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Water Chemistry of the Nilambe Oya, a Tributary in the Central Mahaweli Valley of Sri Lanka 1. Some Physicochemical Characteristics

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Abstract

Monthly and spatial variations of temperature, pH, electric conductivity, suspended solids, major cations (Na^+, K^+, Ca^{++} & Mg^{++}) and anions (HCO_3^-, SO_4^{--} & Cl^-) of the Nilambe Oya, draining a sub-catchment (6127 ha) of the Mahaweli basin were determined from Sep. 1989 to Aug. 1990 using standard methods. Temperature ranged from 18.0 °C to 32.2 °C with a significant seasonal variation. The pH varied from 5.40 to 8.10 with significant seasonal and spatial variations. Electric conductivity changed from 9 μ S to 110 μ S with only a significant inter-site variability. The stream water carried suspended solids ranging from 0.9 mg l^{-1} to 31.7 mg l^{-1} during the study period with significant seasonal and spatial variations.

Na^+ and K^+ concentrations ranged from 1.07 mg l^{-1} to 4.24 mg l^{-1} and from 0.25 mg l^{-1} to 1.77 mg l^{-1} respectively with significant inter-site variations. Ca^{++} and Mg^{++} concentrations ranged between 0.11 mg l^{-1} and 7.16 mg l^{-1} and between 0.11 mg l^{-1} and 4.43 mg l^{-1} respectively also with significant spatial variations. The ranges of HCO_3^- (1.8 - 61.5 mg l^{-1}) and Cl^- (1.50 - 9.5 mg l^{-1}) also showed significant monthly variations whereas the SO_4^{--} concentration ranged from 0.25 mgl^{-1} and 4.98 mg l^{-1}, also with a significant monthly variation.

Concentrations of major ion species and ranges of temperature, electric conductivity, suspended solids and pH of the Nilambe Oya result due to a cumulative product of the geographical location, weather and climate, geochemical processes and anthropogenic activities of the watershed. Land use patterns play a significant role with respect to inter-site variability in physicochemical characteristics of the Nilambe Oya resulting in marked deviations from pristine values so far reported for tropical headwater streams.

Introduction

It is a commonly accepted phenomenon that conditions in the tropics are relatively constant and therefore, seasonality in environmental characteristics are rather small or insignificant (Payne 1986). Temperature variations are also rather restricted but nevertheless most of the tropics do have at least one significant rainy period. In Sri Lanka, there are two distinct monsoon driven rainy seasons (southwest and northeast). Silva & Davies (1987) demonstrated monsoonal seasonality of phytoplankton primary productivity in relation to physicochemical parameters in dry zone manmade reservoirs in Sri Lanka. Further, impacts of anthropogenic changes in the watershed on water chemistry and ecological processes in stream ecosystems have been studied especially in relation to logging, urbanization, industrialization, agricultural practices, infrastructure development and hydropower generation (Ward & Stanford 1983). Very little attention has been paid on the effects of intensive land use forms in sub-watersheds on either physicochemical characteristics or ecological processes of headwater streams, especially in the tropics (Payne 1986). Hitherto this aspect has been totally neglected in Sri Lanka.

Land of Sri Lanka (6°-10° N and 80°- 82° E) which is intensively utilized for agriculture and irrigation since ancient times retains only about 24.8% of natural forest cover of its total land area today (Wijayaratne & Widanapathirana 1995). A majority of mountain watersheds have been replaced by tea, homestead gardens or other crops. Further, these watersheds have been subjected to intensive application of fertilizers and other agrochemical to increase crop yields.

Geisler (1967) was the first to report on the water chemistry of running waters in Sri Lanka. Subsequently Weninger (1972) investigated several rivers (e.g. Kelani, Kalu, Nilwala, Gin and Mahaweli) and their headwater tributaries as a cross-sectional analysis during the Austrian-Ceylon Hydrobiological Mission in 1970. In addition, physicochemical characteristics of headwater streams have been reported during several studies carried out on aquatic flora and fauna or aquatic pollution (Costa & Fernando 1967; Costa & Starmühlner 1972; Moyle & Senanayake 1984; Dissanayake 1985; Dissanayake et al. 1985; Wickramanayake & Moyle 1986; De Alwis 1991; De Silva & Somaratne 1998). However, seasonal and spatial variations of physicochemical characteristics in lotic ecosystems in Sri Lanka are poorly understood. There is no site-specific and time-bound information on physicochemical characteristics of lotic ecosystems in relation to land use pattern and rain cycles respectively. At least to add preliminary information to this long standing lacunae, this study focused on determining site-specific and time-bound patterns of some physicochemical characteristics of a headwater stream namely the Nilambe Oya.

Materials and Methods

Study site. The Nilambe Oya is a fifth order tributary of the Mahaweli (the longest river with the largest watershed in Sri Lanka) drains, about 6127 ha between 450 m and 1500 m above mean sea level in the Central Mahaweli Valley (Fig.1). The watershed of the Nilambe Oya consists of eight land use forms and the remaining natural forest cover is about 6.9% (Anon. 1997). The uppermost elevations of the watershed have been intensively utilized for tea plantation (37.1%). Next to tea, grasslands are the dominant land use in the watershed (19.0%). Different perennial crops (7.9%) have been substituted mid elevation. A few patches of paddy fields (3.1%) are also scattered at lower elevations (Anon. 1997). Although the entire watershed is not evenly populated, human settlements are mainly concentrated around a small township called Galaha. A majority of the tributaries of the Nilambe Oya are perennial and the trunk stream has been regulated by a concrete dam 1.5 km upstream of its confluence with the Mahaweli River, creating a mini-hydropower (3.2 MW) reservoir. In addition, it has been assumed that the Nilambe Oya transports a fair amount of sediment and agrochemical to the Mahaweli river.

