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Impact of Land Use on Surface Water Quality: A Case Study in the Gin River Basin, Sri Lanka

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Abstract: There has been a considerable amount of research investigating suspended sediment (SS) and water quality in river basins. However, there has been less attention to the suspended sediment behaviour in tropical river basins, especially in Sri Lanka. The Gin river basin is one of the major river basins in Sri Lanka and catchments consist of multi-land use systems. The behaviour of water quality, and suspended sediment with land use pattern is still not well studied in tropical river basin. Therefore, the aim of this study was to elucidate land use effects on suspended sediment and water quality in multi-land use tropical river basins. Elevated nitrate nitrogen concentrations were observed in the upper catchment and greater ammonia nitrogen concentrations were recorded in the lower catchment sampling locations. Also, higher fluxes of nitrate nitrogen and dissolved phosphate were observed during April to June and June to July, respectively.

The major land use systems in the upper catchment portion consist of activities related to forest management while the lower catchment region has a higher percentage of agriculture and other land use related functions. Different land use pattern from forest to agriculture was increasing the suspended matter in the river water. Also, there was a very low concentration of suspended sediment and turbidity in the highly forested catchments in upper parts of the basin. This was expected since turbidity and suspended sediments increase with increasing amounts of agriculture and other land use activity. Also, statistical results prove that major physical and chemical water quality parameter means are different with three sub basins. In conclusion, the suspended sediment flux and discharge fits well with the linear regression model (R^2 = 0.97) and would imply that the discharge can be used to predict the SS load from runoff.

Key words: Gin river basin, land use, water quality, suspended sediment.

Introduction

Tropical areas, which have a high rainfall throughout the year and have favourable climatic factors for crop production, can have a large impact on river basins. Freshwater systems such as lakes, rivers and streams are important to humans because these are resources for public health, clean water for households, and also are critical for industrial and agricultural uses. Further, they are also important as habitats for many species of animals and plants (Ruthenberg, 1971; Connell, 1993; Ward et al., 2002; Sivakumar et al., 2005). As human population increases, rapid industrialization, agricultural activities and drinking water requirement are multiplying every day and our understanding of possible contributions to water pollution is utmost important.

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Many pollutants have been found to be ubiquitous in nature; that is, every environmental compartment that has been tested has known some level of contamination (Dunnivant and Anders, 2006). Nevertheless, pollutant levels in water are frequently below the limits of detection. Some may cause chronic effects or result in periodic flushes of poor quality water or bioaccumulation that ultimately may damage the aquatic community or the outbreak of water-borne diseases (Voznaya, 1981; Simon and Grossart, 2002). Presently, many incidents happen, such as diarrhoea, chronic kidney disease, etc., are due to freshwater resources being polluted by industrial wastes, sewage and agricultural runoff.

Agricultural land-use in the catchment can significantly modify surface and groundwater chemistry (Johnson et al., 1997) and recent studies conclude that over-usage of fertilizer and pesticide application can lead to deterioration of surface water quality (Amarathunga et al., 2010; Azmy et al., 2010; Watawala et al., 2009; Amarathunga et al., 2013b). The LULC (Landuse and Landcover) changes have a significant impact on climate at both local and regional levels because of (1) the modifications in the carbon cycle, (2) the local evapotranspiration patterns, and (3) the precipitation regimes. This justifies many concerns that the LULC changes could have in the water resources, particularly in the hydrological regimes worldwide (Stallard, 1998; Mejía and Hochschild, 2012).

The interrelationship between land use and water quality of upland tributaries which drain forests into higher-order streams with a variety of downstream land use has received less attention (Sidle and Hornbeck, 1991). In addition, there are three distinguished attributes between the temperate and tropical catchments: (1) point source pollution, (2) fertilizer usage, and (3) crop species cultivations (Ometo et al., 2000). Also, land-use effects may differ between temperate and tropical river basins because of urban land-use systems with different levels of anthropogenic influences, geology and climate, the impact of agricultural land use, soil properties, and nutrient availability (Dudgeon, 2008). Also, water quality is often degraded by land use. Intensive agriculture increases erosion and sediment load, and leachate of nutrients and other agrochemicals into streams, rivers and groundwater. In fact, agriculture has become the largest source of excess nitrogen and phosphorus to waterways and coastal zones (Foley et al., 2005). Therefore, the purpose of this study was to assess the impact of the interactions of human activities with the natural systems of land use pattern on water quality and the behaviour of suspended sediment from upstream to downstream in tropical river basin.

