Component Analysis was conducted using SPSS (version 22). Canonical Correlation Analysis (CCA) and Pearson's Correlation, diversity indices such as Simpson, Shannon-Weiner, Evenness, and Margalef's indices were calculated using PAST (version 4.06 b).

3. Results

A total of 3563 individuals belonging to 9 orders, 32 families, 32 genera, and 32 species were identified (Table 1). The order Ephemeroptera accounted for 24.06% of the total macrobenthic fauna and was the most dominant, diverse, and abundant group studied. This order was represented by 8 families- Leptophlebiidae (19.88%), Caenidae (19.65%), Baetidae (17.79%), Heptageniidae (10.93%), Teloganodidae (10.11%), Tricorythidae (8.60%), Ephemerellidae (7.55%) and Ephemeridae (5.46%).

The second largest group was Coleoptera with 7 families- Dytiscidae (7.24%), Psephenidae (32.33%), Elmidae (28.26), Scarabaeidae (3.53%), Hydraenidae (20.82%), Hydrophilidae (21.20%), and Noteridae (4.59%). The order Odonata was represented by two sub orders- Anisoptera and Zygoptera. The sub-order Anisoptera was represented by three families- Gomphidae (45.72%), Aeshnidae (28.64) and Libellulidae (25.62) while the sub-order Zygoptera was represented by a single family Euphaeidae The order Diptera was represented by Chironomidae (58.13%), Athericidae (26.42%), Tipulidae (7.18%), and Tabanidae (8.24%). The order Hemiptera was also represented by 4 families- Belostomatidae (31.28%), Vellidae (28.07%), Notonectidae (24.87%), and Nepidae (15.78%). The order Trichoptera was represented by 3 families - Hydropsychidae (43.89%), Philopotamidae (30.97%), and Ecnomidae (25.13%). The orders Plecoptera and Megaloptera were represented by Pearlidae and Corydalidae respectively.

Table 1. Taxonomic composition and seasonal occurrence (PreM = Premonson, Mons = Monsoon and PosM = Post-monsoon seasons) of the studied macrobenthic fauna in the Achenkovil river basin, Kerala. ('+' sign indicates presence and '- 'sign indicates absence).

Order/Family	Genus and species	PreM	Mons	PosM
	Ephemeroptera			
Leptophlebiidae	*Notophlebia jobi* Sivaramakrishnan & Peters, 1984	+	+	+
Caenidae	*Caenis* sp. Stephens, 1836	+	+	+
Ephemerellidae	*Torleya nepalica* Allen and Edmunds, 1963	+	+	+
Teloganodidae	*Dudgeodes* sp. Sartori & Peters & Hubbard, 2008	+	+	+
Tricorythidae	*Sparsorythus gracilis* Sroka & Soldan, 2008	+	+	+
Ephemeridae	*Ephemera* (*Aethephemera*) *nadinae* McCafferty and Edmunds, 1973	+	-	+
Heptageniidae	*Afronurus kumbakkaraiensis* Venkataraman & Sivaramakrishnan, 1989	+	+	+
Baetidae	*Baetis sp.* Leach, 1815	+	+	+
	Plecoptera			
Perlidae	*Neoperla* Needham, 1905	+	+	+
	Diptera			
Chironomidae	*Chironomous* sp. Meigen, 1803	+	+	+
Athericidae	*Atherix* sp. Meigen, 1803	+	+	+
Tipulidae	*Tipula* sp. Linnaeus, 1758	+	+	+
Tabanidae	*Tabanus* sp. Linnaeus, 1758	+	+	+
	Hemiptera			
Notonectidae	*Micronecta* sp. Kirkaldy, 1897	+	+	+
Vellidae	*Microvelia douglasi* Scott, 1874	+	+	+
Belostomatidae	*Lethocerus indicus* Lepeletier and Serville, 1825	+	+	+
Nepidae	*Nepa* sp. Linnaeus, 1758	+	+	+
	Zygoptera			
Euphaeidae	*Euphaea* sp. Selys, 1840	+	+	+
	Anisoptera			
Gomphidae	*Stylogomphus* sp. Fraser, 1922	+	+	+
Aeshnidae	*Anax* sp. Leach, 1815	+	+	+
Libellulidae	*Crocothemis servilia* Drury, 1773	+	+	+
	Megaloptera			
Corydalidae	*Corydalus* sp. Latreille, 1802	+	+	+
	Coleoptera			
Dytiscidae	*Agabu*s sp. Leach, 1817	+	+	+
Psephenidae	*Eubrinax* sp. Lacordaire, 1857	+	+	+
Elmidae	*Cylloepus* sp. Erichson, 1847	+	+	+
Scarabaeida	*Rhyssemus* sp. Mulsant, 1842	+	-	+
Hydraenidae	*Hydrena* sp. Kugelann, 1794	+	-	+
Hydrophilidae	*Hydrophilus* sp. Geoffroy, 1762	+	+	+
Noteridae	*Hydrocanthus* sp. Say, 1823	+	+	+
	Trichoptera			
Ecnomidae	*Ecnomous* sp. Ulmer, 1903	+	+	+
Philopotamidae	*Chimarra* sp. Stephens, 1829	+	+	+
Hydropsychidae	*Hydropsyche* sp. Pictet, 1834	+	+	+

