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The benthic macro-invertebrate diversity in relation to water quality of a stream habitat at Dediyagala, Sri Lanka

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Abstract

The streams collect sediment and other fine and particulate material from their watersheds and transport them downstream as fluvial material. Macro-benthos is the most important secondary producers in stream ecosystem and their diversity explains the water quality of a stream to a greater extent. The present study determines the water quality and macro-benthos diversity at five sites of the 180m stream stretch at Dediyagala for a period of three months from February to April in 2012. Random samples were collected using a Surber sampler for benthos, and a Ruttner sampler for water samples.

Water discharge was significantly different from headwater (0.0198 m^3s^{-1}) to downstream (0.0456 m^3s^{-1}).Bottom substrate was non uniform according to Uniformity Coefficient analysis except at two sampling sites of cascade and riffle habitats. There was no significant site specific or time specific variations in water temperature, pH, biochemical oxygen demand (BOD_3), total suspended solids (TSS), total dissolved solids (TDS), and orthophosphate concentration. Nitrate concentration, dissolved oxygen (DO) and organic matter content of lithophytes varied significantly among the sampling sites ($P<0.05$). Principal Component Analysis (PCA) showed that TDS and DO were the most important parameters for explaining the water quality of the stream stretch studied whereas BOD_3 was important only for the downstream site.

The most abundant families of benthic organisms in the stream were Hydropsychidae, Helicopsychidae, Leptophelibiidae and Psephenidae which belonged to the orders of Trichoptera, Ephemeroptera, and Coleoptera. A Significant positive correlation was observed between DO and Shannon-Wiener diversity index (R^2=0.815, $P< 0.05$). Family Biotic Index (FBI) ranged between 2.63 and 3.16 indicating that water quality was suitable for healthy growth of macro−invertebrates in the stream.

Keywords: FBI index, Lithophytes, Uniformity Coefficient, Macro-benthos, Diversity

Introduction

Headwater streams are critical sites for organic matter processing and nutrient cycling and they are vital for maintaining the health of whole river network (Bengtsson 1998). According to Clarke et al. (2008), the headwater streams are named as nutrient poor, less productive areas and macro-benthos in these areas provides a greater contribution to the secondary productivity in the streams.

River continuum concept (RCC) is one of the conceptual models to describe river ecosystems and integrity of abiotic and biotic environment (Vannote et al. 1980). This concept is based on streams that originate in forested regions and integrates the geomorphological features of streams with the composition and function of the biological communities (Leprieur et al. 2009).Stream discharge is also an important character of stream ecology because it interacts with the gradient and substrate to determine the types of habitats present, the shape of the channel and the composition of the stream bottom (Dai and Trenberth 2002).

Benthic macro-invertebrate species are differentially sensitive to many biotic and abiotic factors in their environment (Mandaville 2002). Relative abundance and diversity of their community have commonly been used as an indicator of the condition of an aquatic system (Mandaville 2002; Azrina et al. 2005). Therefore, freshwater benthic macro-invertebrates can be commonly used as ecological indicators of aquatic ecosystems. Their populations depend on the condition of the environment such as water quality, organic matter content, soil texture, sediment particles and the ability to construct permanent burrows in the substratum (Dahanayaka and Wijeyaratne 2006). Biological monitoring or its chemical contents, is important in determining the health of an aquatic ecosystem. Physicochemical monitoring of a water body is known to be insufficient to fully characterize its status or reliably detect adverse impacts (Mandaville 2002).

The technique of using macro-benthic invertebrates as bio-indicators is a cost effective method widely used in the Northern American and European eco-regions (Azrina et al. 2005) but not a popular method or an option in the Asian region in river classification. Due to the lack of expertise and information on benthic macro-invertebrate populations, they have not properly used as bio-indicators especially in pollution studies in Sri Lanka.

Many studies have reported that anthropogenic activity such as agriculture, recreation, silviculture, land clearing, urban development, and river impoundment resulting organic and metal contamination affect the abundance and distribution of freshwater macro-benthos (Wahizatul et al. 2011). As such, this research was an attempt to determine the use of aquatic macro-benthos in assessing and classifying the health status of selected freshwater stream, through analyzing the macro-benthos diversity, surface water quality, and substrate characteristics in a selected part of a stream.