Sampling and analysis. Ten sampling sites representing all land use forms and stream orders were randomly identified from headwaters to downstream (Fig. 1). Temperature (Glass-Mercury Thermometer), pH (Horiba H7LD pH meter), electric conductivity (Genway Conductivity Meter, Model 4070) and bicarbonate alkalinity (Acidimetric Titration) of stream water at each pre-selected sampling sites were determined monthly in the field for a period of one year from September 1989 to August 1990. Water samples were also transported immediately to the laboratory in clean Nalgene bottles. In the laboratory, a set of 1 l water samples was evaporated to 100 ml at 60°C in a mechanical shaker and the concentrated samples were then filtered through pre-weighed Sartorius membrane filter papers for gravimetric determination of suspended solids (SS). Another set of water samples was filtered through GF/C glass fiber filter papers and filtrates were analyzed for Ca, Mg, Na and K ions (Atomic Absorption Spectrophotometer, Shimadzu, Model AA-670), sulphate (Turbidimetric Method), and Cl^- (Argentometric titration with silver nitrate). Monthly rainfall of the watershed recorded at sites 1, 7 and 9 were obtained from the Mahaweli Authority and from Levolen and Deltota Groups. The results were subjected to one-way ANOVA coupled with Duncan Multiple Range Test (DMRT) to examine the significance of site-specific and time-bound variability ($P = 0.05$).

Results

Figure 2 shows the seasonal variation of monthly mean rainfall and physicochemical characteristics with their lower and upper limits. Figure 3 shows annual mean values of the above said parameters for each site with their ranges irrespective of the season. The lowest water temperature of 18.0°C was recorded at site 7 in November while the highest was 32.2°C in July at Site 2. The lowest monthly mean water temperature (20.6°C ± 1.3 SD) was computed for January and the highest mean (28.2°C ± 2.1 SD) was computed for July (Fig. 2 and Table 1). One-way ANOVA showed significant monthly variation in stream water temperature (Table 1). DMRT grouped monthly temperature variation into six sets (i.e., {Jul}, {Mar, Apr, May}, {Sep, Oct, Feb, May, Jun, Aug}, {Sep, Dec, Jun, Aug}, {Nov, Dec,}, {Nov, Jan}). Irrespective of months, the lowest mean temperature (22.0°C ± 2.5 SD) was computed for site 4 and the highest mean (25.2°C ± 1.6 SD) was computed for site 1 (Fig. 3 and Table 2). One-way ANOVA showed no significant inter-site variability in stream water temperature (Table 2).

The lowest pH of 5.40 was recorded at site 7 in October while the highest was 8.10 at the same site in June. In general, surface water of the Nilambe Oya was slightly acidic except in June, July and August during the study period (Fig. 2). The lowest monthly mean pH (5.96 ± 0.39 SD) was computed for October and the highest (7.20 ± 0.48 SD) was in June and the monthly variation in pH distribution was statistically significant (Table 1). DMRT grouped pH distribution into three categories (i.e. {Jun, Jul, Aug, Mar}, {Jan, Feb, Apr, May, Sep}, {Oct, Nov, Dec}). The lowest annual mean pH (6.08 ± 0.38 SD) was computed for site 7 and the highest (7.02 ± 0.73 SD) was computed for site 4 (Fig. 3 and Table 2). One-way ANOVA showed significant inter-site variability in pH (Table 2) and DMRT grouped inter-site pH variation into three categories (i.e., {6,7,8,9,1,5,8,}, {1,3,5,6,9,10}, {1,2,3,4,5,10}).