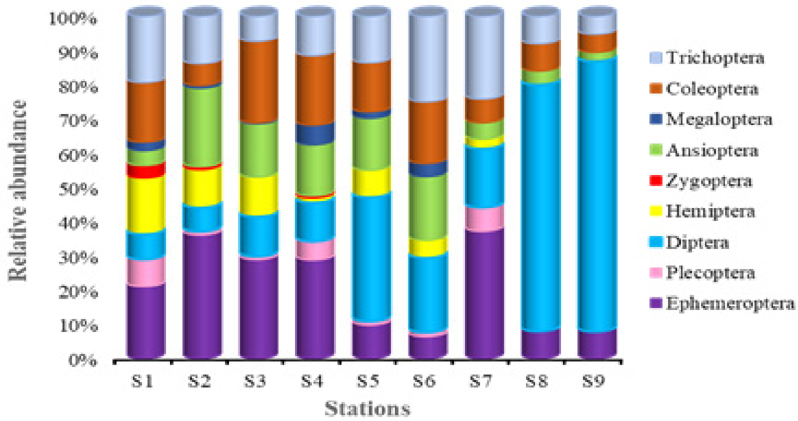

Figure 2. Percentage composition of the studied macrobenthic groups in Achenkovil river basin, Kerala.

The maximum number of individuals were present in station 1 (S1), (1461Ind/m^2 & 32 taxa), and the minimum number of individuals were present in station 9 (S9), (37 Ind/m^2 & 4 taxa) (Figure 2). The highest values for Simpson_1-D (0.95), and Shannon_H (3.23) were reported from station 1(S1), Evenness_e^H/S (0.86), and Margalef's (5.17) in station 3 (S3), and the lowest values for Simpson_1-D (0.34), Shannon_H (0.73) and Margalef index (0.83) were reported from station 9 (S9) and Evenness_e^H/S (0.44) in station 8 (S8) (Figure 3). The most dominant order in station 1 (S1) was Ephemeroptera followed by Trichoptera and Coleoptera and the least dominant was Zygoptera. In the downstream stretches of the river, the pollution-sensitive species were absent or few, and chironomids dominated in stations - S5, S6, S7, S8 & S9. The orders such as Megaloptera, Hemiptera, Zygoptera and Plecoptera were not at all present in S8 and S9 during the entire sampling period. The seasonal analysis reveals that the maximum number of individuals were present during the post-monson season (1794 Ind/m^2 & 32 taxa), and the minimum number of individuals were present during the monsoon season (474 Ind/m^2 & 29 taxa). The highest value for for Simpson_1-D (0.95), Shannon_H (3.23) and Evenness_e^H/S (0.79) were reported during the post-monsoon season, while for Margalef index (4.54) was during the monsoon season. Similarly, the lowest value for Simpson_1-D (0.93), Shannon_H (3.01) and Evenness_e^H/S (0.70) were reported during the monsoon season while for Margalef index (4.13) was during the post-monsoon season. The most dominant order during the post-monsoon season was Ephemeroptera followed by Coleoptera.

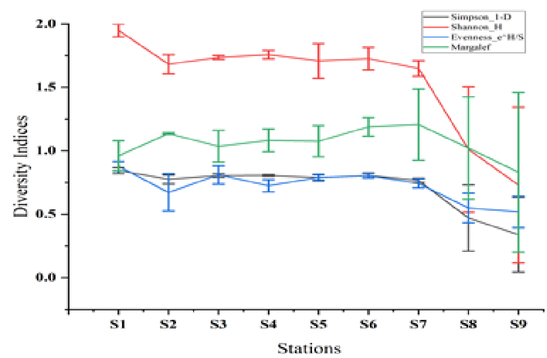

Figure 3. Spatial variations of biological indices (Simpson, Shannon, Evenness and Margalef) in the different studied stations of the Achenkovil river basin, Kerala.

Trichoptera dominated during the premonsoon season while Diptera dominated during the monsoon season.

The mean spatial variation of the studied physicochemical parameters was given in (Tables 2 and 3). The variation in the environmental parameters was analyzed using Principal Component Analysis, which explained 71.69% of the total variance (Table 4). Principal Component 1 explained 28.33% of the total variance and had a strong positive correlation with water temperature, and Biological Oxygen Demand (BOD), a strong negative correlation with silicate with a loading value of >0.75, and a moderate negative correlation with Dissolved Oxygen (DO), (>0.50- 0.75). Principal Component 2 accounted for 21.72% of the total variance and has a strong positive correlation with conductivity, pH, and a moderate positive correlation with TDS. Principal Component 3 accounted for 21.62% of the total variance and had a strong positive correlation with nitrate, and phosphate and a moderate positive correlation with turbidity.