Materials and Methods

Site description

Kanneliya (K), Dediyagala (D) and Nakiyadeniya (N) are contiguous reserves forming a compact forest unit with a total extent of 121,964 ha located in southwest of Sri Lanka. This (KDN) biosphere reserve covers lowland and tropical montne forests, and lies between two rivers (Jayasuriya and Abayawardana 2008). KDN Complex is ranked as the most important natural forest in the Southern Province for the protection of headwaters of river systems including 111 streams (Jayasuriya and Abayawardana 2008).

One of the streams which begins from the Dediyagala forest and connects to the Nilwala River at the low land area was selected as the study area. Five sampling sites (site 1- site 5) within 180 m stream stretch were used for collecting water and biological samples on monthly basis (Figure 1). These five sampling sites were selected according to the flow characteristics. Site 1 was near to a cascade, sites 2, 3, 4 were riffles and site 5 was a pool habitat. Water quality parameters and biological parameters were measured during the study period from February to April, 2012 on monthly basis.

Determination of physical characteristics of the stream

The mid-section method (USEPA, 2012) was applied to compute stream discharge by using a digital current meter (Kenek/VP/1000, Japan). Particle size distribution of sediments was determined using mechanical sieve sets (sample divider) (Serial no: 12101706201 and model: AS 200 basic, Germany) based on the remaining mass in each sieve and the proportions retained in each sieve was used to determine % stream substrate composition. Accordingly, collected soil was separated using seven different sizes of sieves to obtain a breakdown of particle size and the particle size distribution curves were drawn for each site. The particle size distribution curve is a semi-logarithmic graph and it was used to determine useful soil parameters D_{30}, D_{10} and D_{60} in each site (Sivakugan 2000).$D_{30}$is a size such that 30% of the soil particles are smaller than his size and similarly D_{10} and D_{60} were determined. D_{10} is called the effective grain size, which gives a good indication of the permeability characteristics of a coarse grained soil. Then the coefficient of uniformity (C_u) and coefficient of curvature (C_c) were calculated using the following equations (Sivakugan 2000; Wade 2007;).

$$C_u = D_{10} / D_{60}$$

$$C_c = \frac{D_{30}^{\ 2}}{(D_{10} \times D_{60})}$$

Where;

D_{10} – Particle diameter that is 10% of finer [effective grain size]
D_{60} – Particle diameter that is 60% of finer
D_{30} –Particle diameter that is 30% of finer

