SEASONAL FLUCTUATION OF WATER PARAMETERS AND NUTRIENTS IN *BRUGUIERA PARVIFLORA* (WIGHT & ARNOLD) DOMINATED MANGROVE FOREST AT KUALA SELANGOR NATURE PARK, MALAYSIA.

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Abstract

Rainwater, canopy drip, stem flow, river and infiltration water parameters (pH, redox potential, conductivity and salinity) and selected nutrients (NH_4^+, NH_3^-, PO_4^{---} $_4$, K^+, Ca^{++}, SO_4^-, Cu^{+++}, Fe^{+++} $Zn)^{++}$ were measured during dry, wet and intermediate seasons in mangrove forest at Kuala Selangor Nature Park, Malaysia. The different parameters (pH, redox-potential, conductivity and salinity) of water samples showed seasonal fluctuation. Infiltration water showed comparatively higher conductivity (55.83-71.00 dS/m) followed by river water (18.17-22.17 dS/m) and relatively higher conductivity of rainwater, canopy drip, river and infiltration water was observed during the dry seasons. Macro-nutrients in water samples showed seasonal fluctuation and comparatively higher content of K^+, Ca^{++}, Mg^{++}, SO_4^-, Cu^{++}, Fe^{+++} and Zn^{++} were observed in infiltration water. Similar content (0.01 ppm) of Cu^{++}, Fe^{+++} and Zn^{++} were detected in rainwater, canopy drip and stemflow throughout the seasons, but Cu^{++}, Fe^{+++} and Zn^{++} in river and infiltration water show seasonal fluctuation in their content. Macro-nutrients (except NO_3^-) content in rainwater showed positive correlations with canopy drip and stem flow, which indicated the leaching of macro-nutrients from the tree canopy. Irrespectively, NO_3^-, PO_4^{---}, Mg^{++}, SO_4^-, Cu^{++} and Fe^{+++} showed positive correlations between river and infiltration water, and could be the evidence of nutrients exchange among the river and infiltration water. Present study showed that rain water, canopy drip, stem flow, river and infiltration water parameters and their nutrients are not static rather fluctuating with the seasonal changes.

Key words: Water parameters, Macro-nutrients, Micro-nutrients, Seasonal fluctuation, Mangroves, Malaysia

Introduction

Mangrove forests are economically and ecologically important (Field, 1995) and link between marine and terrestrial ecosystems (Aksornkoae, 1993). Mangroves act as an open pathway of nutrient transport to the aquatic ecosystem. The rate of nutrients transport is controlled by biological and physical factors (Boto, 1982) and simultaneously these factors also control the rate of

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input and storage of inorganic or organic compounds (Aksornkoae and Khemnark, 1984) as well as within stand nutrient cycling in a mangrove forest. Nutrient cycling is never completely efficient. Efficient nutrient cycling characterized by low nutrient losses from the system as a whole despite relatively large amounts of nutrient cycling between trees and soil (Vitousek, 1984). The leakage in nutrients cycling is from biological-soil system that must be made up from the soil parent material, the atmosphere or rain wash. There is a continuous source of nutrients input in the forest ecosystem such as rainfall, weathering of soil minerals. On the other hand, there is a continuous loss of nutrients in water moving through the plant and soil to streams and rivers (Golley *et al.,* 1975). Adequate supply of nutrients is essential in maintaining the balance of mangrove ecosystem (Boto, 1982; Aksornkoae, 1993). The sources of nutrients to mangroves are rainwater, canopy drip, stem flow, runoff from surrounding land areas, mineralization, tidal borne and decomposed organic matter (Boto, 1982; Trudgill, 1988; Leite and Valle, 1990; Aksornkoae, 1993; Zulkifli, *et al.*, 1997; Ranger and Turpault 1999; Gordon *et al.*, 2000). In Peninsular Malaysia, little effort was spent on the study of nutrients input through atmospheric and river sources into the mangroves, while most of the studies were concerned with the ecology and productivity of mangroves (Ong *et al.*, 1985; Gong *et al.*, 1984; Putz and Chan, 1986; Gong and Ong, 1990). Present study investigated and quantified the water parameters and selected nutrients (NH_4^+, NO_3^-, PO_4^{---}, K^+, Ca^{++}, Mg^{++}, SO_4^{--}, Cu^{++}, Fe^{+++} and Zn^{++}) in mangroves during intermediate, dry and wet seasons.