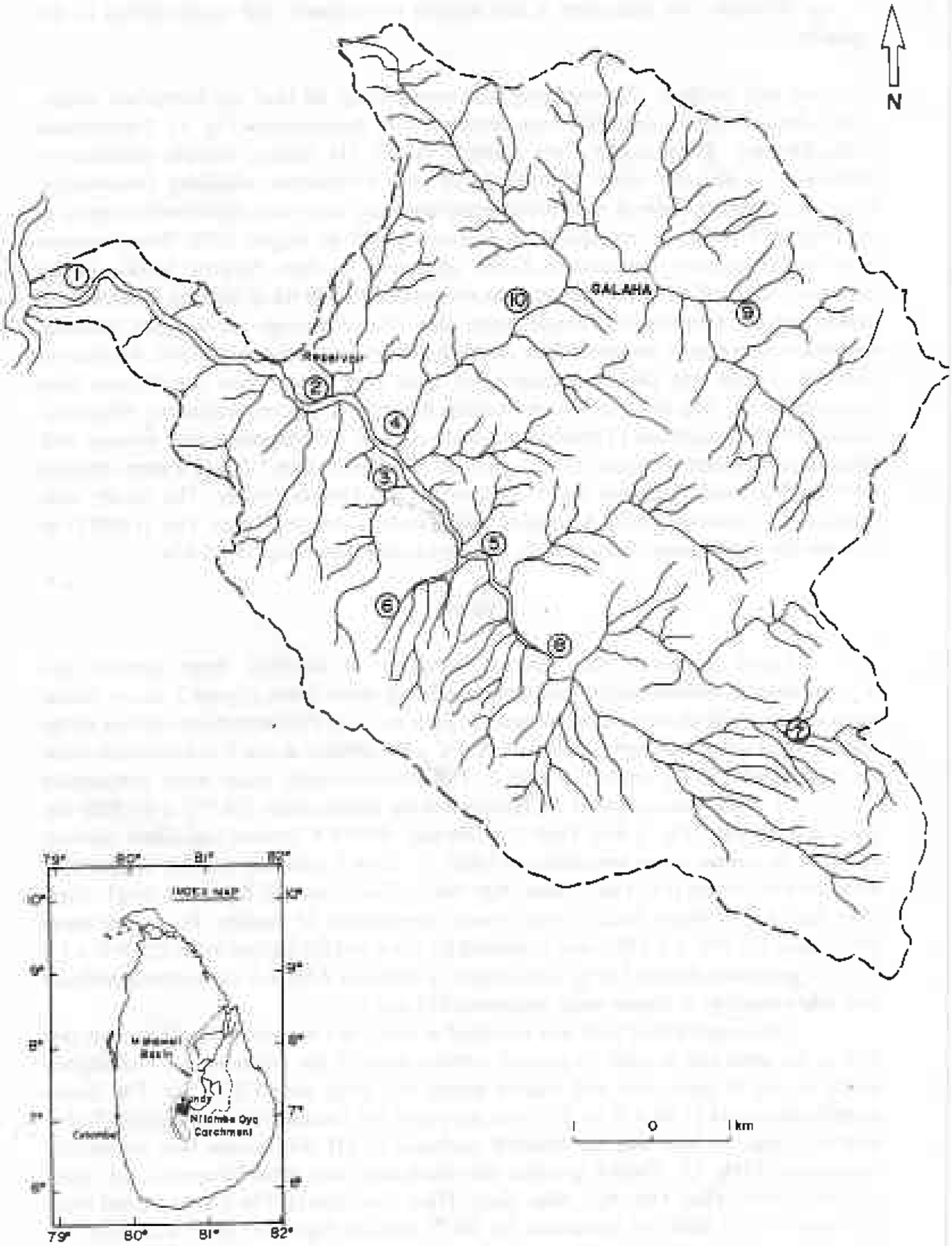

Fig. 1. The watershed of the Nilambe Oya, indicating its location in the Mahaweli basin and the study sites.