Methodology

Study Area

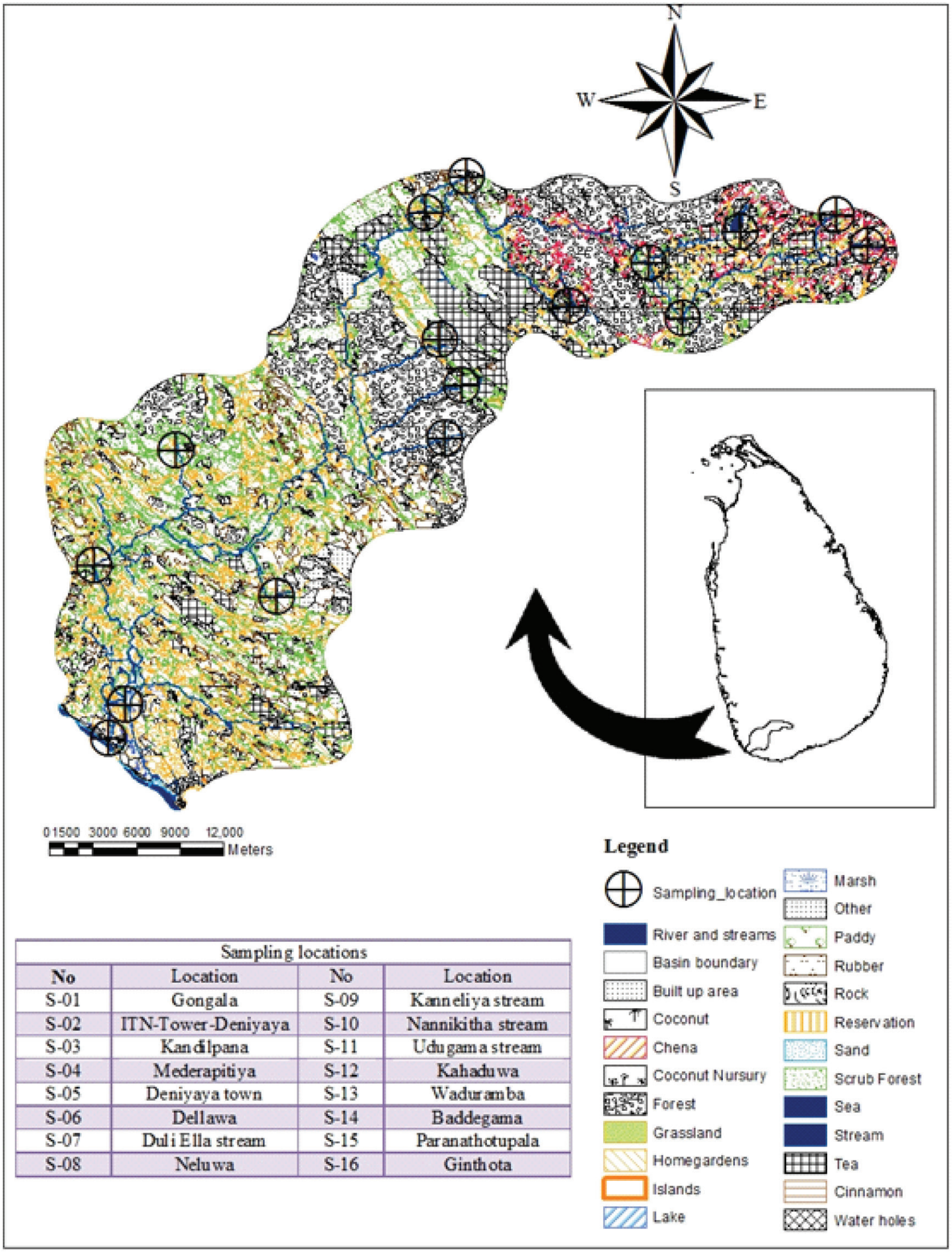
The Gin River is one of the fast flowing large rivers with 113 km length in the southwest of Sri Lanka (Figure 1). The basin source is Gonagal Hills near Deniyaya in the Rakwana mountain range. Gin River starting from Abbey Rock, approximately from 4268 ft above mean sea level and empties into sea level at Ginthota, which is a few kilometres north of Galle (Arumugam, 1969). The Gin River basin has 932 km^2 of catchment areas and the region is covered in a south-west monsoonal area with mean annual rainfall of over 2500 mm. The average annual discharge into the sea is about 2000 million cubic metres (MCM). Major forest reserves that lie within upstream of Gin River basin include Singharaja, Kanneliya, Nakiyadeniya, Dediyagala, Dellawa, and Beraliya forests. Agriculture (mainly tea), paddy, rubber, palm oil production and tourism are the major economies in this basin. The basin is classified into three catchment zones: (1) upper catchment (second and third order feeding tributaries in most upper of the basin) in higher elevated area; (2) middle catchment (main river in elevated areas and second order stream in lower elevated areas); and (3) lower catchment (main river in the lower part of the basin).

Sampling Locations and Surface Water Sampling

Eight major streams (Dellawa stream, Kandillpana stream, Kanneliya stream, Nanikitha stream, Udugama stream, Galabedi stream, Mahadola stream and Duliella stream) were selected for sampling along with the main river. During a two-year (n = 10) period, surface water sampling at 16 locations were carried out in upstream, middle stream and downstream areas of the Gin River basin (Figure 1). Two subsurface water samples were collected from the middle of the stream at 50 cm to 100 cm depth and an in-situ analysis was done after sampling. Water samples were filtered through Whatman GF/C filter paper and stored at 4 °C and in dark conditions until transported to the laboratory for further analysis. Three replicates were used for laboratory analysis in each sampling location and the mean value was used for data analysis.

Analysis of Water Samples

Ammonia nitrogen, nitrate nitrogen, nitrite nitrogen and orthophosphate were analysed in accordance with the Standard Methods for Examination of Water



Sampling locations			
No	Location	No	Location
S-01	Gongala	S-09	Kanneliya stream
S-02	ITN-Tower-Deniyaya	S-10	Nannikitha stream
S-03	Kandilpana	S-11	Udugama stream
S-04	Mederapitiya	S-12	Kahaduwa
S-05	Deniyaya town	S-13	Waduramba
S-06	Dellawa	S-14	Baddegama
S-07	Duli Ella stream	S-15	Paranathotupala
S-08	Neluwa	S-16	Ginthota

Figure 1: Sampling locations and landuse in the Gin River basin.
Source: **Survey department of Sri Lanka.**

and Waste Water (APHA, 2005). In addition, SSC (suspended sediment concentration) was determined using a filtration method (Guy, 1969). In-situ analysis was conducted for the determination of pH (Orion 260A); dissolved oxygen (Orion 830A); turbidity (Hatch 2100P); total dissolved salts (TDS); and water temperature (thermometer). The flow rate was measured using a portable flow meter (FP101) in three different places at a 50 cm to 100 cm depth. Also, water depth was measured using a measuring pole and stream gauging stations at Baddegama.

