RESEARCH ARTICLE

Spatio-temporal variation of water quality and bio indicators of the Badulu Oya in Sri Lanka due to catchment disturbances

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Abstract: Safe and ample supply of freshwater is fundamental to humans and for the sustainability of ecosystem function. Therefore, impacts of catchment disturbances on surface water quality have been given special attention currently. The Badulu Oya sub-catchment of the Upper Mahaweli catchment area in Sri Lanka is one of the landscapes affected by intensive agricultural activities and urban development. This study was aimed at evaluating the spatial and temporal variation of water quality, stream physical habitat quality and macroinvertebrate bioindicators in the Badulu Oya catchment area in relation to disturbances due to agricultural and urban practices. Physico-chemical water quality parameters and macroinvertebrate indices were evaluated at ten sampling sites in the Badulu Oya catchment area within a one year period. The results revealed that water quality variables such as electrical conductivity (EC), total solids (TS), total dissolved solids (TDS), dissolved oxygen (DO), alkalinity, nitrate-N(NO_3-N) and physical variables such as stream channel quality index (CQI) and riparian quality index (RQI) are significantly influenced by the degree of catchment disturbances. Among the macroinvertebrate indices tested, total abundance and family richness significantly varied with the degree of catchment disturbances. The findings of the present study revealed that the land use practices of Badulu Oya catchment result in significant impacts on stream ecological health. Similarly the study also revealed the prospect of using attributes such as water quality, physical habitat quality and macroinvertebrate bioindices for river health monitoring programmes.

Keywords: Agricultural impacts, macroinvertebrate indices, river catchments, river health, urban impacts.

INTRODUCTION

Aquatic ecosystems around the world are increasingly affected by anthropogenic impacts more specifically occurring in the respective catchment landscapes (Allan, 1995; Alam *et al.*, 2006; Jayawardana *et al.*, 2016). Alteration of land cover on the catchments of rivers and streams influences in-stream habitats, water quality and aquatic fauna in a number of ways. It has been reported that catchment alteration may impact stream ecological functions such as the dynamics of riverine carbon cycle and food web structure and functions (Webster *et al.*, 1983; Gregory *et al.*, 1991). Removal of natural vegetation in catchments may contribute to increase the area of impervious surfaces influencing the evapotranspiration and infiltration and also to alter the natural flow regimes (Changnon & Demissie, 1996). Subsequently, these changes may increase the sediment inputs to streams by erosion and alteration of substratum characteristics and channel morphology, thus reducing aquatic species diversity (Lake *et al.*, 1985; Bunn *et al.*, 1986). Altered catchment hydrology and land use can influence inputs of inorganic nutrients from terrestrial sources and enhance in-stream primary productivity resulting in changes of the aquatic trophic structure and benthic communities (Death & Winterbourn, 1995).

Agricultural production depends heavily on intensive agricultural practices resulting in negative impacts on

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the environment. The major rivers of Sri Lanka originate from the central hills and their catchment areas are subjected to a variety of land use changes as a result of development activities and intensive agricultural practices (Watawala *et al*., 2010). The Mahaweli River catchment is the largest catchment in Sri Lanka, which provides water to the Mahaweli River and the major reservoirs built along the river. This catchment is considered very important to the Sri Lankan economy as it also provides water needed to generate 55 % of the electricity requirement of the country, and to irrigate a large extent of paddy and other field crops (Bandara & Thiruchelvam, 2008). Badulu Oya originates from the Namunukula mountain range and is one of the main tributaries of the Mahaweli River. The catchment of this river has also been subjected to various land use changes during the last few decades. Previously forested catchment areas have been continuously cleared and converted into agricultural land and urban settlements. Evaluation of such land conversion impacts on stream ecological integrity is important for taking decisions in catchment management and for the adoption of better management practices. Effect of such land use changes on the ecological integrity of streams have to be assessed through holistic approaches taking into account physical, chemical and biological criteria.

In many countries in temperate regions of the world, macroinvertebrate bioindicators are commonly used to assess the stream health in conjunction with water quality data (Hilsenhoff, 1987; Muirhead-Thompson, 1987; Plafkin *et al*., 1989; Johnson *et al*., 1993; Lenat, 1993; Jayawardana *et al*., 2006a; 2006b; 2010; Jayawardana & Westbrooke, 2010). These bioindices are very effective for the assessment of river health since they reflect long-term environmental impacts effectively and efficiently compared to physico-chemical parameters. Such indices are also important for the accurate assessment of the status of river health and development of mechanisms for catchment management in Sri Lanka. The lack of baseline data on responses of aquatic bioindicators to land use impacts is one of the limitations of application of bioindices in river health monitoring programmes in Sri Lanka. Therefore, this study was conducted with the aim of evaluating the spatial and temporal variation of water quality and macroinvertebrate bioindicators in Badulu Oya catchment area with respect to agricultural and other land use disturbances.

METHODOLOGY

Study area

Badulu Oya catchment is one of the sub-catchments of the Upper Mahaweli catchment area, which extends 318 km^2. It is located in latitudes 7°12'43.2" N and longitudes 80°59'50.63" E within the Wet Zone of Sri Lanka. The study region receives an annual average rainfall of 2000 mm. The Badulu Oya catchment receives rains during the wet season (October to March) and dry weather prevails in the catchment from April to September. The landscape of the catchment area varies from undulating, rolling topography to hilly, steeply dissected mountain terrain. The predominant soil type in the area is red yellow podzolic (De Alwis & Panabokke, 1972). The landscape of the catchment was covered with natural vegetation until the early 19th century (Wickramagamage, 1988). Subsequently the forest cover of the catchment area has been greatly reduced due to the expansion of agricultural lands and urban development activities. Presently fragmented patches of natural forest are present in the catchment and the rest of the area is covered by tea, vegetable and paddy cultivated lands, and urban settlements. Vegetable crops are predominantly grown in the Badulu Oya catchment area during the dry season and paddy is cultivated during the rainy season.

Ten locations in 2nd or 3rd order tributaries of Badulu Oya were selected as sampling sites for the study (Figure 1). The catchment area land cover patterns were analysed using Landsat TM satellite images (Data or acquisition 10th March 2011, with 30 m × 30 m resolution), 1:50000 topographic maps (Department of Survey, Sri Lanka), Google Earth satellite images and field observations. The land cover of micro-catchments of the selected sampling tributaries ranged from pristine undisturbed natural forests to landscapes, which have been severely altered by deforestation, agriculture and urban settlements. The selected sampling sites were classified based on the extent of agricultural, urban and forested land cover in the respective micro-catchments of the sampling tributaries. The micro-catchments, which have less than 20 % forest cover were classified as highly disturbed sites; 20 – 35 % forest cover as medium disturbed sites and more than 35 % forest cover as less disturbed sites/ reference sites (Table 1).