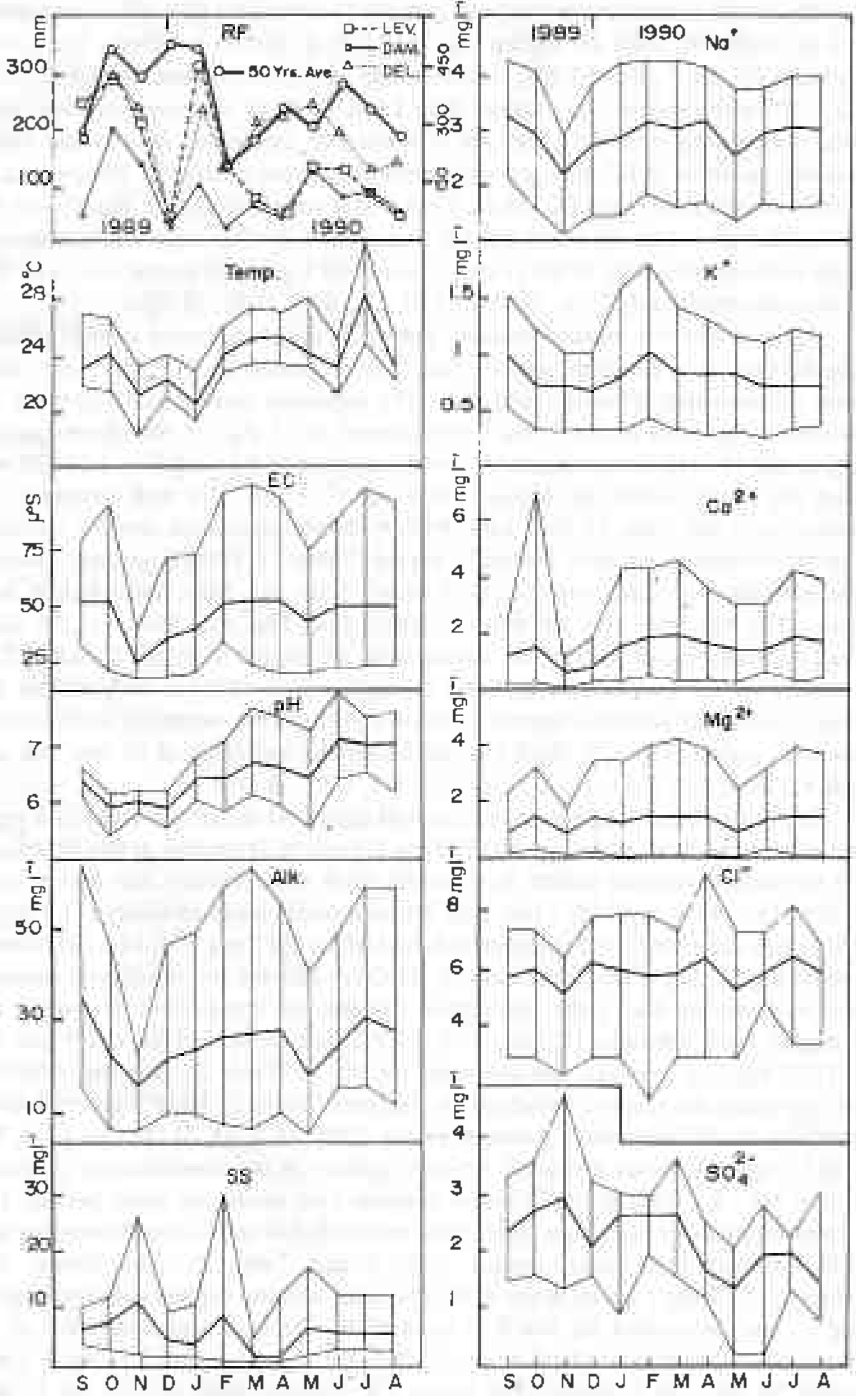

Fig. 2. Variations of monthly rainfall and physicochemical characteristics with their lower and upper limits.

The lowest electric conductivity (EC) of the Nilambe Oya (9.0 μS) was recorded at Site 6 in November while the highest was (110 μS) at Site 10 in March. The lowest monthly mean EC (24.7 μS ± 8.3 SD) was computed for November and the highest (53.7 μS ± 25.2 SD) was computed for October (Fig. 2 and Table 1). However, monthly mean EC of the stream water was >50 μS except in November, December, January and May. The monthly variation in EC was not statistically significant (Table 1). Irrespective of months, the lowest annual mean EC (16.4 μS ± 5.4 SD) was computed for site 6 while the highest was 86.0 μS ± 19.8 SD at site 10 (Fig. 3 and Table 2). One-way ANOVA showed significant inter-site variability of EC (Table 2) and DMRT grouped stream water into five distinct sets with respect to EC (i.e., {4,10}, {1,2}, {3,2,8,9}, {7,8}, {6,7}).

Figure 2 shows a marked seasonal pattern in suspended solid content (SS) in the Nilambe Oya over the study period. The slight increases in SS in the water were noticeable in November, February, and May. The minimum content of SS (0.9 mg l^{-1}) was determined in April at site 7 and the maximum (31.7 mg l^{-1}) was determined in February at site 10. The lowest monthly mean SS content of 2.34 mg l^{-1} ± 1.35 SD was computed for March while the highest (11.8 mg l^{-1} ± 8.0 SD) was computed for November (Fig. 2 and Table 1). One-way ANOVA showed significant monthly variation in SS in the Nilambe Oya over the study period (Table 1). DMRT grouped seasonal variation in SS into four categories (i.e., {Feb, Nov}, {Feb, Apr, May, Jun, Jul, Aug, Sep, Oct, Dec}, {Jan, Apr, May, Jun, Jul, Sep, Oct, Dec}, {Jan, Mar, Apr, May, Jun, Jul, Aug, Sep, Dec}). Irrespective of months, the annual mean SS content (2.78 mg l^{-1} ± 1.05 SD) was computed for site 6 while the highest (12.93 mg l^{-1} ± 7.53 SD) was computed for site 10 (Table 2). One-way ANOVA showed significant site- specific variability in SS content over the study period (Table 2). DMRT grouped inter-site variability of SS into four sets (i.e., {10, 4}, {1, 2, 3, 4, 8, 9}, {1, 2, 3, 5, 8,9}, {2, 3, 5, 6, 7, 8, 9}).

The lowest bicarbonate concentration (alkalinity) of the stream water (1.8 mg l^{-1}) was at site 7 in May while the highest (61.5 mg l^{-1}) was in September at site 10. Figure 2 shows no marked seasonal pattern in alkalinity but it was relatively low during rainy months (i.e., Oct - Nov, and May - Jun). The lowest monthly mean alkalinity (11.9 mg l^{-1} ± 5.06 SD) was computed for November and the highest (34.2 mg l^{-1} ± 14.3 SD) was in September (Fig. 2 and Table 1). One-way ANOVA showed no significant seasonal variation in alkalinity during the study period (Table 2). Irrespective of month, the lowest annual mean alkalinity (5.5 mg l^{-1} ± 3.1 SD) was computed for site 7 and the highest (57.6 mg l^{-1} ± 11.6 SD) was computed for site 10 (Table 2). One-way ANOVA showed significant site-specific variability in alkalinity (Table 2). DMRT grouped inter-site variability of alkalinity into six categories (i.e. {10}, {4 }, {1, 2}, {1, 5}, {3, 5, 9}, {6, 7, 8}). Figure 2 shows a marked seasonal pattern in the concentration of major cations (i.e. Na^+, K^+, Ca^{++} & Mg^{++}) in the Nilambe Oya during the study period. The cation concentrations in the stream water were relatively low in October-November and April-May compared to other months (Fig. 2 and Table 3). The lowest Na^+ concentration (1.07 mg l^{-1}) was at site 6 in November and the highest concentration of 4.24 mg l^{-1} was determined for site 9 in September. The lowest concentration of K^+ (0.25 mg l^{-1}) was recorded in April at site 7 while the highest value (1.77 mg l^{-1}) was determined for site 1 in February. The lowest Ca^{++} concentration of 0.11 mg l^{-1} was determined in December for site 6 while the highest of 7.16 mg l^{-1} in October at site 2. In the case of Mg^{++}, the lowest concentration of 0.11 mg l^{-1} was determined in January for the stream water at site 6 and the highest was 4.43 mg l^{-1} in March at site 10.