Computation of Nutrient and Suspended Sediment Load
Dissolved nutrient loads and suspended sediment (TSS) loads were calculated at the Baddegama sampling location. The load was calculated using equation (1) where L is load (kg/day), F is a unit conversion factor, C is the concentration of the parameter (mg/l) and Q is discharge (m^3/s) (Buchanan and Somers, 1969).

$$L = F \times C \times Q \quad (1)$$

Data Analysis
Met-lab software, Arc GIS version 10, Microsoft Excel and SPSS-20 were used for data analysis. In addition, cluster analysis was performed on the nutrient and sediment loading data sets at each sampling location to determine similar groups of pollutants locations. Furthermore, hierarchical cluster methods and the euclidean distance of the data sets were followed for the cluster analysis. Also, Kruskal-Wallis test followed by ANOVA was used to test the significance of the mean variation in three different catchments. Land use data were obtained from the survey department of Sri Lanka (2008 updated) and land use planning department in District Secretariat. Maps were prepared using Arc GIS 10.1 version based on the above data.

Results

Land-use Systems in the Gin River Basin
The land use systems for natural forest and tea (more than 80%) are located mainly in upper catchment (UC). Therefore, the upper catchment has good land cover with the main agricultural crop being tea. The middle catchment (MC) consists of forest, scrub forest, homegardens, rubber, paddy and tea. Homegardens, paddy, rubber, scrub forest and tea have a significant role in the land use of the lower catchment (LC). Existing land-use pattern is shown in Figure 1 and percentage of land use in different basins is given in Table 1.

Table 1: Landuse pattern in the Gin River basin (percentage)

Landuse category	*River basins*		
	UC	*MC*	*LC*
Built-up area	-	-	0.41
Coconut	0.18	0.19	7.65
Chena	6.42	1.69	-
Forest	59.88	41.94	0.96
Grassland	0.11	0.02	0.01
Homesteads/Garden	5.08	12.4	32.64
Inland Island	-	-	0.001
Lake	-	-	0.04
Marsh	-	0.01	1.32
Other	0.86	3.13	2.77
Paddy	2.1	10.8	21.54
Rubber	-	9.47	13.02
Rock	0.29	0.14	0.01
Reservoir	-	-	0.08
Sand	-	-	0.42
Scrub forest	3.21	10.56	9.42
Stream and rivers	0.6	0.99	1.29
Tea	21.26	8.63	8.42
Unclassified	-	0.001	-
Water holes boundaries	0.01	0.03	-

Surface Water Quality
Mean water temperature in the Gin river basin was 25.8 ± 2.4 °C and atmospheric temperature was 27.7 ± 0.7°C. Summary of the physico-chemical parameters in three different regions of the basin are shown in Table 2. Figure 2 shows the physical parameter variation in the Gin River basin during the study period. The water temperature in MC and LC were similar while the upper catchment area was different. However, EC increased in the lower catchment area in the month of February. Analytical results indicated that pH is mildly acidic in all three regions of the basin. Nitrogen and phosphorus are the major factors responsible for the productivity of a water body. Ammonia, nitrate and phosphate parameters behaved similarly in this basin. Figure 3 shows the behaviour of dissolved nutrients in the three different regions of the basin. Similar ammonia-nitrogen concentration was observed in MC and LC basins while UC was lesser during every month with exception of November.

MC recorded greater ammonia concentrations than the other two regions in April and November-December months. Nitrate-nitrogen was very high in UC and MC when compared with LC during every month except February in year 2009. Specially, nitrate-N concentration was greater during April to May and September to December in the three regions of the basin. Dissolved phosphate concentrations were greater during April to July and September in the basin. Turbidity and suspended sediments in the MC and LC were greater than UP (Figure 4a and 4b) while turbidity and suspended solids were greater during the April to July period.

Table 2: Mean variation of the water quality in Gin River basin

No.	*Parameters*	*UC*	*MC*	*LC*
1	WT (°C)	24.56 ± 2.2 (19.5-29.0)	26.24 ± 1.6 (23.6-28.7)	28.03 ± 1.7 (24.8-32.3)
2	pH	6.27 ± 0.5 (5.01-7.54)	6.19 ± 0.6 (4.91-7.04)	6.09 ± 0.4 (5.45-7.31)
3	DO (mg/l)	6.72 ± 1.4 (4.8-11.6)	6.28 ± 1.0 (4.4-8.4)	5.88 ± 1.1 (4.2-8.8)
4	EC (µS)	24.05 ± 16.6 (13.9-178.2)	37.70 ± 9.9 (25.5-69.1)	466.39 ± 1373.1 (25.3-7460.0)
5	Turbidity (NTU)	3.05 ± 2.8 (0.51-17.81)	13.59 ± 15.5 (2.4-68.5)	24.5 ± 22.3 (5.83-80.9)
6	TDS (mg/l)	10.58 ± 2.7 (6.1-22.8)	18.06 ± 4.9 (12.0-32.6)	239.11 ± 730.1 (11.8-3980.0)
7	BOD (mg/l)	14.14 ± 7.7 (3.0-33.0)	16.33 ± 7.8 (1.0-28.0)	17.06 ± 7.2 (1.0-32.0)
8	Ammonia-N (mg/l)	0.13 ± 0.2 (0.01-0.96)	0.13 ± 0.1 (0.01-0.98)	0.23 ± 0.4 (0.01- 1.92)
9	Nitrite-N (mg/l)	ND	ND	ND
10	Nitrate-N (mg/l)	1.28 ± 1.2 (0.09-6.75)	2.12 ± 1.6 (0.33-6.32)	2.54 ± 1.4 (0.23-5.40)
11	Ortho-phosphate (mg/l)	0.39 ± 0.3 (0.01-1.18)	0.53 ± 0.5 (0.01 -1.63)	0.48 ± 0.5 (0.04-1.63)
12	SSC (mg/l)	13.57 ± 4.3 (1.2-32.3)	30.56 ± 13.3 (15.4-60.6)	36.5 ± 14.3 (18.1-60.9)
13	Ferrous (mg/l)	0.15 ± 0.1 (0.00-0.16)	0.24 ± 0.2 (0.00-0.22)	0.26 ± 0.1 (0.00-0.20)
14	Chl-*a* (mg/m^3)	3.37 ± 2.6 (0.02-11.5)	3.17 ± 2.2 (0.2-6.7)	2.51 ± 1.9 (0.5-6.5)
15	COD (mg/l)	20.07 ± 7.6 (3.5-29.6)	22.75 ± 7.8 (9.1-38.4)	24.83 ± 8.4 (14.7-37.5)
16	Cd (mg/l)	0.03 ± 0.0 (0.00-0.05)	0.04 ± 0.0 (0.00-0.05)	0.03 ± 0.0 (0.00-0.04)

UC – Upper catchment, MC – Middle catchment, LC – Lower catchment, ND – Not detected.