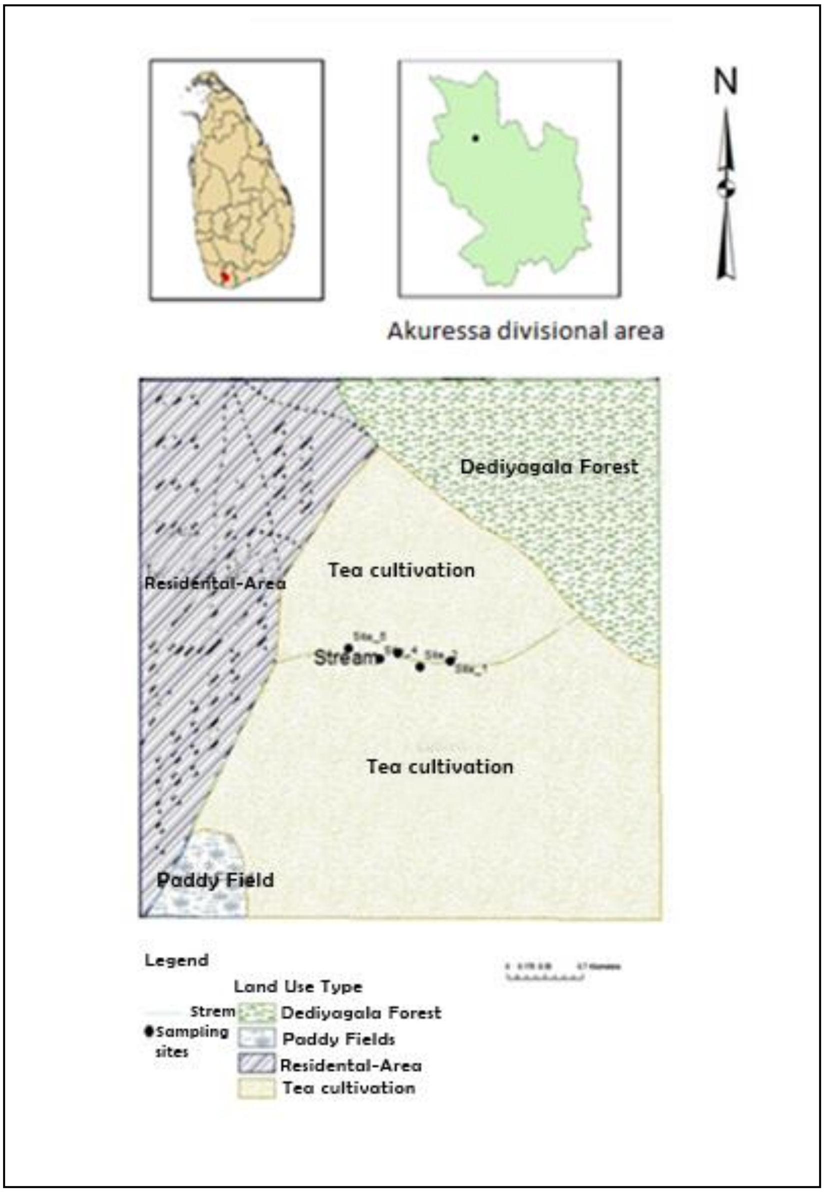

Figure 1. Locations of study sites.

Determination of chemical parameters

Water samples with three replicates were collected pre-washed bottles at each sampling site using a Ruttner sampler and kept in ice until arrival to the laboratory. The samples were analyzed for total suspended solid (TSS), total dissolved solid (TDS).Orthophosphate and Nitrate–N concentrations were measured by colorimetric method using UV spectrophotometer. Dissolved oxygen (DO) concentration and Biochemical oxygen demand (BOD_3) were determined using the Winkler method (APHA 1985).

Collection and identification of benthic macro−invertebrates

Random sampling technique was employed to collect benthos using a Surber sampler. Macro-invertebrates were separated from the sediment and preserved in 70% alcohol until further analysis. Several identification keys such as Bouchard (2004), Hartmann (2006), Dailey (2006), River Watch Network 1992), and Fernando and Weerawardhena (2002) were used to identify the collected benthic organisms at least up to their family level.

Shannon–Wiener diversity index (H) was calculated using the following equation.

$$H= -\sum (p_i) (\ln p_i)$$

Where p_i is the proportion of individuals in the i^{th} taxon of the community.

EPT index (Ephemeroptera, Plecoptera, and Trichoptera index) displays the taxa richness within the insect groups which are considered to be sensitive to pollution. The EPT index is equal to the total number of families represented within these three orders in the sample of each site (Mandaville 2002).

Family Biotic Index (FBI) provides a single tolerance value which is the average of the tolerance values of all species within the benthic arthropod (Mandaville 2002).

$$\text{FBI} = \sum \frac{x_i t_i}{\text{n}}$$

where x_i is the number of individuals in the i^{th} taxon, $t_i$is the tolerance value of the i^{th} taxon and n is the total number of organisms in the collected benthos sample of each site.

Statistical analysis

One-way ANOVA was used to analyze the spatiotemporal variation of physicochemical parameters in the stream. The principal component analysis (PCA) was employed as a method of data reduction to select the most suitable parameters for explaining the biological variation at the sampling sites based on the covariance or correlation matrix.

Results

Physical characteristics of the stream

The depth profiles of each site shown in Figure 2 explain the depth variation between the stream banks at each site. Maximum width (7 m) was recorded at the cascade habitat (site 1) and minimum width (3.8 m) was recorded at a riffle habitat of site 3. Average maximum depth (0.57 m) was recorded from site1 and the minimum average depth (0.29m) was at the site 2.

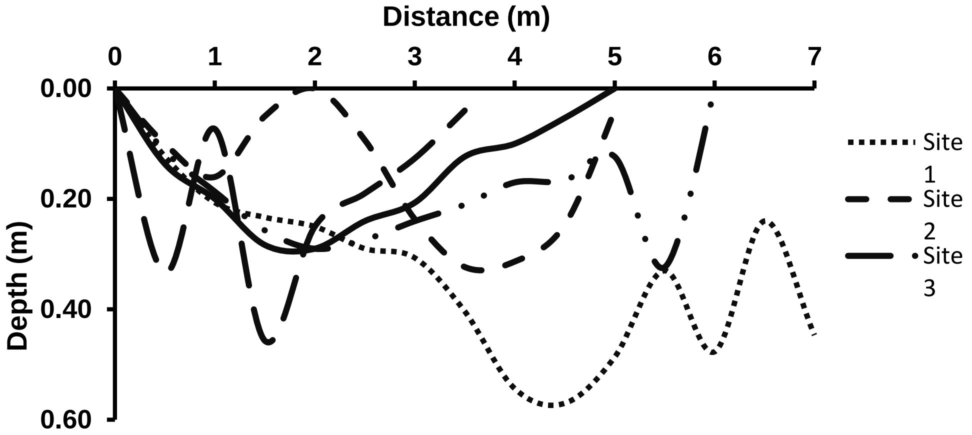

Figure 2. Depth profile at the sampling sites.