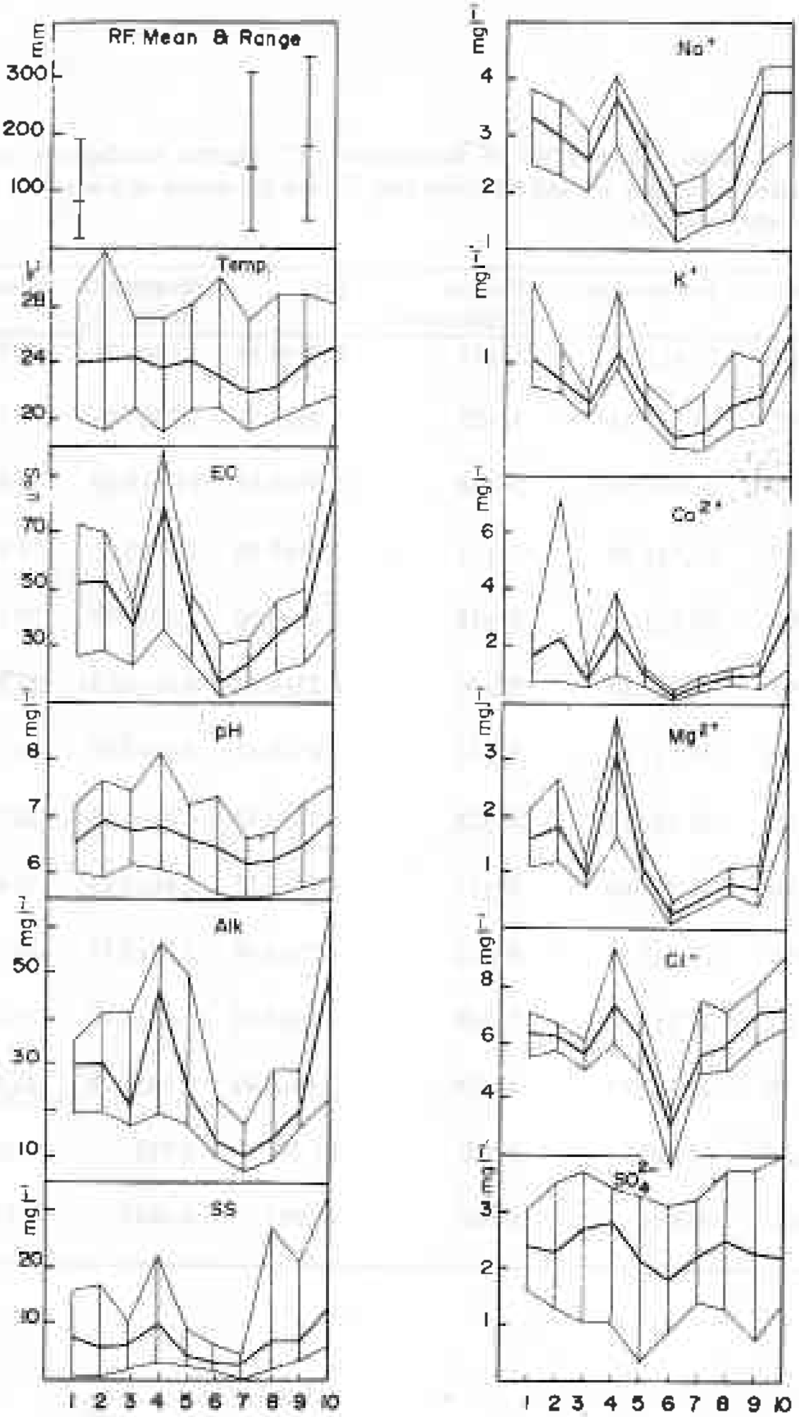

Fig. 3. Annual mean values of the physicochemical characteristics for each site and average rainfall values for sites 1,7 and 9 with their ranges irrespective of the season.

Table 1. Mean values ± SD of temperature (^{0}C), electric conductivity (μS), pH, suspended solids (mg l^{-1}) and alkalinity (mg l^{-1}) and the results of a one-way ANOVA for monthly variation.