Based on CCA (Canonical Correlation Analysis), the first canonical axis of the ordination plot explained over 46.01% (Eigenvalue, 0.124) and the second 31.36% (Eigenvalue, 0.084) of the variation in the macrobenthic fauna data set. The Monte Carlo permutation test performed on the first two axes showed no significant differences ($p>0.05$). The CCA reveals that water quality parameters such as water temperature, BOD, turbidity, TDS, conductivity, pH, nitrate, and phosphate show a positive correlation with macrobenthic groups such as Diptera and Anisoptera. The DO and silicate show a negative correlation with Ephemeroptera, Plecoptera, Hemiptera, Zygoptera, Megaloptera, Coleoptera, and Trichoptera. The studied physicochemical parameters have a strong influence on the community structure of macrobenthic fauna. From the CCA ordination plot, the macrobenthos shows spatial variations concerning their environmental requirements (Figure 4). The Pearson's correlation matrix also showed similarity with the Canonical Correlation Analysis results. The major macrobenthic groups are negatively correlated with water temperature, Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), turbidity, and conductivity. The CCA and the correlation matrix (Table 5) revealed, how the environmental variables influence the variation of macrobenthic fauna in the Achenkovil River basin.

Table 2. Mean ± SD of the studied physicochemical parameters in the Achenkovil river, Kerala.

Stations	Water temperature (°C)	DO (mg/L)	BOD (mg/L)	Turbidity (NTU)	TDS (mg/L)
S1	24.33 ± 1.92	6.98 ± 1.14	1.34 ± 0.73	5.17 ± 5.13	102.0 ± 22.5
S2	25.60 ± 1.54	6.62 ± 1.13	1.68 ± 0.81	4.90 ± 2.74	117.8 ± 35.86
S3	26.05 ± 1.23	6.59 ± 1.02	2.17 ± 0.74	5.08 ± 1.92	110.5 ± 40.47
S4	27.06 ± 0.89	6.84 ± 0.96	2.23 ± 0.64	5.79 ± 3.06	111.9 ± 33.8
S5	27.70 ± 1.18	6.84 ± 0.96	3.17 ± 1.95	6.73 ± 1.76	113.4 ± 32.9
S6	27.75 ± 0.96	6.37 ± 0.95	2.90 ± 1.66	7.17 ± 2.39	152.6 ± 46.80
S7	28.10 ± 0.87	6.15 ± 1.04	2.60 ± 0.79	7.60 ± 2.39	142.0 ± 37.11
S8	29.10 ± 1.02	5.86 ± 1.02	2.97 ± 0.56	8.80 ± 3.13	320.2 ± 120.9
S9	29.52 ± 1.02	5.57 ± 1.03	2.92 ± 0.64	8.64 ± 2.38	338.1 ± 122.0

Table 3. Mean ± SD of the studied physicochemical parameters in the Achenkovil river, Kerala.

Stations	Conductivity (µS/cm)	pH	Nitrate (mg/L)	Phosphate (mg/L)	Silicate (mg/L)
S1	74.53 ± 15.46	6.90 ± 0.31	0.70 ± 0.16	0.52 ± 0.11	3.50 ± 0.57
S2	62.86 ± 14.49	6.77 ± 0.23	0.89 ± 0.15	0.47 ± 0.16	2.70 ± 0.54
S3	60.30 ± 12.90	6.78 ± 0.13	0.88 ± 0.20	0.53 ± 0.16	2.86 ± 0.60
S4	67.27 ± 15.33	6.79 ± 0.20	0.79 ± 0.21	0.64 ± 0.15	3.08 ± 0.75
S5	76.04 ± 22.10	6.85 ± 0.21	0.99 ± 0.21	0.53 ± 0.18	3.02 ± 0.65
S6	75.70 ± 18.56	6.79 ± 0.24	1.03 ± 0.25	0.59 ± 0.20	2.0 ± 0.53
S7	81.6 ± 12.21	6.76 ± 0.28	0.91 ± 0.24	0.52 ± 0.18	2.4 ± 0.34
S8	170.0 ± 161.4	6.91 ± 0.33	0.95 ± 0.15	0.78 ± 0.26	2.07 ± 0.66
S9	182.87 ± 173.3	7.10 ± 0.22	0.95 ± 0.13	0.92 ± 0.21	2.05 ± 0.43

Table 4. shows the variation in the environmental parameters analyzed using Principal Component Analysis.