According to the Table 1 there was a significant difference of stream discharge among the sampling sites ($p<0.05$). The highest discharge was observed at the site 4 and the lowest discharge was observed at the site 3 of riffle habitats. The bottom substrate composed with several particles, those have been categorized according to the grain size. Gravel is the larger particles (particle size >2 mm), sand is medium size (particle size 2>0.06 mm) and silt and clay can be categorized as one category (particle size 0.06>0.002 mm). The Figure 3 describes the distribution of gravel, sand and silt and clay in the stream habitat during the study period.

Table 1. Water discharge of the stream at the sampling sites.

Sampling Site	Stream Discharge (m^3S^{-1}) (mean±SD)
1	0.042±0.004
2	0.037±0.003
3	0.019±0.004
4	0.045±0.001
5	0.035±0.004

Relatively high percentage of sand can be observed at the cascade habitat of the stream (site 1) and at the pool habitat (site 5). However, gravel was predominant in all other three sampling sites and percentage of silt and clay composition gradually increases from site 1 to site 5 (Figure 3).

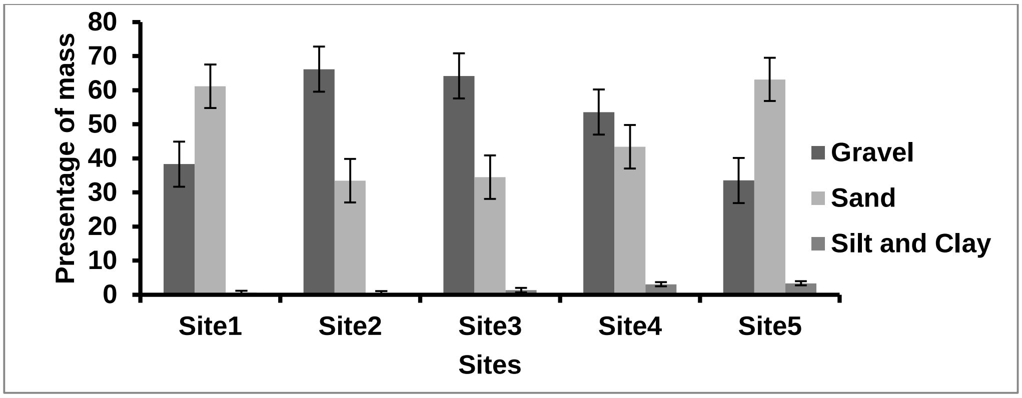

Figure 3. Percentage composition of substrate particles at the sampling sites.