Month	Temperature	Electric Conductivity	pH	Suspended Solids	Alkalinity
Sept. 89	23.6±1.58	52±16	6.50±0.14	7.10±2.35	31.7±14.0
Oct. 89	24.1±1.85	53±25	5.96±0.39	7.76±3.63	19.5±12.2
Nov. 89	21.4±1.50	24±08	6.05±0.14	11.8±8.00	11.6±4.9
Dec. 89	22.5±1.08	34±18	5.95±0.36	4.67±3.11	18.3±12.2
Jan. 90	20.6±1.26	41±18	6.47±0.30	4.06±3.39	20.1±13.4
Feb. 90	24.2±1.13	52±30	6.52±0.46	9.36±10.31	23.1±17.0
Mar. 90	25.7±1.15	54±31	6.83±0.53	2.34±1.35	23.1±18.3
Apr. 90	25.7±2.12	53±28	6.72±0.48	4.26±3.96	23.7±17.7
May 90	24.7±1.06	38±17	6.53±0.55	6.68±4.85	12.8±11.6
June 90	23.7±1.16	49±23	7.20±0.48	5.70±3.17	20.7±17.7
July 90	28.2±2.15	51±28	7.14±0.32	6.47±3.06	27.4±18.3
Aug. 90	23.5±2.15	49±26	7.13±0.45	6.34±3.06	23.7±15.8
F value	18.580	1.580	11.74	2.710	1.260
F prob.	0.0001	0.116	0.0001	0.0041	0.2582

Table 2. Mean values ± SD of temperature (°C), electric conductivity (μS), pH, suspended solids (mg l^{-1}) and alkalinity (mg l^{-1}) and the results of a one-way ANOVA for inter-site variation.

Site	Temperature	Electric Conductivity	pH	Suspended Solids	Alkalinity
1	25.2±1.64	53.8±12.8	6.61±0.43	7.63±4.21	25.6±5.5
2	24.1±2.39	54.6±13.3	6.92±0.67	5.64±4.29	26.2±6.7
3	22.7±2.51	35.6±6.80	6.71±0.49	5.69±3.36	16.4±5.5
4	22.0±2.56	78.6±19.2	6.77±0.64	9.19±5.13	41.4±9.7
5	23.8±2.31	39.0±7.10	6.57±0.48	4.74±2.23	20.1±10.4
6	24.0±2.37	16.0±10.4	6.41±0.57	2.78±1.05	9.1±3.6
7	24.3±1.78	23.6±4.50	6.09±0.39	2.73±1.10	5.5±3.0
8	24.0±2.26	32.1±6.70	6.16±0.37	6.52±7.15	9.1±5.5
9	24.0±3.30	40.5±7.50	6.44±0.44	6.68±5.48	15.8±3.6
10	24.2±2.44	86.0±19.8	6.86±0.47	12.93±7.53	47.5±11.6
F-value	1.400	44.26	4.200	5.22	43.92
F-prob.	0.9988	0.0001	0.0001	0.0001	0.0001

The lowest monthly mean Ca^{++} concentration (0.64 mg l^{-1} ± 0.37 SD) was computed for November and the highest (1.88 mg l^{-1} ± 1.38 SD) was computed for March (Table 4). With respect to Mg^{++} the lowest monthly mean concentration (1.02 mg l^{-1} ± 0.50 SD) was computed for November while the highest mean value (1.72 mg l^{-1} ± 1.09 SD) was computed for October (Table 3).

The lowest monthly mean Na^{+} concentration (2.12 mg l^{-1} ± 0.66 SD) was computed for November while the highest mean concentration (3.14 mg l^{-1} ± 0.73 SD) was computed for September (Table 3). In the case of K^{+} the lowest monthly mean concentration (0.63 mg l^{-1} ± 0.23 SD) was computed for June and the highest (0.99mg l^{-1} ± 0.29 SD) for September (Table 3).

Apparently, there was a noticeable seasonal pattern in the concentration of major cations in the Nilambe Oya during the study period (Fig. 2) which was not statistically significant (Table 3). Irrespective of month, the lowest annual mean Na^{+} concentration (1.57 mg l^{-1} ± 0.275 SD) was computed for site 6 and the highest (3.84 mg l^{-1} ± 0.367 SD) for site 10 (Table 4). In the case of K^{+}, the lowest and highest annual

Table 3. Means ± SD of Na^+, K^+, Ca^{++}, Mg^{++}, Cl^- and SO_4^{--} concentrations (mg l^{-1}) and the results of one-way ANOVA for monthly variation.

Month	Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}
Sep. 89	3.1±0.7	0.9±0.2	1.2±0.7	1.0±0.7	5.9±1.2	2.4±0.5
Oct. 89	2.8±0.8	0.6±0.3	1.5±2.0	1.7±1.0	6.1±1.3	2.8±0.6
Nov. 89	2.1±0.6	0.7±0.2	0.6±0.2	1.0±0.5	5.2±1.2	3.0±1.1
Dec. 89	2.7±0.9	0.6±0.2	0.8±0.5	1.6±1.1	6.2±1.3	2.6±0.4
Jan. 90	2.3±0.8	0.8±0.4	1.5±1.0	1.3±1.1	6.1±1.4	2.1±0.8
Feb. 90	3.0±0.9	0.9±0.4	1.8±1.2	1.6±1.3	5.9±1.8	2.6±0.3
Mar. 90	2.9±0.9	0.8±0.3	1.8±1.3	1.6±1.3	6.0±1.3	2.7±0.6
Apr. 90	3.1±0.9	0.8±0.3	1.7±1.1	1.6±1.3	6.4±1.7	1.8±0.4
May 90	2.4±0.3	0.6±0.2	1.3±0.8	1.0±0.8	5.6±1.0	1.3±0.6
Jun. 90	2.8±0.7	0.6±0.2	1.3±0.7	1.4±1.0	6.0±0.8	2.0±0.9
Jul. 90	2.9±0.8	0.6±0.3	1.7±1.2	1.5±1.3	6.6±1.5	2.0±0.3
Aug. 90	2.9±0.8	0.6±0.2	1.6±1.1	1.5±1.2	5.9±1.1	1.5±0.6
F-value	1.140	1.320	1.220	0.500	0.640	5.440
F- prob	0.382	0.2247	0.2815	0.9000	0.788	0.0001