Figure 5a illustrates the dissolved nutrient load in three different regions of the basin. The elevated nitrate-N load was observed during the April to June and September to December periods. The dissolved phosphorous load was very high in June-July. Additionally, the significant ammonia-N load was observed during the November month. Figure 5b showed TSS and TDS flux during the study period. Total Suspended Solids and TDS flux were fluctuating and higher levels were observed during the April to July period.

The relationship between land use and suspended sediment is illustrated in Figure 6a and correlation is given in equation (2). The R^2 value of land use and suspended sediment correlation is 0.802. A sediment rating curve was developed (Figure 6b) and the linear regression line is used for model with R^2 value of 0.97. The results of the statistical analysis by Kruskal-Wallis test followed by ANOVA is given in Figure 7 and Table 3. Bar graphs (Figure 7) clearly show variation of the mean of three different sub-catchment in the Gin River basin.

$$Y = -8.556X + 40.32 \quad (2)$$

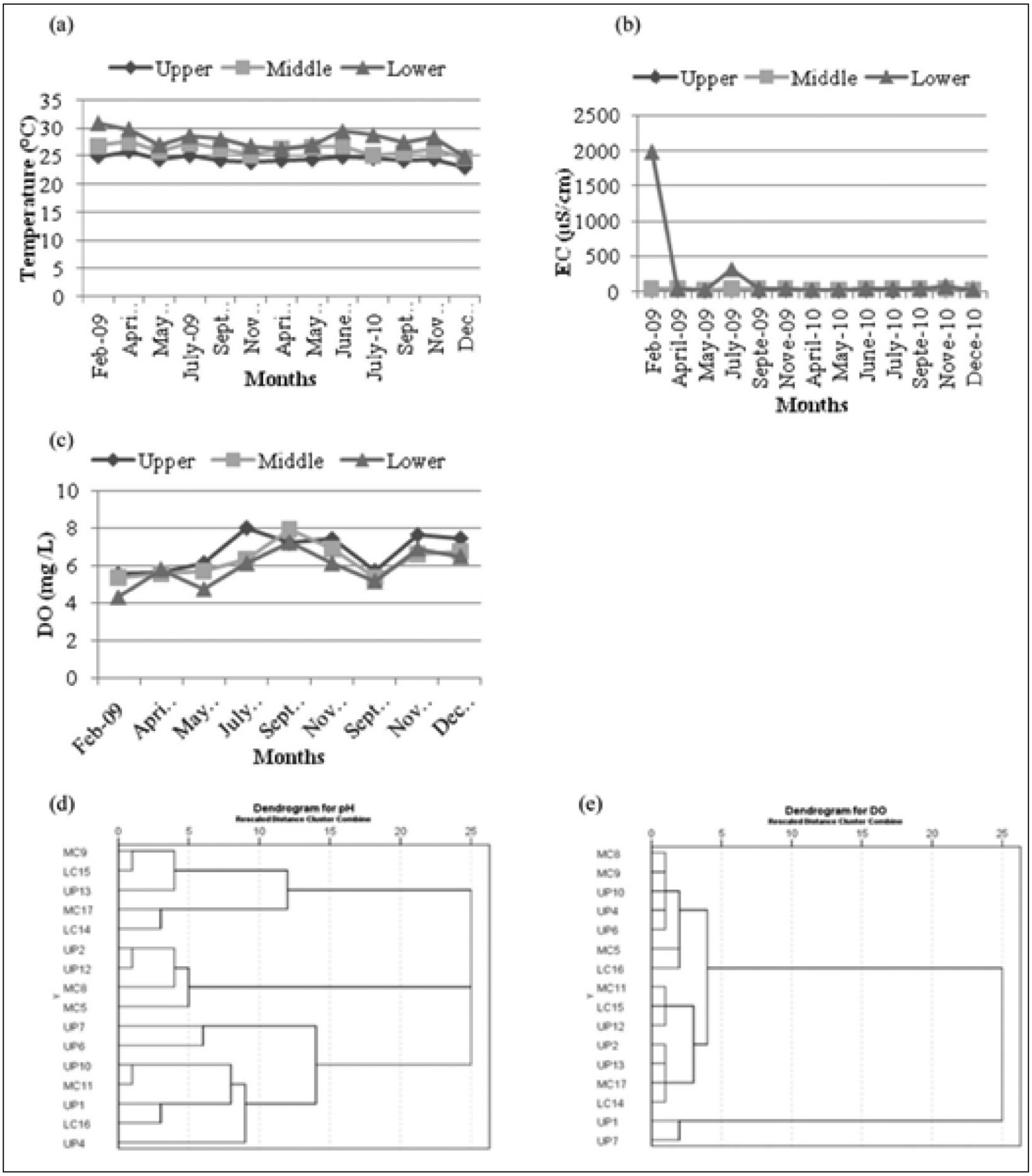


Figure 2: Spatial and temporal variation of EC and temperature in different basins of the Gin River: (a) mean monthly water temperature, (b) mean monthly EC variation, (c) DO variation, (d) results of pH cluster analysis and (e) results of DO cluster analysis.