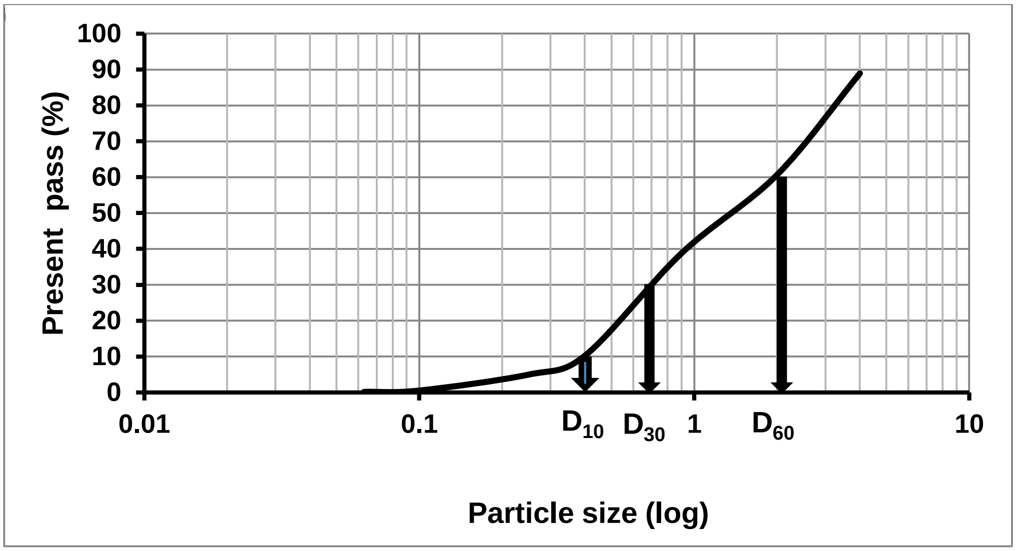

Figure 4. Semi-log curve for site 1.

Coefficient of uniformity (C_u) and coefficient of gradation (C_c) are shown in Table 2. C_u of the site 1 (cascade) and site 2 (riffle) were equal or lower than 5 and it explains uniform substrate structure. Meanwhile, C_u of other three sites was greater than 5 refer as non uniform substrate at the downstream sites of riffle and pool habitats (site 3, site 4 and site 5). Even though sediment composition was non uniform at the downstream sites the C_c values at all five sites were lower than five explains that the presence of well graded soil type at each sampling site. The Figure 4 shows the semi-log curve for site 1 as an example and it indicates the D_{10}, D_{30} and D_{60} values of 0.40, 0.71 and 0.80 respectively those were used for the calculation of C_u and C_c.

Table 2. Coefficient of gradation (C_c) and Uniformity coefficient (C_u) at the sampling sites.

	Site 1	Site 2	Site 3	Site 4	Site 5
C_u	5.00	3.67	5.82	6.83	6.40
C_c	0.84	3.43	1.07	1.97	2.45

Water quality parameters

The water-quality data of stream habitats are summarized as the mean ± SD and are given in Table 3.Water temperature, pH, biochemical oxygen demand (BOD_3), total suspended solid (TSS), total dissolved solid (TDS), and orthophosphate concentration did not vary significantly among the sampling sites and among the sampling days. However, dissolved oxygen (DO), nitrate-N concentration and organic matter content of lithophytes varied significantly among the sampling sites ($p < 0.05$).

According to the results of PCA, the first component which represents >50% of the total variation on the rotated component matrix explained the importance of physicochemical characteristics at all the sites. According to the coefficient values in Table 4, DO was an important parameter for explaining the biological variation at the all sampling sites. Similarly, TDS was an important factor at all the sites except the site 5.

Table 3. Water quality parameters at the sampling sites (mean±SD).

Site	Temperature (°C)	pH	DO (ppm)	BOD (ppm)	TSS (mg/L)	TDS (mg/L)	Orthophosphate Concentration (ppm)	Nitrate-N concentration (ppm)	Percentage organic matter (%)
1	25.3±0.7	6.6±0.0	10.5±0.5	1.9±0.1	6.8±1.5	88.7±8.5	0.02±0.00	0.12±0.02	0.93±0.02
2	24.9±0.5	6.5±0.1	10.1±0.7	1.6±0.2	3.3±1.3	79.0±7.8	0.01±0.00	0.15±0.03	0.89±0.01
3	24.8±0.3	6.4±0.1	11.3±0.2	1.6±0.3	2.6±1.1	79.0±4.6	0.02±0.00	0.22±0.03	1.16±0.03
4	25.0±0.7	6.4±0.1	9.6±0.2	2.0±0.5	4.9±1.5	85.0±2.6	0.01±0.00	0.34±0.05	0.58±0.02
5	24.5±0.3	6.5±0.1	10.6±0.6	1.7±0.4	3.8±2.5	63.0±6.2	0.02±0.00	0.21±0.03	0.91±0.02

Table 4. Coefficient values on component 1 in rotated component matrixes for different physicochemical characteristics at the sites.