Riparian and channel physical habitat quality estimation

Riparian quality index (RQI) and channel physical habitat quality index (CQI) were developed to assess the quality of riparian zone of streams and the channel habitat quality, respectively. RQI and CQI for the sampling reaches were developed using the criteria of rapid bio assessment protocols for use in streams and wadeable rivers (Barbour *et al*., 1999). For the development of RQI, attributes such as the extent of lateral extension of forest
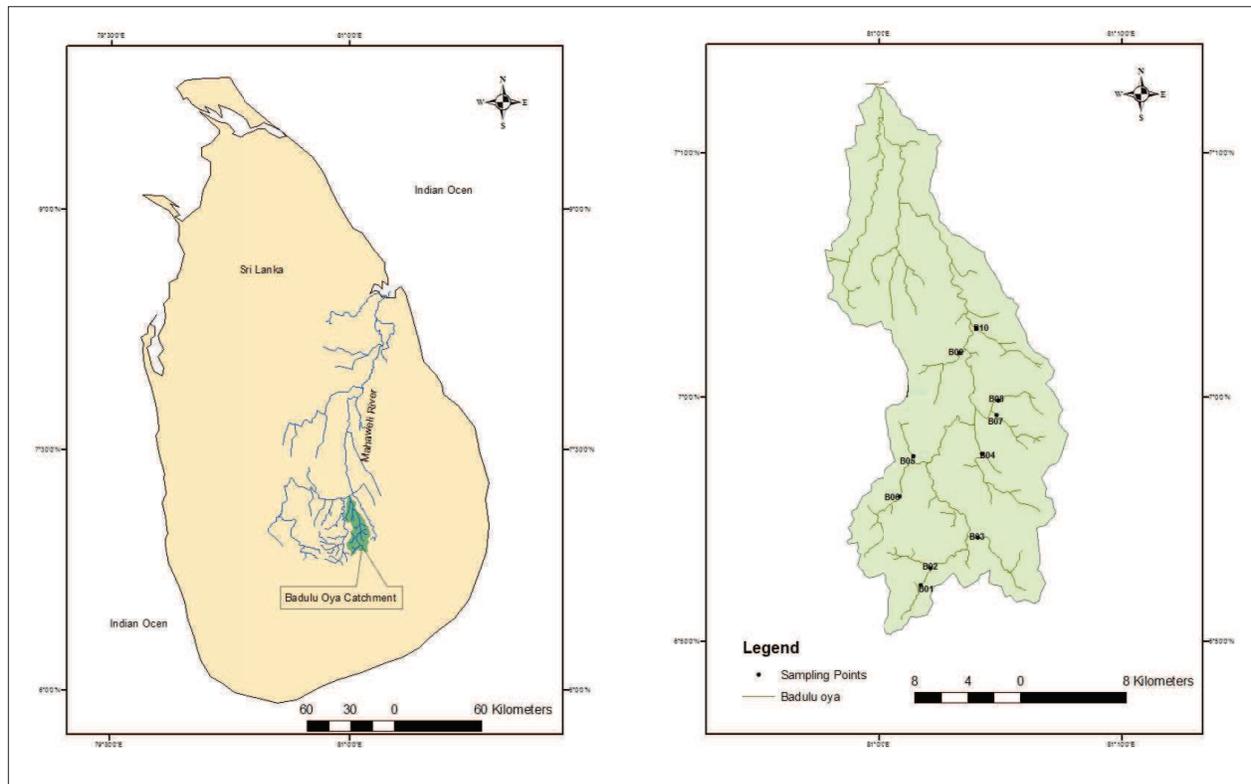
Figure 1: Sampling locations in Badulu Oya

Table 1: Sampling reaches of Badulu Oya catchment area

Sampling reach	Altitude (m)	Remarks
B01 - Kumbalwela	982	Low level of catchment disturbances/ reference site
B02 - Helahalpe	948	Highly disturbed area with agricultural activities
B03 - Demodara	865	Medium scale catchment disturbances. Mainly tea cultivated area
B04 - Wewahinna	657	Low level of catchment disturbances/ reference site
B05 - Moretota	975	Highly disturbed area with agricultural activities
B06 - Haliela	744	Highly disturbed area with agricultural and urban activities
B07 - Sirimalgoda Oya	710	Highly disturbed area with agricultural activities
B08 - Maramgaha Oya	695	Highly disturbed area with agricultural activities
B09 - Ambagaha Oya	410	Medium scale catchment disturbances by agricultural activities
B10 - Pussallawa	409	Low level of catchment disturbances/ reference site

cover on either side of the river, riparian composition (woody trees/ grasses/ bare) and riparian continuity were assessed along a 300 m stream segment upstream from the sampling site. CQI was developed for each sampling reach using the primary channel characteristics (channel dominant substrate, water velocity, embeddedness) and secondary channel characteristics (velocity/depth regimes, degree of bank/channel alterations, sediment

deposition, riffle characteristics, condition of banks, and canopy cover).

Water quality and macroinvertebrate sampling and analysis

Water samples were collected at monthly intervals from 10 sampling locations covering 10 sub-catchments from

August 2014 to July 2015. pH, electrical conductivity (EC), temperature and dissolved oxygen (DO) were measured *in situ* using a portable multi parameter (Hach-MM 156). In addition, physical and hydrological data of the sampling reaches such as water flow, embededness, and substrate characters were also recorded. Water flow was measured using a hand-held flow meter (5" to 15" expandable Global Water Flow Probe) and substrate characters and embededness were visually estimated (Platts *et al*., 1983; Fitzpatrick *et al.*, 1998). Duplicate water samples were collected from each sampling location and brought to the laboratory using 1.5 L sampling bottles under cold conditions for analysis. For the calculation of total solids (TS), 25 mL of samples were dried at 105 °C and the residue weight was taken. Total suspended solids (TSS) was measured after filtering a sample using a 0.45 µm filter paper and residue weight was taken after drying at 105 °C. The difference between TS and TSS was calculated as total dissolved solids (TDS). NO_2-N, NO_3-N, PO_4^{3-}, SO_4^{2-}, and NH_3-N were measured in the laboratory using a Hach DR 2700 spectrophotometer. Biochemical oxygen demand (BOD_5) was measured after incubating a water sample for 5 d using Winkler's method. All analyses were conducted following APHA (2005) procedures. Ephilithic biomass (g/m^2) was determined following the method adopted by Sponseller *et al*. (2001). Total coliform bacteria and faecal coliform bacteria were also measured in collected water samples adopting the US Environmental Protection Agency methodology (USEPA, 1978).

Macroinvertebrate samples were collected from study stream reaches (ten locations) using a surber sampler with a sample area of 12" × 12" at 3 month intervals covering the dry and rainy period of the catchment. Five replicate samples were collected from each sampling location. Macroinvertebrates were sorted and preserved in 70 % alcohol and identified up to family level in the laboratory using identification guides (Pinder & Brinkhurst, 1994; Cranston, 1996; Dean & Suter, 1996; Smith, 1996; CSIRO, 1999; Gooderham & Tsyrlin, 2002; Mendis & Fernando, 2002).

Macroinvertebrate total abundance, family richness, percentage EPT taxa (ephemeroptera: plecoptera: trichoptera), percentage chironomids and Shannon diversity index (SDI) were calculated using macroinvertebrate data. Taxa richness and percentage EPT were calculated because they are universally used macroinvertebrate metrics. These metrics are easily calculated and track water quality changes effectively (Wallace *et al*., 1996; Karr & Chu, 1999). Percentages of chironomidae were also estimated at the sites since they are indicators of the stress caused by pollution (Lencioni

et al., 2012). Information from a number of sources was used to partition the invertebrate fauna into 5 major feeding categories, *viz*. shredders, collectors, predators, grazers and filter feeders (Merritt *et al*., 1984; Hauer & Lamberti, 1996; Gooderham & Tsyrlin, 2002).

Analysis of data

Principal component analysis (PCA) was conducted to explore the patterns of variation of the sites based on stream physical habitat quality, water quality and macroinvertebrate indices. Stream physical habitat quality, water quality data and macroinvertebrate indices were used as variable inputs for PCA. Since the input variables for PCA had different magnitudes and scales of measurements the data were standardised to produce a normal distribution of all variables. From the standardised correlation matrix of the data the initial factor solutions were extracted by multivariate principal components extraction. Components loading (correlation coefficients), which measure the degree of closeness between the variables and the principal components were also estimated. The most significant variables in the components represented by high loadings were taken into consideration for evaluation of the components (Mazlum *et al*., 1999). Multivariate analysis was conducted using PRIMER-7 software (Plymouth Marine Laboratory, Plymouth, UK).