mean concentrations (0.36 mg l^{-1} ± 0.07 SD and 1.23 mg l^{-1} ± 0.158 SD) were computed for sites 6 and 10 respectively (Table 4). Similar results were obtained for Ca^{++} with respect to spatial distribution (Table 4). In contrast, the lowest annual mean Mg^{++} concentration (0.21 mg l^{-1} ± 0.08 SD) was computed for site 5 and the highest value of 0.364 mg l^{-1} ± 0.76 SD was computed for site 1 (Table 3). One-way ANOVA showed statistically significant site-specific variability for the concentrations of major cations (Table 4). DMRT grouping for inter-site variability of major cations is given in Table 5.

The lowest Cl^- concentration (1.50 mg l^{-1}) was determined for site 9 in February and the highest (9.5 mg l^{-1}) was determined for site 4 in April. The lowest monthly mean Cl^- concentration of 5.22 mg l^{-1} ± 1.27 SD was computed for November while the highest mean value of 6.50 mg l^{-1} ± 1.71 SD was computed for April (Table 3). Monthly variation of Cl^- in the Nilambe Oya was not statically significant (Table 3). Irrespective of month, the lowest and the highest annual mean Cl^- concentrations of 2.91 mg l^{-1} ± 0.54 SD and 7.41 mg l^{-1} 0.93 SD were computed for sites 6 and 4 respectively (Table 4). One way ANOVA showed significant inter-site variability in Cl^- over the study period (Table 4). DMRT grouped inter-site variability into five categories (i.e., {4, 9, 10}, {1, 2, 5, 8}, {2, 5, 7, 8}, {3, 5, 7, 8}, {6}).

In the case of sulphate ions, the lowest concentration was 0.25 mg l^{-1} in June at site 5 and the highest value of 4.98 mg l^{-1} was in November at site 10. Sulphate ion concentration was low in December and May compared to other months (Fig. 2). The lowest monthly mean concentration of sulphate ions (1.39 mg l^{-1} ± 0.61 SD) was computed for May while the highest value (3.09 mg l^{-1} ± 1.19 SD) was computed for November (Table 3). Compared to the other anions only the sulphate ion showed statistically significant monthly variation (Table 3). DMRT grouped monthly variability in sulphate ion concentration into six categories i.e., {Sep, Oct, Nov, Dec, Jan, Feb, Mar}, {Sep, Oct, Dec, Jan, Feb, Mar}, {Sep, Jan, Feb, Jun, Jul}, {Sep, Apr, Jun, Jul}, {Apr, Jun, Aug}, {Apr, May, Jun, Jul, Aug}.

Irrespective of month, the lowest annual mean sulphate concentration (1.83 mg l^{-1} ± 0.74 SD) was computed for site 6 while the highest annual mean value (2.78 mg l^{-1} ± 0.71 SE) was computed for site 4 (Table 4). One way ANOVA showed no significant inter-site variability in the concentration of sulphate ions during the study period (Table 4).

Discussion

Although there was a significant monthly variability in temperature, stream water of the Nilambe Oya had slightly low temperatures in the higher altitudes than in the downstream throughout the study period. Non-significant variability between sites located from 450 m to 1500 m above mean sea level may be attributed to changes in land use in the watershed. Of the 6127 ha of the Nilambe sub-catchment, has only 427 ha (6.9%) of natural forest left (Anon. 1997). Thus, the entire watershed is more or less exposed to direct sunlight resulting in increased water temperature during the day time. This is evident from relatively high temperatures recorded during the study period. Soils of the rolling and undulating terrain of the Nilambe watershed is red, yellow podzolic with soft or hard laterite and pH ranges from 4.4 to 5.5 (Ponnamperuma 1987). Therefore, acidic pH dominates throughout the watershed except in few areas. Since stream water is acidic bicarbonate ion concentration is relatively low resulting in low electric conductivity. Relatively low electric conductivity has been reported even for the lower reaches of the Kelani River (Giesler 1967). Weninger (1972) reported conductivity range of 14 -72 μS for the headwater streams of the Kelani, Kalu, Nilwala, Gin and the Mahaweli rivers. In contrast, the highest annual mean electric conductivity of the Nilambe Oya was 86.0 μS at the site 10 which is located at densely populated and intensively land used area. The land use pattern therefore appears to play an important role with respect to water quality of stream ecosystems, which drain even small watersheds.

With respect to suspended solids, the Nilambe Oya transported a fair amount of SS from its headwaters to the downstream. Content of SS was fairly high during the rainy season compared to drier months. Further, the amount of SS transported by tributaries increases with the river order up to site 2. A relatively low SS content determined for site 1 compared to upstream sites may be attributed to the function of the reservoir as a sediment

Table 4. Mean values ± SD of Na^+, K^+, Ca^{++}, Mg^{++}, Cl^- and SO_4^{--} concentrations (mg l^{-1}) and the results of a one-way ANOVA for inter-site variation.