Parameters	Component		
	1	2	3
Water temperature (°C)	**802**	248	187
DO (mg/L)	**-683**	-321	379
BOD (mg/L)	**805**	-074	-193
Turbidity (NTU)	-029	455	674
TDS (mg/L)	507	**630**	330
Conductivity (µS/cm)	356	**840**	012
pH	012	**805**	-036
Nitrate (mg/L)	-118	-117	**829**
Phosphate (mg/L)	-006	034	**833**
Silicate (mg/L)	**-822**	-178	031
Eigenvalues	2.83	2.17	2.16
% of variance	28.33	21.72	21.62
Cumulative %	28.33	50.06	71.69

Table 5. Correlation between the studied physicochemical parameters and the macrobenthic fauna dataset.

	Water temperature	DO	BOD	Turbidity	TDS	Conductivity	pH	Nitrate	Phosphate	Silicate	Ephemeroptera	Plecoptera	Diptera	Hemiptera	Zygoptera	Anisoptera	Coleoptera	Trichoptera
Water temperature	1																	
DO	-0.82	1																
BOD	0.89	-0.57	1															
Turbidity	0.93	-0.86	0.80	1														
TDS	0.78	-0.91	0.53	0.85	1													
Conductivity	0.74	-0.86	0.50	0.84	0.99	1												
pH	0.42	-0.56	0.24	0.53	0.76	0.83	1											
Nitrate	0.70	-0.53	0.84	0.59	0.38	0.30	0.03	1										
Phosphate	0.74	-0.79	0.49	0.76	0.92	0.93	0.83	0.23	1									
Silicate	-0.80	0.88	-0.66	-0.79	-0.73	-0.63	-0.26	-0.77	-0.58	1								
Ephemeroptera	-0.88	0.71	-0.93	-0.78	-0.59	-0.52	-0.20	-0.92	-0.47	0.82	1							
Plecoptera	-0.68	0.55	-0.71	-0.45	-0.37	-0.26	0.08	-0.86	-0.25	0.71	0.86	1						
Diptera	-0.50	0.73	-0.30	-0.41	-0.46	-0.33	0.04	-0.54	-0.30	0.82	0.58	0.72	1					
Hemiptera	-0.80	0.55	-0.77	-0.55	-0.39	-0.30	0.07	-0.76	-0.37	0.70	0.83	0.92	0.65	1				
Zygoptera	-0.69	0.48	-0.70	-0.42	-0.30	-0.20	0.15	-0.78	-0.25	0.65	0.81	0.97	0.67	0.98	1			
Anisoptera	-0.77	0.81	-0.74	-0.84	-0.68	-0.66	-0.39	-0.66	-0.51	0.74	0.83	0.51	0.51	0.46	0.42	1		
Coleoptera	-0.78	0.71	-0.74	-0.64	-0.52	-0.43	-0.06	-0.89	-0.34	0.83	0.89	0.94	0.76	0.86	0.88	0.67	1	
Trichoptera	-0.78	0.62	-0.76	-0.55	-0.46	-0.37	-0.01	-0.80	-0.39	0.73	0.88	0.98	0.71	0.96	0.98	0.57	0.91	1

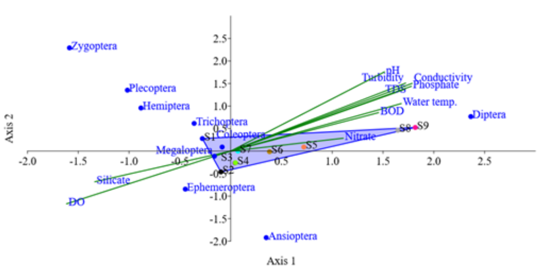

Figure 4. CCA plot showing the spatial variation in environmental variables and the studied macrobenthic fauna of Achenkovil River basin.

4. Discussion

The community assemblages of macrobenthic fauna are structured according to physicochemical as well as biological parameters (Abdelsalam & Tanida, 2013). The macrobenthic fauna of the Achenkovil River was not investigated by any other study so far. In the present study, the most representative group in the undisturbed habitat was Ephemeroptera (8 taxa) followed by Coleoptera and the disturbed habitat was dominated by Diptera (4 taxa). The spatial as well as temporal variation was clear between the studied stations and seasons, especially for the number of individuals and diversity indices. These findings agree with the low value of faunal diversity as we move from stations 1 to 9 (S1 to S9) during different sampling occasions. The higher taxon richness at S1 indicate a site with good ecological status, Medupin (2020). Hence these sites can be considered reference sites to compare with other segments of the river.

The present study also showed that the Achenkovil River basin is also influenced by seasonal variations mostly brought in by the monsoons and anthropogenic activities: however high amount of organic load accumulated in the sediments leads to the survival and proliferation of indicator macrobenhtic species. There is a difference in the species abundance and diversity in accordance to the seasonal changes with higher abundance during the post-monsoon season and least abundance during the monsoon season. The lifecycle of a tropical macrobenthic organism integrates with the monsoon and this results in seasonal differences in occurence and abundance of such organisms (Noyel & Desai, 2020). The least abundance during the monsoon season may be due to the high disturbance such as the sediment agitation caused by the monsoon arrival is not equally tolerated by all macrofauna. As a result, when the monsoon progress the abundance of sensitive species declines and replaced by more tolerant species in greater numbers, consequently overall abundance starts to increase and diversity starts to decline.