Two-way analysis of variance (ANOVA) was conducted to evaluate the effect of land cover disturbance and seasonal impacts on stream water quality and macroinvertebrate indices. The degree of catchment disturbances (high: medium: low) and the season (dry and wet) were considered as main factors in the analysis. Data were checked for normality and homogeneity of variance before the analysis, and the data were log or square root transformed as necessary to meet the assumptions of linear models. Homogeneity of variance was tested with Levene's test, and normality of residuals was assessed from normal probability plots. The significant differences among sites and seasons were expressed at 0.05 significant level ($p \leq 0.05$). All analyses were conducted using SPSS statistical software (IBM SPSS Statistics for Windows, Version 20.0 Armonk, NY: IBM Corp) and Microsoft Excel 2007.

RESULTS AND DISCUSSION

Multivariate analysis

PCA of the physical habitat, water quality and macroinvertebrate indices in response to catchment scale

land cover is depicted in Figure 2. The results of the PCA could be used to interpret the underlying trends of variation of stream water quality, physical habitat quality and macroinvertebrate indices in the Badulu Oya with respect to catchment disturbance.

The first five principal axes of PCA represented 69 % of the data variability. Vector loading to the principal component axis indicated that SDI, NO_2-N, family richness, RQI and CQI are highly associated with the PC1 axis. Conductivity, TDS, SO_4^{2-}, grazers and collectors were associated with PC2. There was a separation of sites along the PC1 axis based on the levels of disturbance of the catchments. Sites associated with a high percentage forest cover at the catchment were grouped together in the positive side of the PC1 and the sites with low percentage forest cover in the negative side of the axis. SDI, family richness, RQI and CQI were associated with high percentage forest cover in the catchment while NO_2-N, NO_3-N, TSS, PO_4^{3-} and percentage chironomidae were associated with highly disturbed sites. The results of the PCA indicate a pronounced impact to the stream ecological health exerted by the catchment disturbance.

The spatial and temporal variations of water quality in highly and less disturbed sites were tested using two-way ANOVA. The averages and ranges of the selected water quality variables reported at sampling sites during the sampling period are given in Table 2. Many of the water quality parameters tested were within limits of ambient water quality standards for inland waters Sri Lanka (CEA, 2001) except TSS, PO_4^{3-} and total and faecal coliform levels.

The results of two-way ANOVA indicated a significant ($p < 0.05$) variation of some water quality parameters between seasons and the sites associated with varying degree of catchment disturbances (Table 3). Among the water quality variables tested, temperature is a vital factor for the growth and development of many aquatic species and for the function of all biological and biochemical reactions in the water. The temperature of the stream water can be affected by the level of solar radiation reaching the stream channel (Beschta & Taylor, 1988; Rutherford *et al.*, 1997). According to the results of the present study, average stream temperature varied from 21 to 26 °C among sampling sites. Results of the
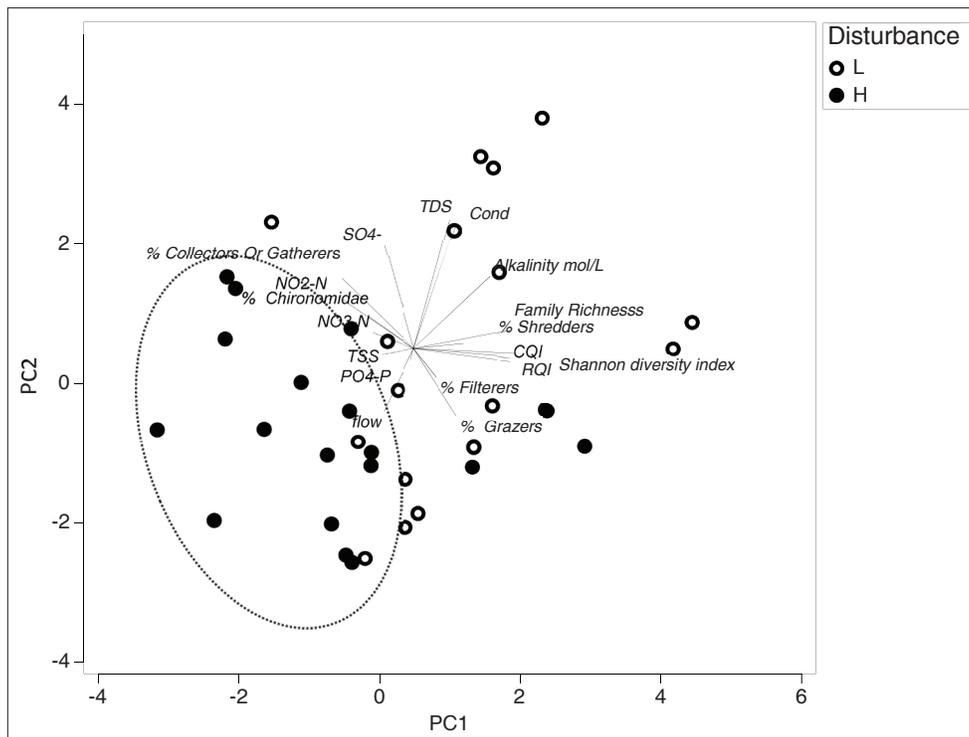
Figure 2: PCA plot indicating site variation based on stream physical habitat, water quality and macroinvertebrate bioindices (two letters in the legend indicate level of disturbed land cover based on the percentage forest cover at catchment scale L = low disturbed sites; H = highly disturbed sites)

Table 2: Mean and the range of water quality at sampling sites during 12 month sampling period