Site	Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}
1	3.31±0.34	1.02±0.27	1.67±0.51	3.46±0.76	6.29±0.39	2.43±0.59
2	3.07±0.35	0.86±0.11	2.19±1.65	0.74±0.19	6.16±0.25	2.27±0.83
3	2.60±0.32	0.67±0.08	0.94±0.22	0.79±0.12	5.62±0.57	2.66±0.64
4	3.66±0.41	1.17±0.20	2.67±0.98	0.50±0.09	7.41±0.93	2.78±0.71
5	2.67±0.29	0.67±0.09	1.02±0.27	0.21±0.08	6.12±0.61	2.13±1.00
6	1.57±0.27	0.36±0.07	0.24±0.08	0.64±0.35	2.91±0.54	1.83±0.74
7	1.66±0.31	0.39±0.18	0.63±0.16	0.90±0.14	5.75±0.69	2.23±0.69
8	2.09±0.39	0.63±0.20	0.89±0.23	3.11±0.65	5.86±0.55	2.50±0.83
9	3.80±0.46	0.67±0.17	1.04±0.30	1.84±0.45	7.08±0.63	2.33±0.89
10	3.84±0.36	1.23±0.15	3.06±1.24	1.04±0.16	7.25±0.54	2.21±1.14
F-value	67.78	20.32	17.30	96.9	51.83	0.89
F-prob	0.0001	0.0001	0.0001	0.0001	0.0001	0.5362

Table 5. DMRT grouping of inter-site variability for major cations.

Na^+ : {4, 9,10}, {1, 2}, {3, 5}, {8}, {6, 7}
K^+ : {4, 10}, {4, 1}, {1, 2}, {2, 3, 5, 9}, {3, 5, 8, 9}, {6, 7}
Ca^{++} : {4, 10}, {2, 4}, {1, 2}, {1, 5, 9}, {3, 5, 7, 8, 9}, {6, 7, 8}
Mg^{++} : {10}, {4}, {1, 2}, {3, 5, 8, 9}, {7, 8, 9}, {6, 7}

trap. A major portion of the SS is transported by the tributaries draining the Galaha area which has been subjected to intensive land use and urbanization.

With respect to cations, the stream water was rich in Na^+. The concentrations of Ca^{++} and Mg^{++} were almost similar but K^+ had the lowest concentration, which is not unusual. Though the bicarbonate ion concentration was relatively high, the stream water was also rich in Cl^- when compared to sulphate. This situation can only be explained by the sources of individual ionic species. The dominance of Na^+ and Cl^- perhaps, may be attributed to oceanic fallout. Na^+ and Cl^- may also increase from industrial sources and urban waste waters (Ownbey & Kee 1967). Relatively high concentrations of Na^+ and Cl^- were noticeable in the Nilambe Oya with the onset of the southwest monsoon (May - Sep) which drives oceanic winds towards the mainland. However, the concentration decreased with increasing rainfall. The Nilambe watershed experiences the second inter-monsoon dominant rainfall (Oct -Nov) because of the influence of the southeast Bay of Bengal and northwest Arabic Sea. The rainfall in December 1989 was extremely low compared to the 50 years average. Further, Na^+ and Ca^{++} are also washed out from the magmatic stones and transported to waterways. In Sri Lanka, almost all the land where tea grows are strongly acidic and continuous heavy application of nitrogenous fertilizer tend to increase the acidity resulting in decrease in Ca^{++} and Mg^{++} in the soils (Ponnamperuma 1987).

Gibbs (1970) classified surface waters of the world according to their proportion of Na^+ to Ca^{++} and Cl^- to HCO_3^- in relation to total dissolved salts. Accordingly, the majority of the larger rivers draining tropical watersheds have low concentrations of total salts and relatively high levels of Na^+ and Cl^- compared to Ca^{++} and HCO_3^-. According to Gibbs (1970) the principal source of Na^+ and Cl^- is sea spray. However, in this case it would be applicable only if the rainfall plays a significant role with respect to ionic concentration when the other sources are scarce. For example, the greater part of the Brazilian Amazon produce waters that are very poor in lithogenic dissolved salts. A similarity of Sri Lanka's stream water with the Brazilian Amazon has been attributed due to poor dissolved salt content (Weninger 1972). Irrespective of seasons, the overall average cationic ratio of the Nilambe Oya was Na:K:Ca:Mg = 4: 1.2: 2. With respect to anionic species, the Nilambe Oya was rich in bicarbonate ions but there was a substantial amount of Cl^- while the SO_4^{--} concentration was the lowest. The overall average anionic ratio of $HCO_3^-:Cl^-:SO_4^{--}$ was 18:5:2 by weight. The source of bicarbonate may be either lithogenic or atmospheric fall-outs while the source of sulphate includes rocks, fertilizers, atmospheric precipitation and dry deposition. Although the Nilambe Oya had a fairly low content of cations and anions, the concentrations have exceeded the natural value at several sites because of loading of chemical constituents due to intensive land use changes and other anthropogenic activities.

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