With the end of the monsoon season and the environment starts to progress towards stability the abundance of tolerant species declines due to the competition for food and space which results in increased eveness with other species and subsequently high diversity and stable benthic environment during post-monsoonal conditions (Pandey & Thiruchitrambalam, 2019).

Most species of Ephemeroptera are sensitive to environmental stress and their presence marked a positive condition (Merritt & Cummins, 1996). The order Plecoptera is extremely sensitive to environmental degradation (Hershey et al., 2010). The presence of Plecoptera in the upstream as well as the midstream segments of the river is an indication of larger microhabitat diversity and their decline/absence in thedownstream segments (S8 & S9) is a piece of clear evidence for deteriorating habitat and water quality (Masese et al. 2009). High richness in protected habitats and low richness in disturbed habitats is the foundation of biomonitoring programs using macroinvetebrates (Hepp et al., 2010). A study on the biodiversity indices revealed that the sampling station with the highest dissolved oxygen level, station 1(S1) had the highest Simpson and Shannon - Weiner diversity index. Higher values of these indices indicate less stress, higher abundance, and more even distribution of species in the ecosystem (Bagalwa et al., 2019). The maximum DO value observed in S1 may be the result of low water temperature, increased turbulence, and oxygenation as a result of the rugged topography of the river basin (Alam et al., 2007).

Higher sub-catchment areas and urban covers were the features of stations 3 to 9 (S3 to S9), and these sites will be impacted by other factors such as silted banks and modified river channels. These factors impede the ability of the river to maintain its biodiversity, Brown (2007). The number of species was not very high in station 3 (S3), and the number of individuals was low when compared to other stations and this is the reason for the highest values for Eveness_ e^H/S and Margalef index in station 3 (S3), Gamito (2010).

Low rainfall, low water flow, elevated temperature, and anthropogenic stress, may be a reason for the high BOD value in S5 (Girija et al., 2007). *Chironomus* sp. is the most dominant group in S5 and is an indicator of poor water quality (Copatti et al., 2013). The famous Ayappa Temple and Pandalam Palace are located at the bank of station 5 (S5). Being a place of pilgrimage large number of devotes visit the place during Mandalakalam. The devotees and the locals use the waterbodies for various purposes like bathing, washing, garbage disposal, and religious activities. This hampers the biological diversity and results in the dominance of some tolerant taxa like chironomids. When water quality deteriorates the more sensitive species disappear and tolerant species dominate, thus reducing species richness and diversity (Copatti et al., 2013).

Based on Principal component analysis, an absolute loading value >0.75 is of strong significance and these parameters can be used to monitor the variations in water quality (Liu et al., 2003). The mean values of the studied physicochemical variables like temperature, turbidity, TDS, pH, conductivity, nitrate, and phosphate were maximum in station 9 (S9) followed by station 8 (S8). These sites are bare lands without canopy cover and highly under anthropogenic stress. Higher instream and near stream activities such as laundry washing, bathing, cattle cleaning, agricultural activities, vehicle cleaning, and dumping of poultry waste are common in the downstream stretches of the river. These activities deteriorate the water quality and disturb the benthic fauna, as has been found in similar studies (Malmqvist & Rundle, 2002; Masese et al., 2009). Most members of the macrobenthic insect groups such as some species of Ephemeroptera, Plecoptera, Trichoptera were not common in regions with increasing pH and conductivity (Abdelsalam & Tanida, 2013) as is evident in this study.

Moreover, the areas with less vegetation usually experience a temperature rise. When atmospheric temperature increases a corresponding increase in water temperature also occurs (Li et al., 2014). A decrease in the value of DO at station 8 (S8) and station 9 (S9) can be attributed to lower oxygen saturation at higher temperatures and an increase in organic decomposition (Kannan & Joseph, 2022). When the water flow impedes during the dry month, stations S8 & S9 are facing saltwater intrusion from Kayamkulam Lake. The highest values noted for pH, conductivity, and TDS in stations 9 and 8 (S9 and S8) might be due to low-intensity rainfall and the intrusion of salt water into the river (Chithra et al., 2022). Besides this addition of organic matter, solid waste, a higher concentration of nutrients in the water may causes an increase in turbidity, pH, conductivity, and TDS (Qureshimatva et al., 2015). A higher concentration of phosphate in station 9 (S9) is an indication of 'poor' chemical status (James et al., 2012). All these factors contribute to a decline in the number of individuals and taxa in stations 8 and 9 (S8 and S9) during the premonsoon season.