	B01	B02	B03	B04	B05	B06	B07	B08	B09	B10
Temperature (°C)	21 (17−25)	21 (15−27)	22 (17−25)	23 (20−27)	21 (15−27)	23 (18−28)	26 (19−28.9)	25 (18−28)	26 (19−29)	25 (20−28)
pH	7.31 (6.59−7.9)	7.28 (6.63−7.81)	7.28 (6.71−7.86)	7.44 (6.99−7.92)	7.26 (6.66−7.72)	7.3 (6.88−8.02)	7.32 (7.03−7.67)	7.43 (7.13−7.92)	8.26 (7.97−8.75)	8.05 (7.71−8.58)
Conductivity (μScm^{-1})	225 (127.7−304)	136 (94−169.3)	98 (49.3−131.9)	91 (43.6−124.9)	90 (11.4−122.9)	136 (68.9−187.3)	126 (61.8−167)	79 (47−107.9)	289 (173.4−363)	222 (192.2−276)
TS (mg L^{-1})	234 (160−340)	153 (110−230)	120 (70−200)	120 (60−220)	148 (80−210)	220 (90−350)	135 (90−180)	103 (60−170)	242 (180−310)	171 (130−230)
TDS (mg L^{-1})	114.7 (61−153)	71.58 (44.5−102)	49.18 (23.1−66)	46.2 (19.7−62.4)	50.41 (28.1−61.6)	71.68 (34.5−96.1)	64.04 (29.1−83.5)	40.47 (20.6−54.10)	146.4 (82.9−182)	109.17 (91.9−138)
TSS (mg L^{-1})	120 (17−279)	80 (16.3−185.5)	71 (23.9−142.5)	74 (8−176.9)	98 (22−177.1)	151 (10.6−305.3)	72 (16.7−130.9)	62 (18.1−144.3)	95 (18−187.1)	62 (12−127.1)
DO (mg L^{-1})	10.9 (4.8−16.8)	10.3 (5.6−15.2)	11 (7.2−16)	11.4 (8−15.2)	9.1 (6.4−11.2)	10.17 (8−14.4)	10.4 (8−16)	9.76 (6.4−12.8)	10.7 (6.4−16)	12.57 (8.8−16.8)
BOD (mg L^{-1})	3.3 (0.8−7.2)	4.87 (0.8−32)	3.8 (0.8−16)	0.9 (0−2.8)	1.6 (0.8−4.8)	2.23 (0.8−4)	1.87 (0−6.4)	1.4 (0−3.2)	2.96 (0.8−5.6)	3.48 (0.8−6.4)
Alkalinity (mol L^{-1})	0.0032 (0.0018−0.0049)	0.0019 (0.0012−0.0024)	0.0016 (0.0011−0.002)	0.0019 (0.0006−0.0059)	0.0014 (0.001−0.0021)	0.002 (0.0015−0.003)	0.0021 (0.001−0.0038)	0.0019 (0.0011−0.0065)	0.0046 (0.0016−0.006)	0.0041 (0.003−0.0058)
NO_3-N (mg L^{-1})	0.7 (0.2−1.6)	0.98 (0.3−2.6)	0.9 (0.2−2.5)	0.57 (0.1−1)	1.2 (0.5−2.9)	0.77 (0.2−1.4)	0.69 (0.1−1.9)	0.67 (0.3−1.6)	0.59 (0.1−2.5)	0.32 (0.2−0.5)
NO_2-N (mg L^{-1})	0.0097 (0.005−0.02)	0.007 (0.003−0.013)	0.007 (0.003−0.013)	0.004 (0.003−0.007)	0.006 (0.004−0.01)	0.011 (0.005−0.03)	0.005 (0.004−0.008)	0.006 (0.003−0.019)	0.005 (0.003−0.008)	0.006 (0.002−0.017)
NH_3-N (mg L^{-1})	0.12 (0.02−0.29)	0.09 (0.02−0.24)	0.13 (0.01−0.6)	0.09 (0.02−0.5)	0.12 (0.02−0.43)	0.08 (0.01−0.21)	0.04 (0−0.11)	0.04 (0.01−0.1)	0.02 (0.01−0.04)	0.03 (0.02−0.04)
PO_4^{3-} (mg L^{-1})	0.41 (0.09−1.32)	1.81 (0.17−19)	0.38 (0.13−1.24)	0.43 (0.08−1.42)	0.2 (0.04−0.39)	0.63 (0.11−4.78)	0.23 (0.05−0.76)	0.27 (0.06−0.98)	0.65 (0.13−4.73)	0.34 (0.16−0.78)
SO_4^{2-} (mg L^{-1})	11 (5−35)	8 (3−21)	2 (0−3)	0.58 (0−3)	2.75 (0−7)	4.58 (1−12)	0.17 (0−2)	0.08 (0−1)	5 (3−8)	0 (0−0)
Average velocity (ms^{-1})	0.5 (0.18−0.9)	0.4 (0.1−1)	0.4 (0.2−0.8)	0.6 (0.2−1.1)	0.4 (0.07−0.9)	0.56 (0.38−1.3)	0.36 (0.1−1)	0.42 (0.18−1.1)	0.52 (0.2−1.1)	0.22 (0.08−0.4)
Discharge ($m^3 s^{-1}$)	0.47 (0.04−2.16)	0.32 (0.07−1.05)	0.84 (0.21−4.13)	1.53 (0.16−9)	0.25 (0.007−0.81)	1.4 (0.16−4.13)	0.69 (0.05−4.1)	0.52 (0.09−2.16)	1.4 (0.16−5.04)	0.24 (0.04−0.71)
Embeddedness (%)	54 (30−75)	63.5 (45−80)	52.5 (30−80)	42.9 (30−60)	49.6 (30−75)	53.33 (30−70)	61.25 (30−90)	45 (25−70)	41.25 (20−50)	40.71 (25−80)

- continued from page 56

	B01	B02	B03	B04	B05	B06	B07	B08	B09	B10
Total coliform / 100 mL (×10⁶)	48 (22 – 73)	62 (27 – 110)	77 (12 – 130)	82 (18 – 190)	76 (40 – 136)	91 (26 – 140)	71 (8 – 112)	73 (32 – 105)	40 (20 – 53)	53 (26 – 100)
Faecal coliform/ 100 mL (×10⁶)	34 (14 – 52)	52 (21 – 94)	49 (6 – 89)	28 (6 – 93)	54 (21 – 97)	70 (20 – 123)	51 (3 – 88)	52 (19 – 79)	26 (13 – 53)	41 (15 – 77)
Total abundance	93 (28 – 141)	29 (13 – 40)	108 (28 – 152)	72 (14 – 175)	58 (16 – 100)	37 (12 – 56)	119 (33 – 236)	60 (31 – 79)	95 (8 – 174)	398 (328 – 439)
Family richness	10 (6 – 17)	6 (3 – 11)	16 (10 – 25)	13 (7 – 17)	9 (7 – 11)	7 (3 – 10)	14 (9 – 22)	11 (7 – 15)	13 (7 – 19)	22 (17 – 27)
% EPT	72.2 (48.75 – 86.29)	67.7 (48.1 – 88.2)	67.11 (46.09 – 81.51)	55.2 (37.14 – 69.44)	77.02 (57.33 – 87)	57.05 (25 – 80.36)	63.24 (48.45 – 77.9)	74.16 (58.1 – 84.8)	57.44 (37.5 – 79.8)	41.7 (33.7 – 53.6)
SDI	1.6 (0.88 – 2.43)	1.4 (1.1 – 2.0)	2.08 (1.84 – 2.51)	2.1 (1.7 – 2.56)	1.64 (1.53 – 1.71)	1.3 (0.56 – 1.88)	2.02 (1.77 – 2.61)	1.81 (1.4 – 2.3)	1.89 (1.52 – 2.11)	2.2 (1.7 – 2.55)
% Chironomidae	10.56 (3.23 – 6.25)	25.6 (58.8 – 33.3)	6 (0 – 12)	17.56 (5 – 32.6)	7.25 (0 – 24)	33.33 (17.9 – 62.5)	13.59 (7.79 – 19.92)	13.53 (5.1 – 29.03)	16.98 (7.45 – 25)	26.7 (4.5 – 50.7)

two-way ANOVA indicated significant ($p < 0.05$) variation of average stream temperature between the two seasons but with no significant differences among sites associated with micro-catchments with varying levels of land disturbances (Table 3). Sri Lanka is a tropical island with no marked seasonal changes of temperature during the year as in many other temperate countries. The Badulu Oya catchment receives comparatively high rainfall during the wet season than in the dry season. It is evident from the results of the present study that the significant seasonal temperature variations of the study locations could be related to dry and wet seasons of the catchment.

Among the other water quality variables tested in the present study, EC, TS, TDS, TSS, DO, alkalinity and NO_3-N were significantly influenced by the seasonal impacts and the degree of catchment disturbances. The EC of sampling sites ranged from 79.31 to 289.2 µS cm^{-1}. Water EC significantly increased ($p < 0.05$) during the dry period in comparison to the wet season and in sites associated with highly disturbed landscapes (Table 3 and Figure 3). TSS values varied between 62 to 151 mgL^{-1} among sampling sites, and in many sites these values exceeded the ambient water quality standards for fish and aquatic life in inland waters Sri Lanka (CEA, 2001). It has been observed that in the given catchment most of the soil preparation activities for vegetable cultivation are conducted during the dry period. Especially irrigation return flow, which carries fertiliser, dissolved ions and soil particles coupled with low flow during the dry period may have contributed to the observed water quality variables in disturbed sites. Land degradation and water quality deterioration due to soil erosion by unplanned agricultural activities carried out in the Mahaweli catchment is also reported by many authors (Dharmarathne *et al*., 2008; Gunawardena *et al*., 2010; Hewawasam, 2010).