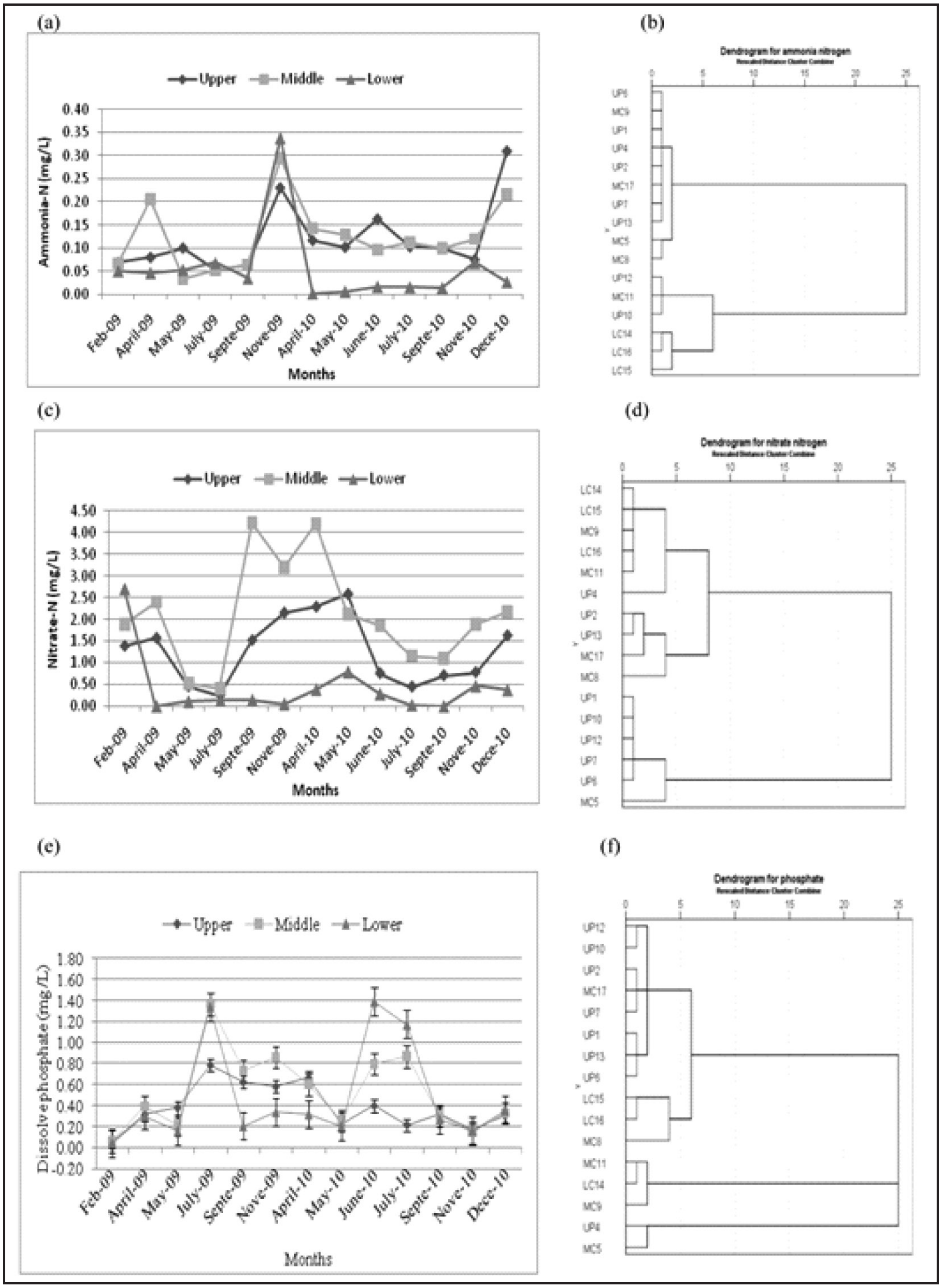


Figure 3: Temporal variation of nutrient in three different basins in the Gin River: (a) ammonia-nitrogen, (b) nitrate nitrogen and (c) dissolved phosphate.