Parameter	Sites				
	1	2	3	4	5
DO	0.998	0.764	0.787	-0.982	0.787
TDS	0.991	0.987	0.98	-0.796	-0.052
Organic matter content of lithophytes	0.983	0.275	-1	-0.392	-0.945
Stream discharge	-0.944	-0.928	-0.253	-0.253	0.875

Biological parameters

Aquatic insects collected from stream habitats during the study period were represented by 17 families from 6 orders. Ephemeroptera, Plecoptera, Trichoptera and Coleoptera were the most abundant orders of the stream habitats. Shannon–Wiener diversity index, Ephemeroptera, Plecoptera and Trichoptera index (EPT) and Family biotic index (FBI) values are given in Table 5. The EPT value varied between 2 at the site 5 of pool habitat and 8 at the site 3 of riffle habitat of the stream. Meanwhile, the FBI value varied between 2.53 at the site 2 of riffle and 3.28 at the site 5 of pool habitat. However, there was no significant site-specific difference of any of above said index values. The identified families in each order with their total abundance in the study period are given in the Table 6. The highest total abundance (432/m^2) was observed for family Leptophlebiidae in order of Ephemeroptera. Shannon-Wiener diversity index (H) shows a significant positive correlation with dissolved oxygen (DO) concentration in the stream (Figure 5) and with the percentage of organic matter content in lithophytes (Figure 6).

Table 5. Biological parameters. FBI - Family Biotic Index; EPT Index – Ephemeroptera, Plecoptera and Trichoptera index

Sampling Site	Shannon-Wiener diversity index (H)	FBI	EPT Index
1	1.927±0.19	2.93±0.05	4±1.00
2	1.692±0.25	2.63±0.10	4±1.73
3	2.256±0.13	2.91±0.07	6±2.00
4	1.613±0.91	2.99±0.08	5±1.73
5	1.730±0.26	3.16±0.12	4±2.00

Table 6. Aquatic insect families and total abundance at five sites during the study period.

Taxonomic order	Family	Total abundance (nos m^{-2})
Odonata	Euphaeidae	52
	Gomphidae	16
	Calopterygidae	<4
Ephemeroptera	Leptophlebiidae	432
	Baetidae	20
	Ephemeridae	56
	Hepatageniidae	84
Diptera	Athericidae	4
	Psychodidae	4
	Simulidae	<4
	Chironomidae	12
Coleoptera	Psephenidae	300
	Elmidae	4
Trichoptera	Helicopsychidae	192
	Odontoceridae	<4
	Hydropsychidae	220
Plecoptera	Perlidae	8

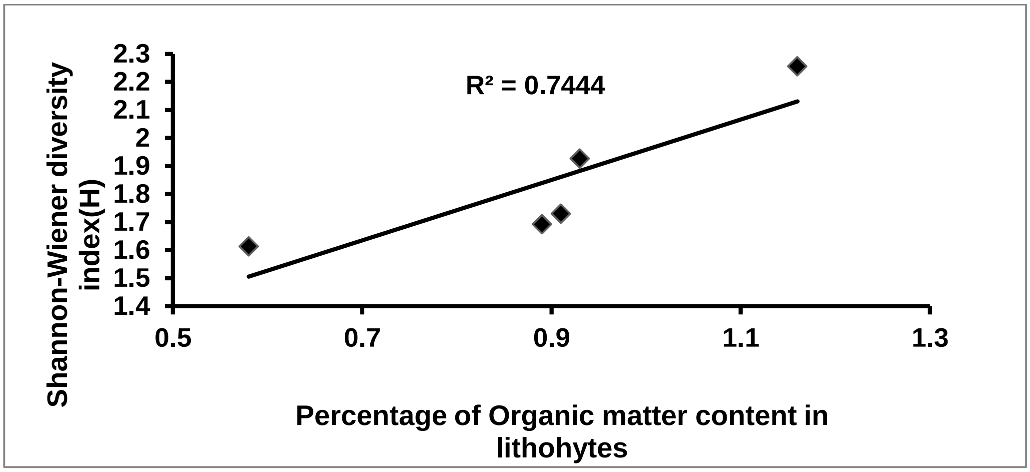

Figure 5. Relationship between % of organic matter in lithophytes and Shannon index.