NO_3-N levels in sampling sites varied between 0.1 to 2.9 mgL^{-1} and it has been significantly influenced ($p < 0.05$) by land cover disturbances at the catchment (Table 3 and Figures 3 and 5). Similar results were reported by many authors that the land cover at the catchment scale is a good predictor of in-stream nutrient concentration, particularly nitrate (Omernik, 1977; Close & Davies-Colley, 1990; Johnson *et al*., 1997). It has been reported that the sediment input to streams resulting from soil erosion carries more nitrate and phosphate than that of in the dissolved fraction in water (Waters, 1995; Amarathunga *et al*., 2013). Heavy sediment loads

carried with runoff from vegetable cultivated lands may have increased the nutrient levels in the stream water in disturbed landscapes. There was also an increase of NO_2-N, NH_3-N and SO_4^{2-} levels in sites associated with highly disturbed catchments but these variations were not significant (Figure 3). It has been reported by many authors that nitrites, ammonia containing compounds and organic loads contaminate waterways through wastewater discharge from urban areas (Allan, 1995). It can be expected that the waste from urban settlements in the catchment may have also contributed to such results. The microbiological quality of the water in study sites indicated elevated total and faecal coliform bacteria levels, which exceeded the proposed ambient water

quality standards (total coliform < 20000 colonies /100 mL, faecal coliform; 250 – 600 colonies /100 mL) for fish and aquatic life in inland waters Sri Lanka (CEA, 2001) (Table 3). Two-way ANOVA results indicated a significant ($p < 0.05$) variation of faecal coliform levels between the two seasons and among sites associated with micro-catchments with varying levels of land disturbances. The amount of faecal coliforms in the river water reflects the levels of sewage contamination of the river (Gregory & Fric, 2000; Ecology's Water Quality Program, 2005). The elevated levels of faecal coliforms reported in highly disturbed sites in the Badulu Oya may have resulted from sewage input from urban areas and human settlements in the catchment.

Table 3: Results of main factors and their interaction for the tested water quality variables in the two-way ANOVA (p values)

Parameter	Degree of catchment disturbances (Cat_Disturb)	Seasonal effect	Cat_Disturb*Season
Temperature	0.611	0.000*	0.822
pH	0.016*	0.159	0.691
Conductivity	0.000*	0.046*	0.719
TS	0.000*	0.720	0.960
TDS	0.000*	0.004*	0.769
TSS	0.088	0.000*	0.991
DO	0.022*	0.000*	0.081
BOD_5	0.119	0.626	0.756
Alkalinity	0.000*	0.001*	0.393
NO_3^- N	0.041*	0.066	0.251
NO_2^- N	0.338	0.478	0.937
NH_3^- N	0.846	0.135	0.544
PO_4^{3-}	0.930	0.252	0.725
SO_4^{2-}	0.157	0.576	0.418
Stream velocity	0.233	0.000*	0.237
Stream discharge	0.003*	0.000*	0.338
Embeddedness	0.050	0.045	0.378
Ephilithic biomass	0.050*	0.035*	0.509
Total coliform	0.588	0.000*	0.895
Faecal coliform	0.000*	0.014*	0.879
Total abundance	0.001*	0.103	0.856
Family richness	0.024*	0.006	0.907
Shannon diversity index	0.167	0.047	0.628
% EPT	0.108	0.860	0.827
% Chironomidae	0.044*	0.504	0.862
% Grazers	0.488	0.010*	0.120
% Shradders	0.024*	0.315	0.376
% Collectors	0.349	0.041*	0.136
% Filter feeders	0.451	0.288	0.780
% Predators	0.675	0.496	0.879