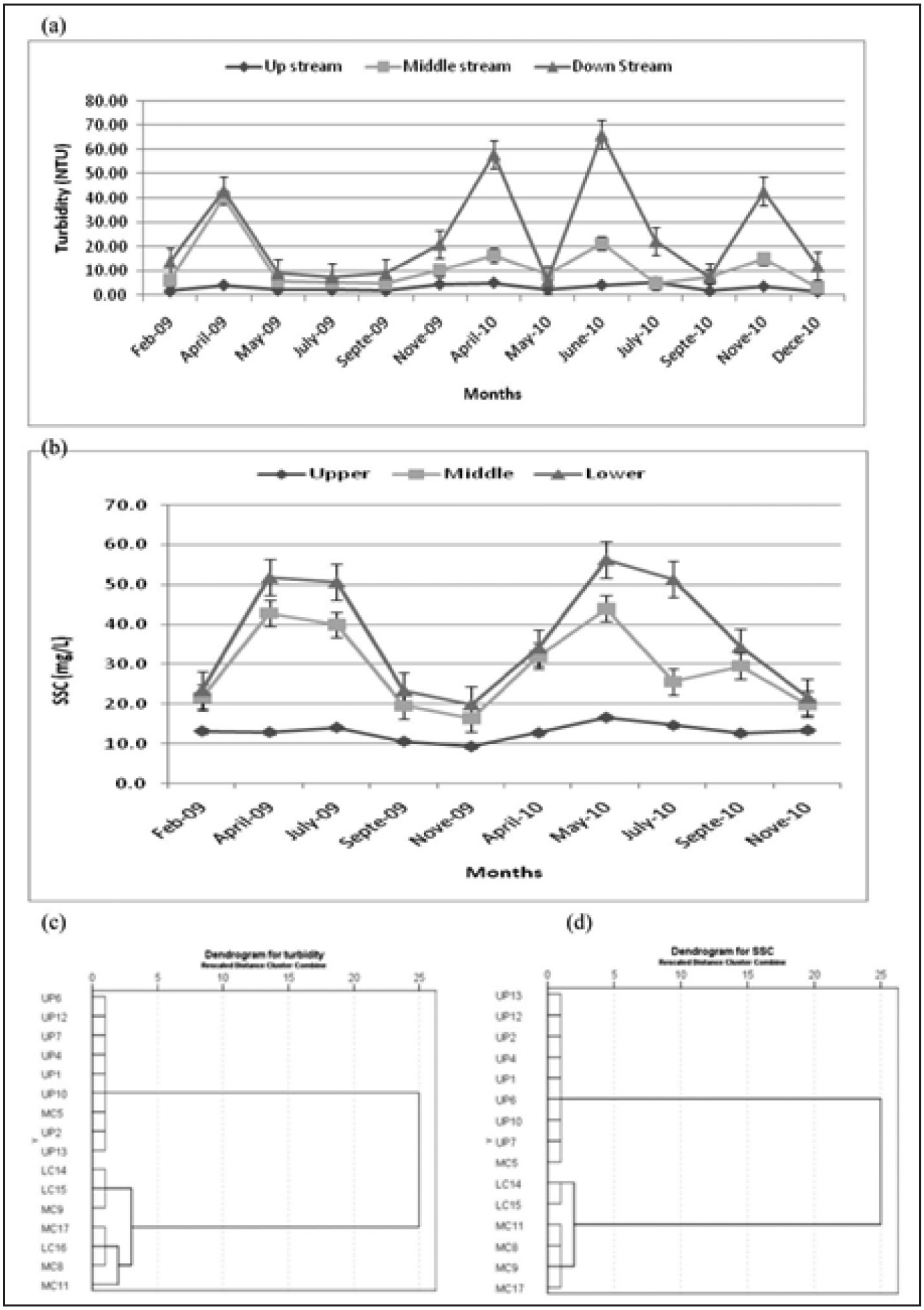


Figure 4: Spatial and temporal variation of sediment: (a) turbidity variation, (b) SSC variation, (c) cluster analysis results for turbidity and (c) cluster analysis results for SSC.

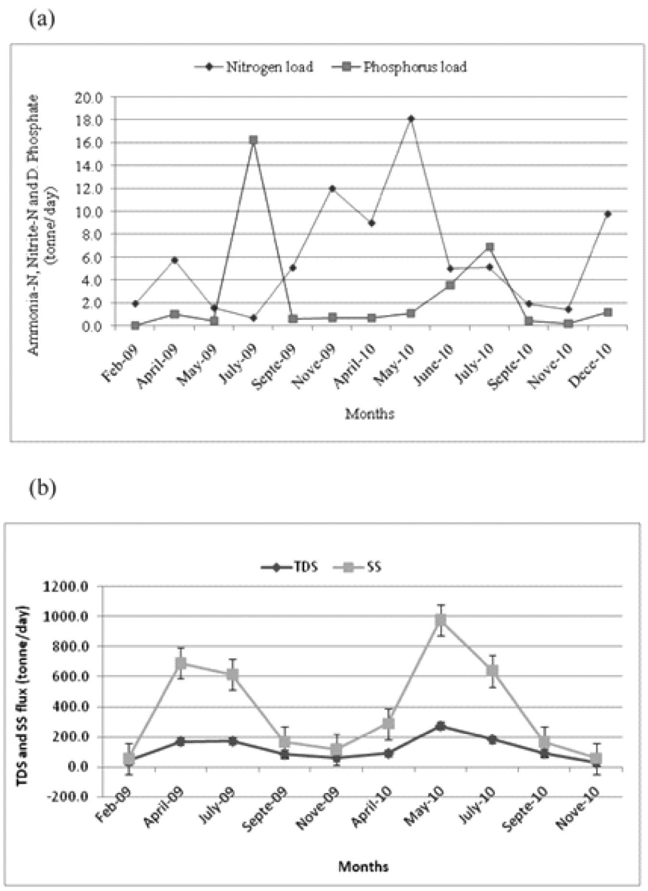


Figure 5: Total flux from Baddegama sampling location in Gin river basin: (a) nutrient flux and (b) sediment flux.

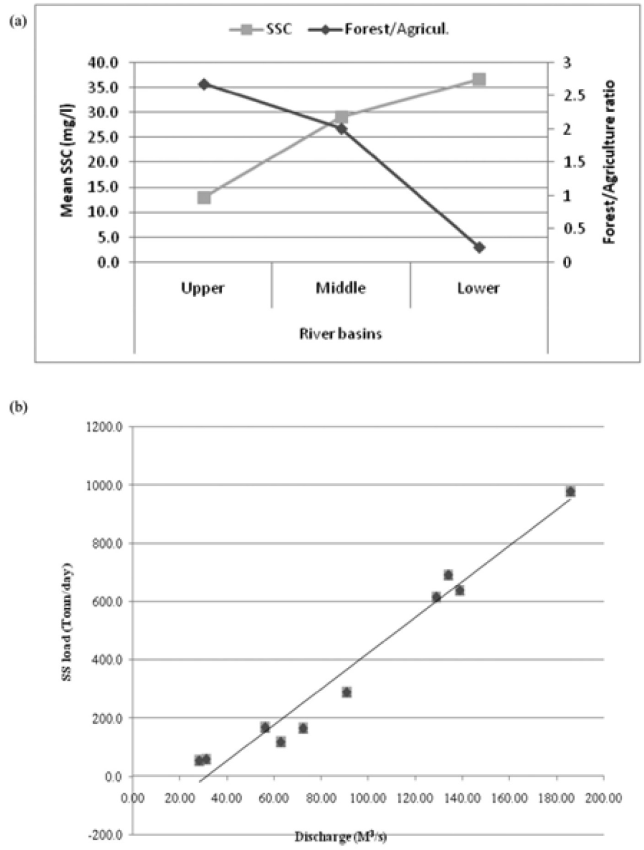


Figure 6: (a) Land-use correlation with land cover (forest/agriculture) and (b) relationship of SS with discharge from Baddegama sampling location.