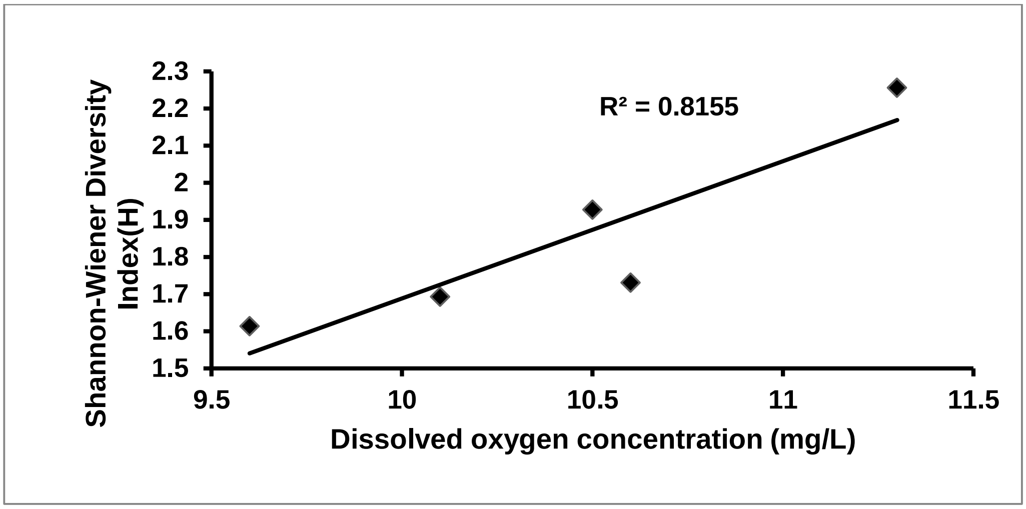

Figure 6. Relationship between Dissolved oxygen and Shannon Wiener index.

Discussion

The upstream area of the stream contains much more cobbles and pebbles than silt and clay and the substrate characteristics are often sensitive indicators of the effect of human activities on the streams (Toriman et al. 2009). Increase of silt and clay in the stream as found in the present study can be due to land use activities in the area including deforestation for tea cultivation. Urban and agricultural land uses and deforestation are reported to often increase the sediment and nutrient load of streams and it may reduce the habitat space and its availability for benthic fish and macro invertebrates (Houser et al. 2006).

Accumulation of dead leaves (allochthonous materials) was a distinct feature of pool habitats in the stream and it could be a reason for relatively low pH at these sites due to release of acidic substances (humic acid) from these materials (Young et al. 2009). The significant positive correlation that was observed between benthic organisms diversity and DO concentration in water would be due to the reason that as mentioned by Silva (2009), DO concentrations in water can vary dramatically as a result of various physical, chemical, and biological processes. Similarly, a significant positive correlation between organic matter content of lithophytes and diversity benthic organisms of was observed. Relatively higher organic matter content in lithophytes was observed at the riffle habitat (site 3) with the presence of more gravels and large boulders. According to Munari and Mistri (2007) biogeochemical processes in the sediments and sediment stability and presence of meiofaunal and nekton communities are important for diversity variation of macro–benthos in streams. In the present study the significant difference of benthos diversity among the sampling sites explains that the variation of substrate characteristics and water quality in the stream.

Table 7. Values of family biotic index and relevant water quality (Mandaville 2002).

Family biotic index	Water quality	Degree of organic pollution
0.00-3.75	Excellent	Organic pollution unlikely
3.76-4.25	Very good	Possible slight organic pollution
4.26-5.00	Good	Some organic pollution probable
5.01-5.75	Fair	Fairly substantial pollution likely
5.76-6.50	Fairly poor	Substantial pollution likely
6.51-7.2	Poor	Very substantial pollution likely
7.26-10.0	Very poor	Severe organic pollution likely

The most abundant group of benthic macro-invertebrates in streams is generally aquatic insects, which account for ~70% of known species of major groups of aquatic macro-invertebrates (Mandaville 2002). Among the aquatic insects the taxonomic orders of Ephemeroptera, Plecoptera, Tricoptera, Coleoptera and Odonata were found to be highly abundant during the present study. Leprieur et al. (2009) have documented that most of the agricultural sites show lower EPTC (Ephemeroptera, Plecoptera, Tricoptera, Coleoptera) taxa richness and diversity than the forest sites. The PCA has shown that DO was the most important parameters of each site for explaining the macro−benthos diversity and abundance in the stream. Abundance of the families of benthic macro−invertebrates can be used to assess the water quality according to their tolerance value and the FB index which indicates excellent water quality of the Dediyagala stream (Table 7; Mandaville 2002).The taxonomic orders of Ephemeroptera, Plecoptera, Trichoptera and Coleoptera can be used to assess response of anthropogenic disturbances in rivers (Leprieur et al. 2009). Therefore, the EPT index values at the sites of the stream describe the water quality as slightly impact (6 − 10) or moderately impact (2 – 5) according to the classification given by Mandaville (2002).According to the EPT and FBI values for the stream the water quality is suitable for the healthy life of macro−invertebrates in the period of study.

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