* indicate significant p values at 0.05 level

Temperature

pH

Conductivity

TS

DO

BOD

TDS

TSS
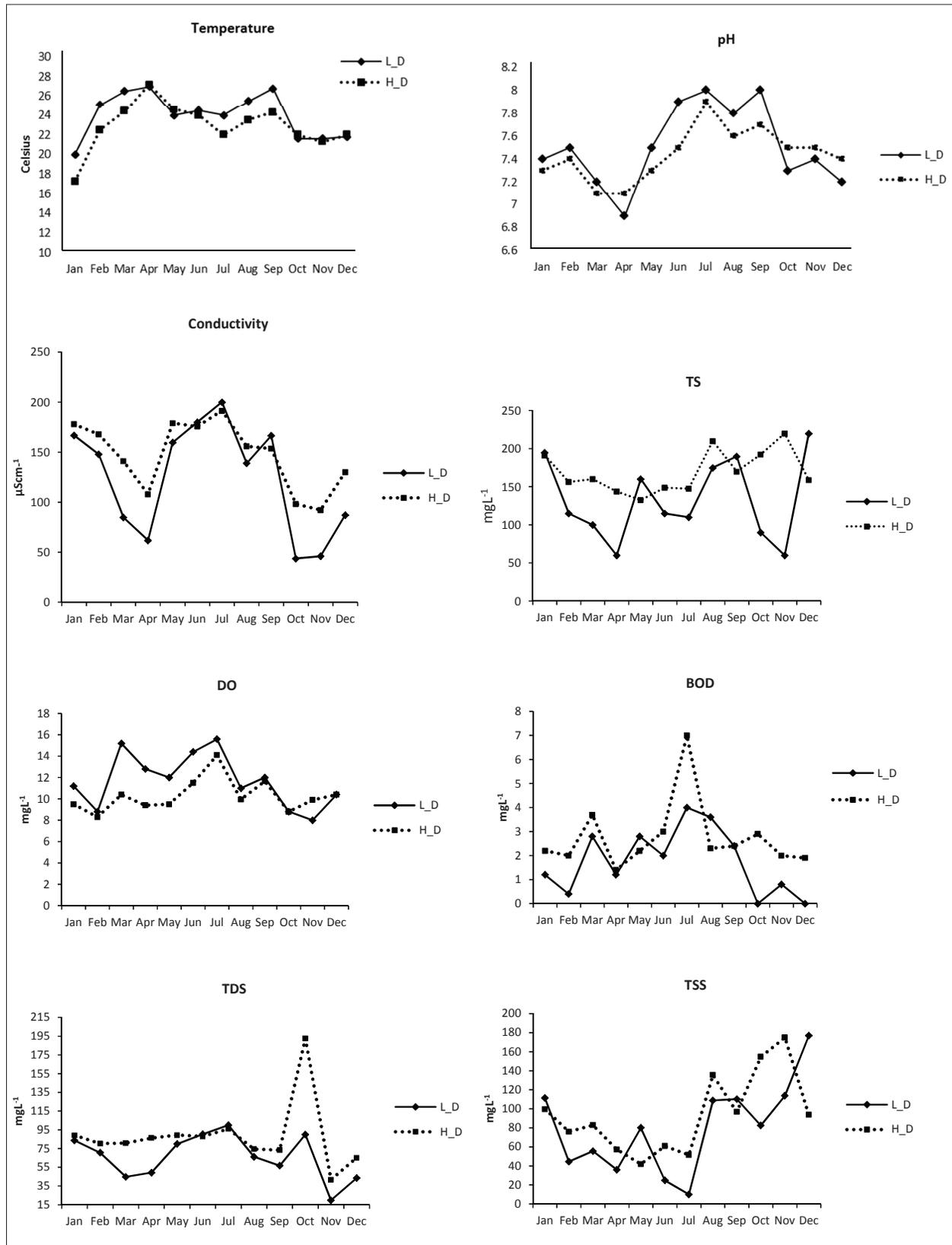
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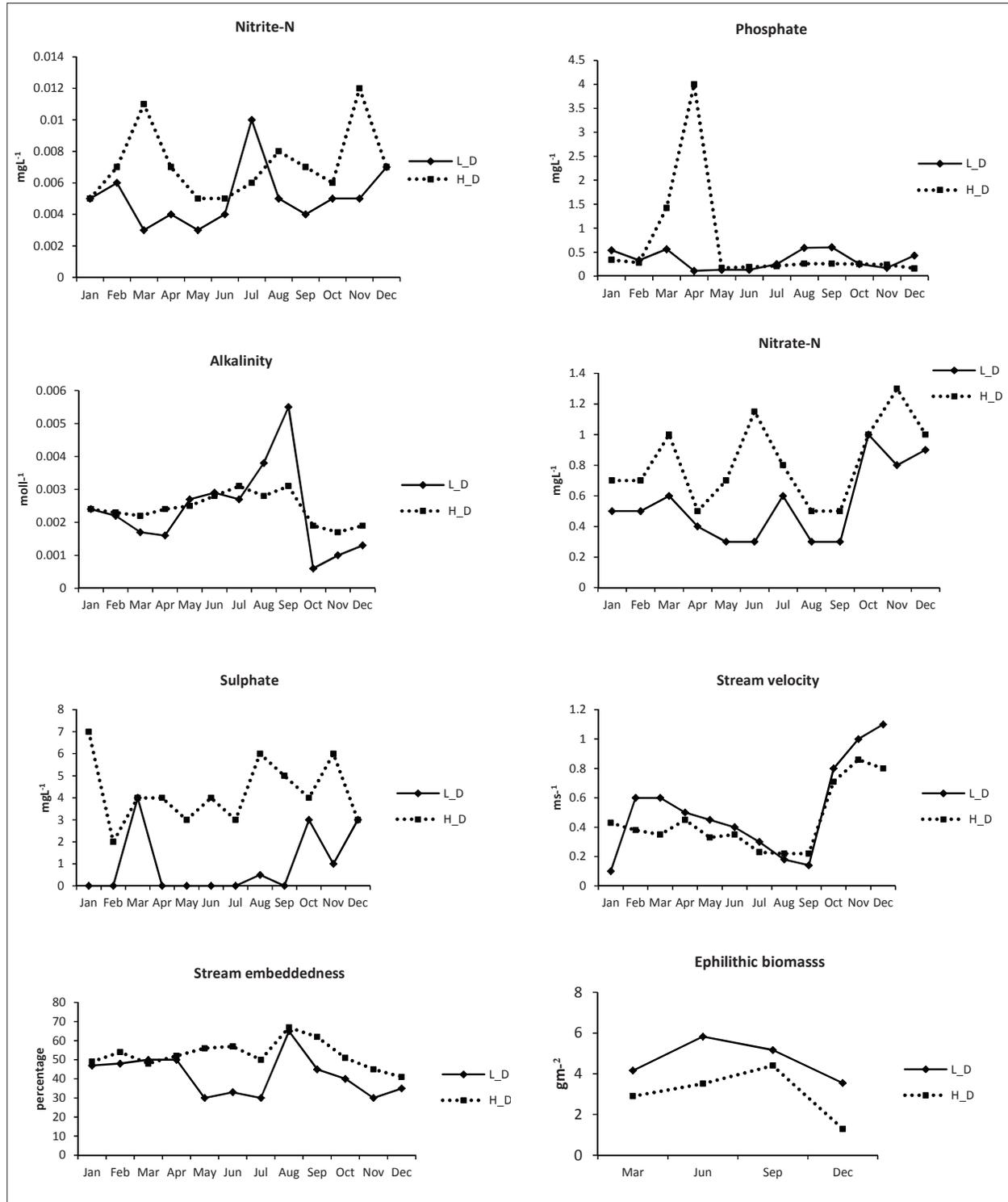
Figure 3: Monthly average water quality variation in sites associated with high (H_D) and low (L_D) catchment disturbances at entire catchment area

RQI reflect the relative healthiness of the riparian vegetation in terms of quality of vegetation structure (Tánago & Jalón, 2011). In the present study RQI scores ranged from 3 to 17 and high scores were recorded in less disturbed sites. PCA results also indicated that RQI is associated with sites with high percentage forest cover in the catchment. Human induced activities such as agriculture can have a significant impact on the riparian quality (Aguiar & Ferreira, 2005). In many sites of the study, encroachment of banks of the streams by cultivated lands was evident and the riparian vegetation is completely cleared or fragmented. Lack of riparian cover along the river in agricultural and urban areas may have contributed to the higher inputs of contaminants in stream water through runoff.

Table 4: Macroinvertebrate taxa recorded in sampling sites during wet and dry seasons (+ present; - absent)