Table 3: Kruskal Wallis ANOVA results for three catchments of the Gin River basin

Parameter	*P Value*
Water temperature	0.001
pH	0.210
Dissolved oxygen	0.230
Electrical conductivity	0.001
Turbidity	0.001
Biochemical oxygen demand	0.029
Ammonia nitrogen	0.001
Nitrate nitrogen	0.001
Nitrite nitrogen	0.001
Dissolved phosphate	0.753
Suspended sediment	0.032

ALPHA = 0.05, CI Level = 95.

Discussion

Statistical tests (Table 3) have proved that, there are no significant differences of the mean variation in pH, dissolved oxygen and dissolved phosphate in the three catchment. Water temperature has shown significant differences because of altitude variation. Water temperature is closely related with the atmospheric temperature and therefore may not be harmful for aquatic life. Oxygen (in its dissolved form) is required for plants and other aquatic life forms. Solubility is dependent on many factors such as partial pressure of gas in the atmosphere, temperature and salinity of water etc. Water contains relatively small amounts of dissolved oxygen and when untreated sewage is released into a stream, the oxygen needed to oxidize this organic waste far exceeds the oxygen present in stream water. The biological organisms which depend on DO are killed (Dunnivant and Anders, 2006). In the case of DO, higher values of DO were recorded in UC and MC sampling locations, whereas it depleted significantly in

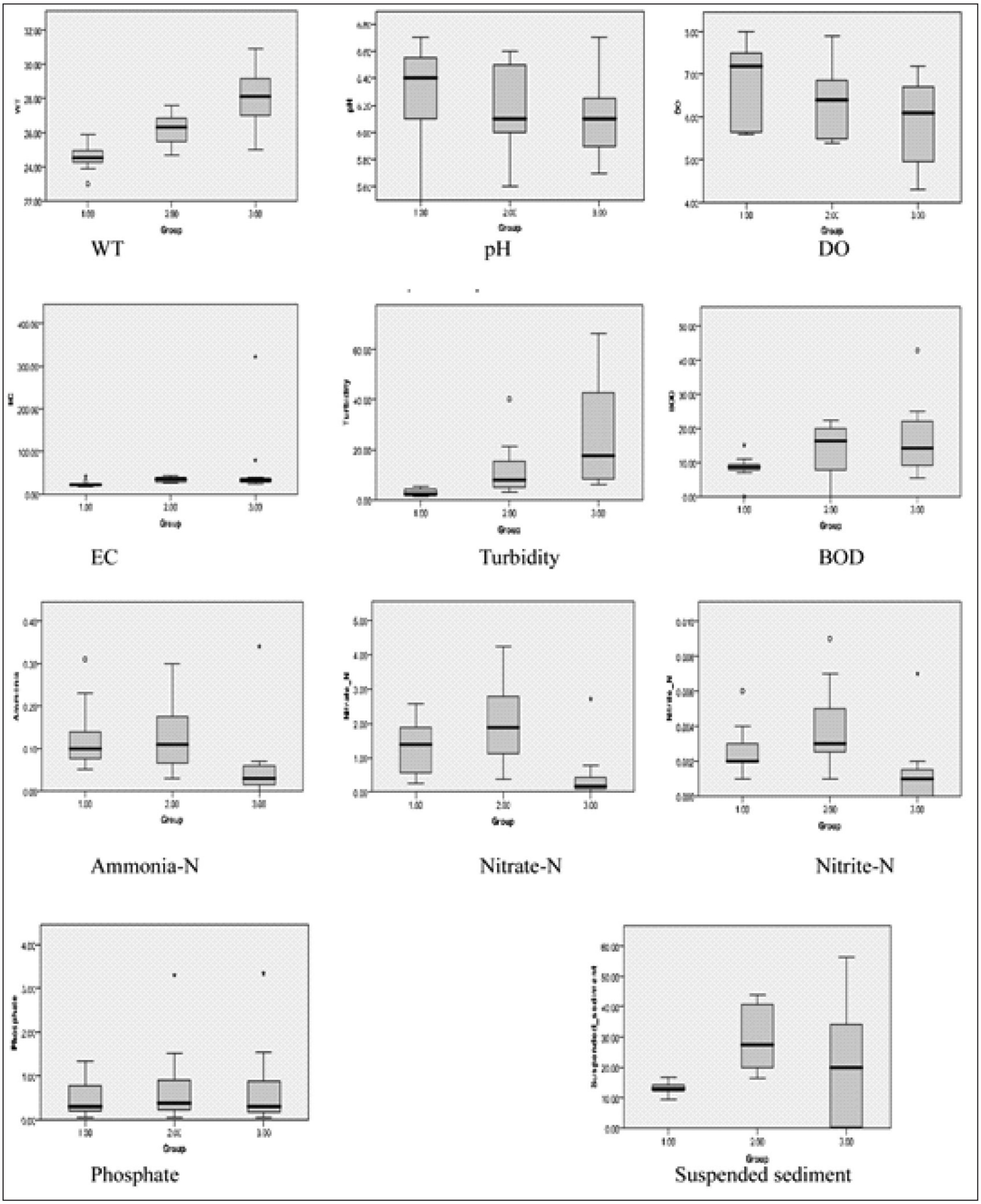


Figure 7: Results of the Kruskal-Wallis test for mean comparison in the three different catchments.

the LC sampling locations, specifically in urban areas such as Waduraba, Kahaduwa, and Baddegama.

Urban waste dump to streams as well as synthetic fertilizer draining through the stream is good media for microbial activities which reduce the oxygen level in streams with onset of rains. The chemical analysis of stream waters shows that pH in most of the UC, MC and LC sampling locations are below 6.5 (Table 2). The pH is the logarithm of the reciprocal of hydrogen ion concentration and the pH of any solution depends on temperature. However, irrespective of the temperature, the concentrations of hydrogen and hydroxyl ions are equal in neutral medium (Voznaya, 1981). Favourable pH range is 6.5-8.5 for drinking water and aquatic life (BCS, 1983; WHO, 1993) and results reveal that mean pH is below the standard level in the basin.