The smaller number of other benthic fauna in stations 8 and 9 (S8 and S9) may be due to some ecological imbalance of certain factors that govern the abundance and distribution of macrobenthic faunal communities. Anthropogenic activities influence the number, diversity, and abundance of macrobenthic fauna noted in the study. The obvious change is due to fluctuation in water bodies. The fluctuation was due to the seasonality of rainfall and dilution factors as well as anthropogenic activities. Besides these, natural environmental conditions play a significant role in the diversity of benthic organisms (Yap et al., 2003). The distribution pattern of benthic organisms frequently changes in response to pollution stress in predictable ways (Silveira et al., 2006). The presence of organic wastes increases the species number and relative abundance of tolerant taxa (Masese et al., 2009). The effect of physicochemical factors on the abundance of macrobenthic fauna based on Canonical Correspondence Analysis and Pearson's coefficient of correlation revealed that the abundance of macrobenthic fauna is high when DO increases and water temperature, BOD, turbidity, TDS, conductivity, nitrate, phosphate were negatively correlated to macrobenthic abundance. Macrobenthic invertebrates usually prefer microhabitats with high DO levels (Bagalwa et al., 2019. The downstream stations mainly S8 and S9 with high temperature, turbidity, TDS, pH, conductivity, nitrate, and phosphate colonized with pollution-tolerant taxa such as Chironomidae but the site upstream with high DO and low temperature was colonized with pollution-sensitive taxa. The upstream site S1 is unimpacted by human activities and is situated at high altitudes. From this study, it is clear that the abundance of macrobenthic fauna in a site depends on a combination of many physicochemical parameters and not a single factor.

5. Conclusion

It can be concluded that Ephemeroptera, Coleoptera, and Trichoptera were the most dominant groups in the undisturbed habitats in the river during the study period. The predominance of Chironomids especially *chironomous* species in the midstream and downstream segments of the river is possibly due to their ability to adapt to various environmental conditions or habitats and their tolerance to the low oxygen content in anoxic conditions of the bottom sediment. The lowest abundance of macrobenthos at all the studied stations was observed at S9 during dry seasons. Station 9 and 8 (S9 and S8) are highly impacted regions, characterized by high temperature, turbidity, TDS, pH, conductivity, nitrate, and phosphate values. For this reason, anthropogenic stress and changing environmental conditions are the main factors affecting the distribution of the macrobenthic fauna of the Achenkovil River basin, Kerala.

Macrobenthic diversity and abundance is an efficient tool in the monitoring of the spatial and seasonal variations in the Achenkovil River basin, showing its deteriorating condition mainly in the premonsoon season and towards the downstream segments of the river. Macrobenthos could be a viable tool for long-term and community-based monitoring of freshwater ecosystems. Macrobenthic fauna was abundant in undisturbed habitats. Physicochemical parameters play a major role in the distribution of macrobenthic fauna. Some species of macrobenthic fauna are pollution sensitive and some are pollution tolerant. So, their presence or absence can be used to predict water quality. To conclude, Macrobenthic fauna has the potential to act as biological indicators of pollution status. Thus, keeping in mind the importance of the study, steps should be taken for the maintenance and conservation of freshwater ecosystems.

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References

Abdelsalam, K.M., & Tanida, K., 2013. Diversity and spatiotemporal distribution of macro-invertebrate's communities in spring flows of Tsuya Stream, Gifu Prefecture, central Japan. Egypt. J. Aquat. Res. 39(1), 39-50. http://dx.doi.org/10.1016/j.ejar.2013.03.003.

Alam, M.J., Islam, M.R., Muyen, Z., Mamun, M., & Islam, S., 2007. Water quality parameters along rivers. Int. J. Environ. Sci. Technol. 4(1), 159-167. http://dx.doi.org/10.1007/BF03325974.

American Public Health Association – APHA, 2017. Standard methods for the examination of water and wastewater (23rd ed.). Washington, DC.

Bagalwa, M., Mukumba, I., Ndahama, N., Zirirane, N., & Kalala, A.O., 2019. Assessment of river water quality using macroinvertebrate organisms as pollution indicators of Cirhanyobowa River, Lake Kivu, DR Congo. Int. J. Curr. Microbiol. Appl. Sci. 8(4), 2668-2680. http://dx.doi.org/10.20546/ijcmas.2019.804.310.

Brown, B.L., 2007. Habitat heterogeneity and disturbance influence patterns of community temporal variability in a small temperate stream. Hydrobiologia 586(1), 93-106. http://dx.doi.org/10.1007/s10750-006-0531-3.

Chakraborty, A., Saha, G.K., & Aditya, G., 2022. Macroinvertebrates as engineers for bioturbation in freshwater ecosystem. Environ. Sci. Pollut. Res. Int. 29(43), 64447-64468. PMid:35864394. http://dx.doi.org/10.1007/s11356-022-22030-y.