Order	Family	Dry season										Wet season									
		B01	B02	B03	B04	B05	B06	B07	B08	B09	B10	B01	B02	B03	B04	B05	B06	B07	B08	B09	B10
Ephemeroptera	Baetidae	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Caenidae	+	-	+	+	-	-	+	+	+	+	-	-	+	+	+	-	-	+	-	+
	Leptophlebiidae	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+
Plecoptera	Notonemouridae	+	+	+	+	-	-	+	+	+	+	-	-	-	+	+	-	-	+	+	+
Trichoptera	Calamoceratidae	-	-	-	+	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	+
	Goeridae	+	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	+
	Helicopsychidae	+	-	+	-	+	-	-	-	-	+	+	-	+	-	-	-	+	-	-	-
	Hydroptilidae	+	-	-	-	+	+		+	+	+	-	-	+	+	-	-	+	+	+	+
	Hydropsychidae	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Leptoceridae	+	+	+	+	+	+	+	+		+	-	-	-	-	-	-	-	-	-	-
	Odontoceridae	-	-	+	+		+	+	+	+	+	-	+	-	-	-	-	+	+	+	+
	Philopotamidae	-	-	-	+	-	-	+	+	-	+	-	-	+	-	-	-	+	-	-	+
	Psychomyiidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Rhycophilidae	-	-	+	-	-	-	+	-	-	+	-	-	+	-	-	-	-	-	-	+
Odonata	Aeshnidae	+	+	+	-	+	-	+	+	+	+	+	-	-	-	-	-	-	-	-	-
	Synthemistidae	-	-	+	-	-	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-
	Lestidae	-	-	+	-	-	-	-	-			-	-	-	-	-	-	-	-	-	-
	Diphlebiidae	-	-	+	-	-	-	+	-	+		-	-	-	-	-	-	-	-	-	+
	Coenagrionidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Coleoptera	Elmidae	+	-	+	+	+	+	+	-	+	+	+	-	+	+			+	+	+	+
	Psephenidae	+	-	+	+	+	-	+	+	+	+	-	-	+	+	+	+	+	-	+	+
	Gyrinidae	+	-	-	+	-	-	-	+	+	+	-	-	-	+	-	-	+	+		+
Diptera	Chironomidae	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Culicidae	+	-	+	+	-	-	+	+	+	+	-	-	-	-	-	-	-	-	-	-
	Psychodidae	+	+	+	+	+	+	+	-	+	+	+	-	+	+	+	-	+	+	+	+
	Scymyidae	-	-	-	-	-	-	-	+	+		-	-	-	-	-	-	-	-	-	-
	Simuliidae	+	-	+	+	-	-	+	+	+	+	+	-	+	+	+	-	+	+	+	-
	Stratiomyidae	-	+	+	-	-	-	-				-	-	-	-	-	-	-	-	-	-
	Tabanidae	-	-	-	-	+	-	-	-	+	+	-	-	-	-	-	-	-	-	-	+
	Tipulidae	-	-	+	+		+	+		+	+	+	-	+	-	-	-	+	+	+	+
Hirudinae	Rhynchobdelle	+	+	+	+	+	+	-	+	-	+	-	-	-	-	-	+	-	-	-	-
Oligochaeta	Lumbricidae	+	-	+	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-
Decapoda	Potamonidae	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-	+
	Atyidae	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-
Sorbeoconcha	Paludomidae	+	+	+	+	-	-	+	-	-	+	+	+	+	-	-	-	+	+	+	+
	Pilidae	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Neotaenioglossa	Thiarinae	+	-	+	+	+	+	+	-	-	+	-	-	-	-	-	+	-	-	-	+
Hygrophila	Planobidae	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Among the physical attributes tested, channel physical habitat quality index (CQI) reflects the habitat diversity within the channels. Improved habitat diversity within channels support diverse communities and increase the species richness (Barbour *et al.*, 1999). In the present study CQI varied from 3.1 to 18 among the sites. High CQI values were recorded in sites associated with high forest cover and low CQI values resulted in sites associated with low forest cover. This suggests that local riparian vegetation has a strong impact on structuring stream channel features. Among the various functions of the riparian zone on structuring channel features, riparian canopy contributes to channel shade (Davies-Colley & Rutherford, 2005). Wood recruitment in riparian forests determines the amount of large woody debris in the river channel and plays an important role in determining
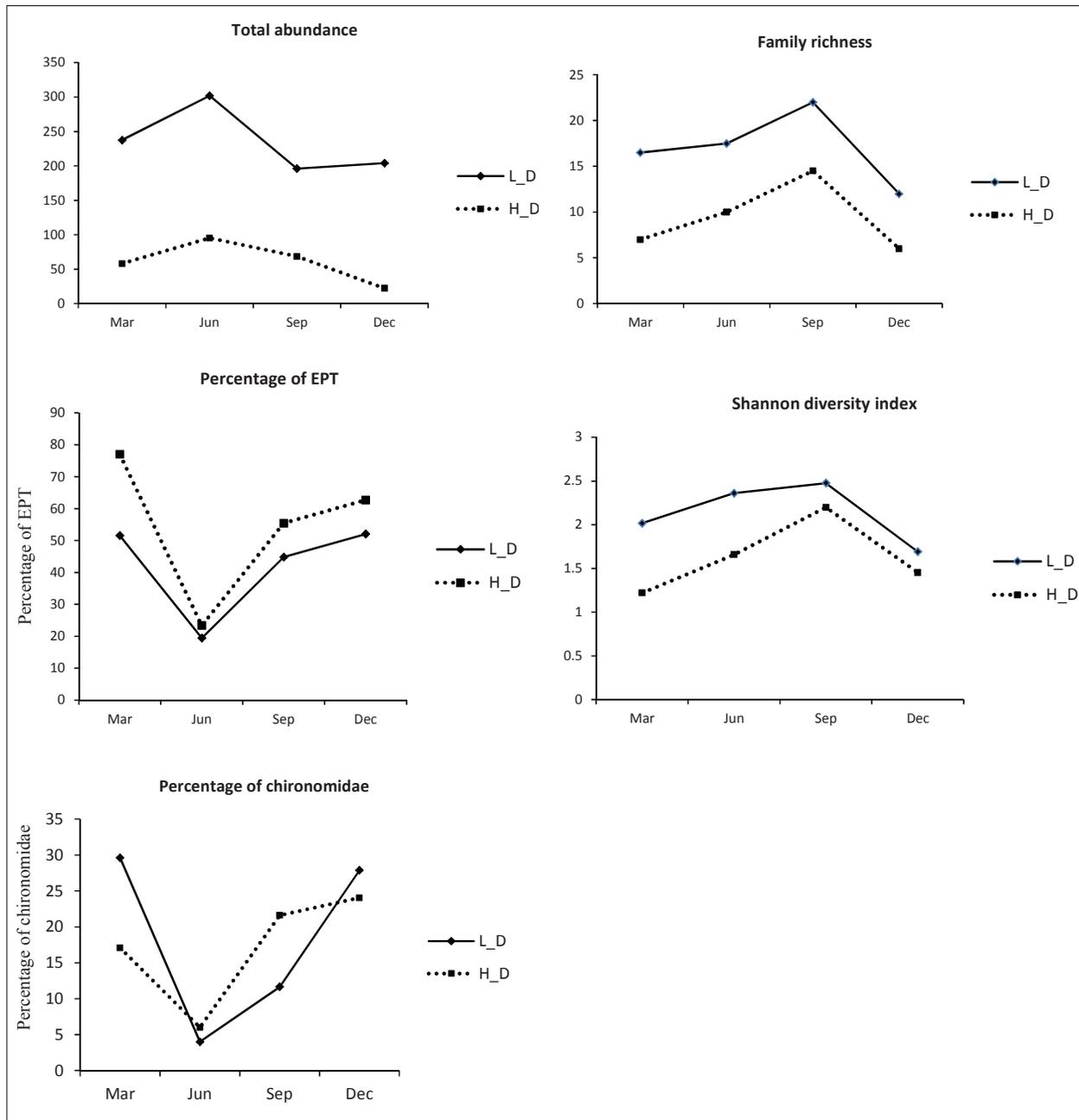
Figure 4: Variation of macroinvertebrate indices in sites associated with high (H_D) and low (L_D) catchment disturbances at entire catchment area
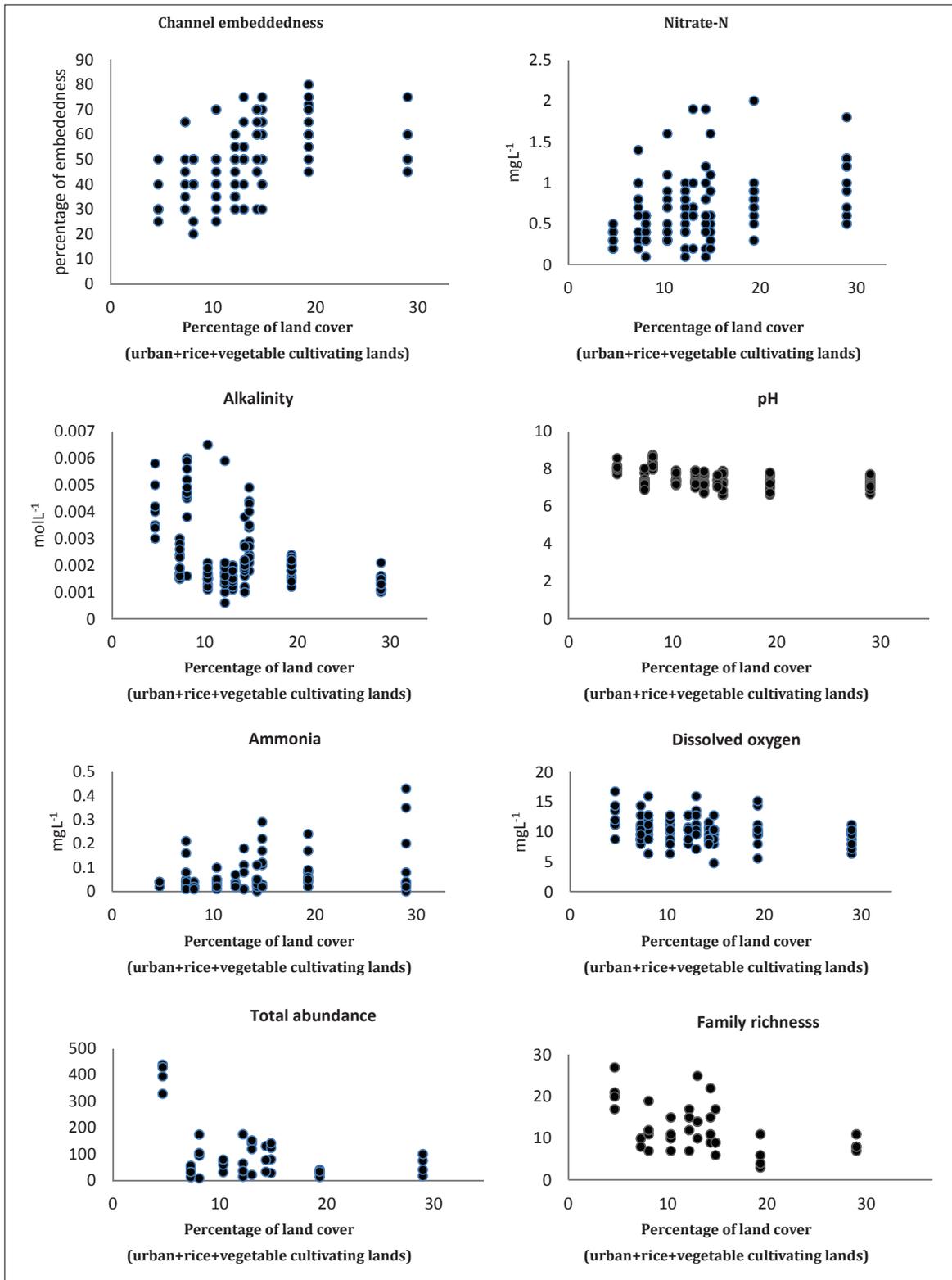
Figure 5: The variation of stream physical habitat, water quality and some macroinvertebrate indices with level of disturbance of micro catchments (as measured by the percentage of urban + rice and vegetable cultivating land cover in micro catchments)