Electrical conductivity (EC) is a measure of the ease with which electrical current can pass through water. Electrical conductivity increases with the number of ions in solution. However, the relation is inherently nonlinear because, at higher concentrations, interactions among ions can impede their mobility (Moore et al., 2008). Spatial distribution indicated that EC increases towards the sea mouth of Gin River. Normal range of EC in fresh water streams range 0-800 μS/cm (DWAF, 1996; Keene et al., 2007; Moore, et al., 2008; Amarathunga et al., 2013a: Amarathunga et al., 2013b). Our study supports this range in the UC and MC regions of the Gin River basin. In contrast, because of continuous sea water intrusion into the estuary, the LC recorded higher EC than previous observations. However, mean EC value in LC is within the above range. Also, electrical conductivity showed significant difference with comparing three catchments due to various ions coming through the runoff from lower catchment and its variation is given in Figure 7.

Nutrient enrichment of surface waters has generated concern due to the ecological impacts on freshwater systems (Prior and Johnes, 2002). Clean water is very important for human as well as aquatic health. Many rivers and streams are contaminated by point source and non-point source pollution. Agriculture is one of the major sources for contaminant and a greater part of the fertilizer used in agriculture end up in ground and surface waters and ultimately in the sea, if there is no degradation (Hill et al., 1999). Lower part of the Gin River basin shows high ammonia-N because of input of fertilizer to paddy lands, in contrast to very less to paddy lands in UP and MC compared to LC. Nitrate is highly soluble and the concentration of nitrate increases as water flow increases (Hill et al., 1999). Many studies reported low concentration of nitrate-N in upper catchments in rivers (Azmy et al., 2010; Vuai et al., 2012; Amarathunga et al., 2013a), except in those which have intensive agricultural practices or major point source polluter in upper catchments (Amarathunga et al., 2013b). The highest nitrate-nitrogen concentration was 6.75 mg/l in the Dellawa and Kandilpana sampling locations. The mean nitrate nitrogen in Gin River UC shows higher levels, when compared to other rivers (Azmy et al., 2010; Amarathunga et al., 2013a; Amarathunga et al., 2013b).

Tea plantations are the major agriculture landuse type in this area and there are no other major dominant agricultural landuse types or point source polluters in UC. In addition, two peak loading of nitrate-N load from Baddegama flow gauging station synchronize with major two monsoons of North-East and South-West seasons and major paddy cultivating seasons Yala (May to August) and Maha (November to February). The statistical test for mean comparison among the three sub-catchments for nitrate-N, ammonia-N and nitrite-N are significantly different (Table 3) and its variations are illustrated in the box plot graphs (Figure 7) in the three sub-catchments. The results of the analysis also indicate that magnitude of ammonia-N, nitrite-N and nitrate-N concentrations in the middle catchment are greater than upper catchment, which is greater than the lower catchment (MC>UC>LC). The highest dissolved phosphate concentration was 1.63 mg/l recorded in MC and LC sampling locations. However, mean values from three basins are low. The dissolved phosphate load is synchronized only with South-West seasons. Hence, it reveals that major contributing factors for nitrate-nitrogen and dissolved phosphate are tea and paddy cultivation in the Gin River basin. In addition, biochemical oxygen demand was higher in LC and it dosen't show significant differences amoung the three sub-catchments (Table 3).

Turbidity and SSC content showed significant differences among three sub-catchments (Table 3) and lower catchment shows higher variation (Figure 7) in the box plot than upper catchment. The 63% of upper catchment in Gin River basin is comprised of forest cover (forest and scrub jungles) and it decreases to 42% and 1% in middle and lower catchment, respectively. Thus, middle and lower catchments have a much greater anthropogenic impact than the upper catchment. Also, tea plantations covered 21%, 8% and 8% in UC, MC and LC respectively. Thus, UC has greater land cover and less open areas. Although there is little paddy (2.1%) and other agricultural practices contribution in UC, the tea lands in UC have good management practices which may lead to the low level of erosion. High turbidity levels in surface waters have been linked to high percentages of impervious surfaces within a watershed caused by sediment loading from runoff and erosion (Eisma, 1993; Mehaffey et al., 2005; Boechat et al., 2013). Agricultural landuse systems led the increases of SSC streams and rivers (Figure 6a). Also, higher forest/agriculture ratio shows less SSC in streams and rivers. Therefore, linear correlation fitted data suggest that landuse have impact to suspended sediment in water. The results from the current study showed that, in general, high turbidity and suspended-sediment concentrations coincide with major monsoons and both turbidity and SSC levels are very high in urbanized areas where flows are affected by human-related factors and lesser in forested areas (Figure 4a and 4b). However, higher SS load highly coincide with South-West seasons (Figure 5b) and a scatter plot was used to determine how well data fit a specific distribution. SS load to discharge relationship well fitted with the linear correlation R^2 with 0.97 (Figure 6b).

Conclusions

The landuse system in the Gin River basin show that higher forest cover in upper catchment, and however, middle and lower catchment have much anthropogenic influences. Therefore, agricultural landuse increases instead for forest. This led to increases of suspended sediment in middle and lower catchments. Also, tea estate activities and other anthropogenic activities increase nutrient in upper catchment streams. Because of that, Dellawa stream and Kandilpana streams contribute highest nitrate-N and orthophosphate concentration in the basin; apart that, nutrient concentration in the upper catchment of Gin river is very low and middle and lower catchments contribute high amount of phosphate and nitrate, even though, below the guidelines for drinking potable water published by WHO and SLSI. In addition, low concentration of SSC illustrated control of upper catchment having higher land cover (forest) with less soil erosion; however, middle and lower catchments vice versa. In addition two main rainy seasons bring higher amount of SS load to sea. Also, statistical results prove that major physical and chemical water quality parameter means are different with three sub basins. Also, study reveals that discharge data can be used to predict the runoff SS load from Baddegama gauging station.

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