Chithra, S., Joseph, S., & Kannan, N., 2022. A study of saltwater intrusion in the Kallada River, southwest coast of Kerala, India. Water Sci. Technol. Water Supply 22(2), 2194-2211. http://dx.doi.org/10.2166/ws.2021.367.

Copatti, C.E., Ross, M., Copatti, B.R., & Seibel, L.F., 2013. Bioassessment using benthic macroinvertebrates of the water quality in the Tigreiro river, Jacuí Basin. Acta Sci. Biol. Sci. 35(4), 521-529. http://dx.doi.org/10.4025/actascibiolsci.v35i4.18934.

Covich, A.P., Palmer, M.A., & Crowl, T.A., 1999. The role of benthic invertebrate species in freshwater ecosystems: zoobenthic species influence energy flows and nutrient cycling. Bioscience 49(2), 119-127. http://dx.doi.org/10.2307/1313537.

Deborde, D.D.D., Hernandez, M.B.M., & Magbanua, F.S., 2016. Benthic macroinvertebrate community as an indicator of stream health: the effects of land use on stream benthic macroinvertebrates. Sci. Diliman (Online), 28(2), 5-26. Retrieved in 2023, February 20, from https://journals.upd.edu.ph/index.php/sciencediliman/article/view/5507

Dhanya, V., 2014. Basin asymmetry and associated tectonics: a case study of Achankovil river basin, Kerala. Transactions (Online), 36(2), 1-10. Retrieved in 2023, February 20, from https://iigeo.org/wp-content/uploads/2015/02/5-Basin_asymmetry_and_associated_tectonics_case-study-IIG-Vol.36-No.2.pdf

Dudgeon, D., 1999. Tropical Asian streams: zoobenthos, ecology, and conservation. Hong Kong: Hong Kong University Press.

Gamito, S., 2010. Caution is needed when applying the Margalef diversity index. Ecol. Indic. 10(2), 550-551. http://dx.doi.org/10.1016/j.ecolind.2009.07.006.

Girija, T.R., Mahanta, C., & Chandramouli, V., 2007. Water quality assessment of an untreated effluent impacted urban stream: the Bharalu tributary of the Brahmaputra River, India. Environ. Monit. Assess. 130(1-3), 221-236. PMid:17106781. http://dx.doi.org/10.1007/s10661-006-9391-6.

Heatherly II, T., Whiles, M.R., Royer, T.V., & David, M.B., 2007. Relationships between water quality, habitat quality, and macroinvertebrate assemblages in Illinois streams. J. Environ. Qual. 36(6), 1653-1660. PMid:17940265. http://dx.doi.org/10.2134/jeq2006.0521.

Hepp, L.U., Milesi, S.V., Biasi, C., & Restello, R.M., 2010. Effects of agricultural and urban impacts on macroinvertebrates assemblages in streams (Rio Grande do Sul, Brazil). Zoologia 27(1), 106-113. http://dx.doi.org/10.1590/S1984-46702010000100016.

Hershey, A.E., Lamberti, G.A., Chaloner, D.T., & Northington, R.M., 2010. Aquatic insect ecology. In: Thorp, J.H., & Covich, A.P., eds. Ecology and classification of North American freshwater invertebrates (pp. 659-694). Amsterdam: Academic Press. http://dx.doi.org/10.1016/B978-0-12-374855-3.00017-0

James, P., Atkinson, S., Barlow, D., Bates, A., Comyn, F., Duddy, M., & Causer, K., 2012. The Irwell catchment pilot: the rivers return. Warrington, UK: The Environment Agency. Retrieved in 2023, February 20, from http://salfordfriendlyanglers.co.uk/wp-content/uploads/2013/11

Kannan, N., & Joseph, S., 2022. Spatio-temporal variations in hydrochemistry and quality of surface water in Bharathapuzha River Basin, Kerala, India. Water Sci. 36(1), 70-84. http://dx.doi.org/10.1080/23570008.2022.2127556.

Korte, T., Baki, A.B.M., Ofenböck, T., Moog, O., Sharma, S., & Hering, D., 2010. Assessing river ecological quality using benthic macroinvertebrates in the Hindu Kush-Himalayan region. Hydrobiologia 651(1), 59-76. http://dx.doi.org/10.1007/s10750-010-0290-z.

Li, X., Li, P., Wang, D., & Wang, Y., 2014. Assessment of temporal and spatial variations in water quality using multivariate statistical methods: a case study of the Xin'anjiang River, China. Front. Environ. Sci. Eng. 8(6), 895-904. http://dx.doi.org/10.1007/s11783-014-0736-z.

Liu, C.W., Lin, K.H., & Kuo, Y.M., 2003. Application of factor analysis in the assessment of groundwater quality in a Blackfoot disease area in Taiwan. Sci. Total Environ. 313(1-3), 77-89. PMid:12922062. http://dx.doi.org/10.1016/S0048-9697(02)00683-6.