meso-habitat sequences (Brooks *et al*., 2003), velocity patterns, substrate composition and in-stream habitat heterogeneity (Elosegi *et al*., 2010). Embeddedness reflects the degree to which larger particles (e.g., boulder, rubble, gravel) in the stream bed are surrounded or covered by fine sediments (Platts *et al*., 1983; Fitzpatrick *et al*., 1998). The results clearly demonstrated that stream embeddedness significantly varied in sites associated with high level of catchment disturbances, and with the season (Table 3). The results suggest that stream channels in sites with disturbed landscapes are highly embedded by fine sediments than the reference sites (Figures 3 and 5). It is possible that the high input of soil particles from landscapes disturbed by vegetable cultivation and urban settlements in the given catchment may have contributed to the observed differences.

Macroinvertebrate bioindicators

During the study a total of 38 benthic macroinvertebrate families were recorded in the Badulu Oya catchment (Table 4). PCA and the results of two-way ANOVA indicated the factors contributing to the variation of macroinvertebrate indices in the sampling sites. Among the macroinvertebrate indices that were tested, total abundances and family richness were significantly influenced by the degree of catchment disturbance (Table 3; Figures 2 and 5). Macroinvertebrate total abundance and richness decreased with increasing catchment disturbances (Figures 4 and 5). As reflected

in the PCA, improved water quality along with improved habitat quality (as reflected by CQI) has higher association with macroinvertebrate indices such as family richness and total abundance. It has been reported by many authors that stream features such as substratum characteristics and flow regimes interact with thermal regime generate habitat templates upon which macroinvertebrate assemblages are structured (Southwood, 1977; Poff & Ward, 1990), which would be the case for the trends observed in the present study. However, other bioindices measured in the present study, i.e. percentage ETP taxa and percentage chironomidae, did not show significant association with catchment disturbance as depicted in the results of ANOVA test. However, in the PCA chironomidae percentage was associated with degraded catchments. This suggests that those indices need to be further tested for their application in the local context. The results of the present study also suggest that catchment scale land use activities in the Badulu Oya catchment influence the stream habitat features and water quality, ultimately determining the macroinvertebrate assemblage structure.

The present study shows that catchment disturbance through agriculture and urban activities also affect the functional feeding groups of macroinvertebrates. The functional feeding categories of biota in the streams are a better indicator of the energy dynamics within the streams as described in the river continuum concept (Vannote *et al*., 1980). The results of the present study indicated
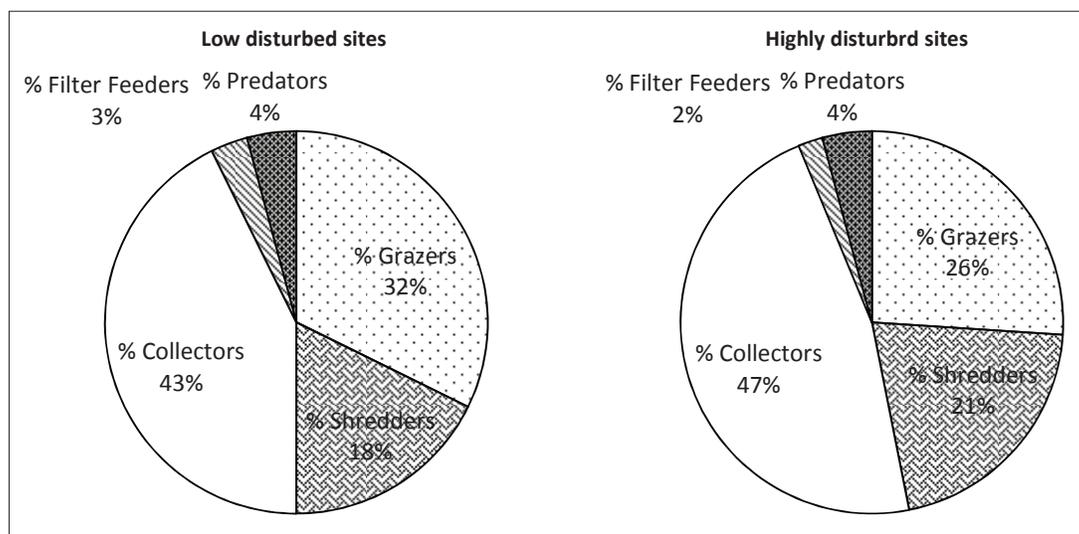
Figure 6:   Variation of macroinvertebrate feeding groups in sites associated with high (H_D) and low (L_D) catchment disturbances at entire catchment area

that the sites, which are impacted by land disturbance in the adjacent catchments are mostly dominated by collectors (Figure 6). The sites which are less affected by disturbance were dominated by grazers (Figure 6). It can be expected that the high level of fine particles coupled with increased levels of organic sediments entering the streams in disturbed sites may have contributed to increased number of collector gatherers in the impacted sites.

Overall the findings of the present study clearly indicate that catchment disturbance impacts by land use changes exert on stream ecological health of the Badulu Oya catchment.

CONCLUSION

In conclusion the findings of the present study suggest that land use activities in the Badulu Oya catchment significantly affects the ecological health of the stream. Chemical water quality variables such as EC, TS, TDS, DO, alkalinity and NO_3-N; physical variables such as stream CQI and RQI indices; biological variables such as faecal coliform counts, macroinvertebrate indices like total abundance and family richness were significantly influenced by the degree of catchment disturbances. This suggests that there is a possibility to incorporate such variables in river health monitoring programmes in the given catchment.

However, many of the water quality monitoring programmes in Sri Lanka mainly focus on onsite water quality analysis to estimate the level of pollution. The present approach is important for accurate assessment of stream ecological health since it incorporated diverse attributes to assess the stream health. Lack of baseline data on biological indices to measure stream health in Sri Lanka makes this approach even more important for further development of bioindices and their application in river health monitoring programmes in Sri Lanka.

Acknowledgement

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