Malmqvist, B., & Rundle, S., 2002. Threats to the running water ecosystems of the world. Environ. Conserv. 29(2), 134-153. http://dx.doi.org/10.1017/S0376892902000097.

Masese, F.O., Raburu, P.O., & Muchiri, M., 2009. A preliminary benthic macroinvertebrate index of biotic integrity (B-IBI) for monitoring the Moiben River, Lake Victoria Basin, Kenya. Afr. J. Aquat. Sci. 34(1), 1-14. http://dx.doi.org/10.2989/AJAS.2009.34.1.1.726.

Medupin, C., 2020. Spatial and temporal variation of benthic macroinvertebrate communities along an urban river in Greater Manchester, UK. Environ. Monit. Assess. 192(2), 84. PMid:31900601. http://dx.doi.org/10.1007/s10661-019-8019-6.

Merritt, R.W., & Cummins, K.W., eds., 1996. An introduction to the aquatic insects of North America. Dubuque: Kendall Hunt. http://dx.doi.org/10.2307/1467288.

Noyel, V., & Desai, D.V., 2020. Spatio-temporal variation in the macrobenthos of Paradip port, east coast of India. Curr. Sci. 119(1), 68-82. http://dx.doi.org/10.18520/cs/v119/i1/68-82.

Pandey, V., & Thiruchitrambalam, G., 2019. Spatial and temporal variability of sandy intertidal macrobenthic communities and their relationship with environmental factors in a tropical island. Estuar. Coast. Shelf Sci. 224, 73-83. http://dx.doi.org/10.1016/j.ecss.2019.04.045.

Picapedra, P.H.D.S., Fernandes, C., Baumgartner, G., & Sanches, P.V., 2022. Drivers of zooplankton spatial dynamics in a small neotropical river. Acta Limnol. Bras. 34, e13. http://dx.doi.org/10.1590/s2179-975x6421.

Poff, N.L., & Allan, J.D., 1995. Functional organization of stream fish assemblages in relation to hydrological variability. Ecology 76(2), 606-627. http://dx.doi.org/10.2307/1941217.

Prasad, M.B.K., & Ramanathan, A.L., 2005. Solute sources and processes in the Achankovil River Basin, Western Ghats, Southern India. Hydrol. Sci. J. 50(2), http://dx.doi.org/10.1623/hysj.50.2.341.61798.

Qureshimatva, U.M., Maurya, R.R., Gamit, S.B., Patel, R.D., & Solanki, H.A., 2015. Determination of physicochemical parameters and water quality index (Wqi) of Chandlodia Lake, Ahmedabad, Gujarat, India. J. Environ. Anal. Toxicol. 5(288), 2161-0525. http://dx.doi.org/10.4172/2161-0525.1000288.

Selvakumar, C., Subramanian, K.A., & Sivaramakrishnan, K.G., 2019. Mayflies (Insecta: Ephemeroptera) of India. In: Ramani, S., Mohanraj, P., & Yeshwanth, H.M., eds. Indian insects (pp. 7-28). Boca Raton: CRC Press. http://dx.doi.org/10.1201/9780429061400-2.

Sharma, M.P., Sharma, S., Gael, V., Sharma, P., & Kumar, A., 2006. Water quality assessment of Behta River using benthic macroinvertebrates. Life Sci. J. (Online), 3(4), 68-74. Retrieved in 2023, February 20, from https://www.semanticscholar.org

Silveira, M.P., Buss, D.F., Nessimian, J.L., & Baptista, D.F., 2006. Spatial and temporal distribution of benthic macroinvertebrates in a southeastern Brazilian river. Braz. J. Biol. 66(2B), 623-632. PMid:16906294. http://dx.doi.org/10.1590/S1519-69842006000400006.

Strahler, A.N., 1957. Quantitative analysis of watershed geomorphology. Trans. Am. Geophys. Union 38(6), 913-920. http://dx.doi.org/10.1029/TR038i006p00913.

Thorp, J.H., & Rogers, D.C., eds., 2015. Thorp and Covich's freshwater invertebrates (pp. 65-82). London: Elsevier. http://dx.doi.org/10.1016/B978-0-12-385026-3.00004-8.

Yap, C.K., Ismail, A.R., Ismail, A., & Tan, S.G., 2003. Species diversity of macrobenthic invertebrates in the Semenyih River, Selangor, Peninsular Malaysia. Pertanika, J. Trop. Agric. Sci. (Online), 26(2), 139-146. Retrieved in 2023, February 20, from https://www.researchgate.net/publication/266895309

Yorulmaz, B., & Ertaş, A., 2021. Water quality assessment of Selendi Stream and comparative performance of the indices based on benthic macroinvertebrates and physicochemical parameters. Biologia 76(9), 2599-2607. http://dx.doi.org/10.1007/s11756-021-00756-3.

Yule, C.M., & Sen, Y.H., 2004. Freshwater invertebrates of the Malaysian region. Malaysia: Academy of Sciences.

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