Materials and methods

The study area consists of 100 ha of mangrove forest (Latitude $3^0$20' N and Longitude $101^0$14' E) in the Kuala Selangor Nature Park, Kuala Selangor, Malaysia. This mangrove forest has been totally protected since 1987 and categorized under Watson's (1928) tidal inundation class 4. Species of mangroves from the families of *Avicenniaceae, Rhizophoraceae, Sonneratiaceae* and *Euphorbiaceae* are found in this forest. *Bruguiera parviflora* contributes 80% of the growing stock. The mean annual rainfall is 1790 mm and mean minimum and maximum temperature varies from 24 to 32 ^{O}C. Mean monthly rainfall varies from 80 mm to 242 mm. Wet season from September to December contributes 46% of total annual rainfall, intermediate season contributes 31% of annual rainfall from January to April and dry season contributes 23% of annual rainfall from May to August.

Samples of rain, canopy drip, stem flow, river and infiltration water were collected during March 2002 (intermediate season), July 2002 (dry season), November 2002 (wet season), March 2003 (intermediate season) and July 2003 (dry season). Fixed position funnel type collectors (14 cm diameter) were used for rainwater and canopy drip samples as recommended by Reynolds and Neal (1991). Six collectors were placed randomly in open place beside the forest area and under the forest canopy for collecting rain and canopy drip samples, respectively. Stemflow was intercepted by six spiral collars of split plastic tubing and gravity fed through intact tubing into plastic containers that were hanged on tree stem at about 1 meter from the ground level (Gordon *et al.*, 2000). Samples of rainwater, canopy drip and stem flow were collected just after the first shower of the respective seasons. Six samples of river surface water were collected by using Vendorn water sampler. Infiltration water samples were collected by digging six pits of 30 cm x 30 cm x 30 cm and accumulation of infiltration water can usually be observed at the bottom of the pit. Once the column reached equilibrium, the water sample was rapidly displaced with suction pump.

pH of different types of water samples was measured by using an automatic temperature compensator pH meter (accuracy ± 0.05). Redox values of the samples were determined in conjunction with pH result by using the same pH meter. Conductivity (dS/m) and salinity (ppt) of water samples were measured directly in the field by using S-C-T meter.

Ammonium (ppm) in water samples was measured by Phenol Hypochlorite procedure (Weatherburn, 1967). Nitrate (ppm) and Phosphate (ppm) in samples were measured by colorimetric method according to Kitamura *et al.* (1982) and Timothy *et al.* (1984), respectively. Sulphate content (ppm) in samples was measured by barium chloride turbidity method according to Tandon (1993). Fifty ml of the filtrate from each sample was treated with 1 ml concentrated HNO_3 and kept refrigerator for the analysis of Potassium, Calcium, Magnesium, Copper, Iron and Zinc within one month. Calcium, Magnesium, Copper, Iron and Zinc content in water samples were measured by Atomic Absorption Spectrophotometer and potassium content in samples were measured by Flame photometer. Parameters (pH, redox potential, conductivity and salinity) and nutrients content in water samples at different seasons were compared by one-way analysis of variance (ANOVA) followed by Duncan Multiple Range Test (DMRT, $p<0.05$) using SAS (6.12) statistical software. Parson correlation coefficients among water nutrients were computed by using SPSS (11.0) statistical software.

Results

Parameters

Rain, canopy drip, river and infiltration water pH varied from close neutral to slightly acidic (6.33-6.91, 6.34-6.72, 6.56-6.92 and 6.27-7.05 respectively), while, stem flow showed acidic pH (5.40-6.18). Comparatively higher pH of rain (6.91) and infiltration water (7.05) was observed during the dry season (July 02). A relatively higher pH of canopy drip (6.72), stem flow (6.18) and river water (6.92) was recorded during the intermediate season (March 02) (Table 1).

Redox potential of rain, canopy drip, stem flow, river and infiltration water varied between 1.68-126.00 mv, 11.84-120.33 mv, 46.00-143.00 mv, 2.50-23.01 mv and –20.93-48.00 mv, respectively. Comparatively higher redox value was recorded for rain water (126.00 mv) and canopy drip (120.33 mv) during the dry season (July 03). Stem flow showed relatively higher redox potential (143.00 mv) during the intermediate season (March 03). River and infiltration water showed comparatively higher redox value of 23.01 and 48.00 mv, respectively during the wet season (November 02) (Table 1).

Rain, canopy drip and river water conductivity were relatively higher during the dry season (July 02) at 0.29, 0.35 and 22.17 dS/m respectively. But, stem flow (0.10 dS/m) and infiltration water (71.00 dS/m) showed relatively higher conductivity during the intermediate season (March 03) and dry season (July 03) respectively. A relatively lower conductivity of rainwater (0.08 dS/m) and canopy drip (0.13 dS/m) was observed during the intermediate seasons. However, comparatively lower conductivity of stem flow, river and infiltration water was recorded during the wet season (November 02) of 0.08, 18.17 and 55.83 dS/m, respectively. River and infiltration water showed comparatively higher salinity of 30 ppt and 40-41 ppt, respectively during the dry seasons (Table 1).

Nutrients

Ammonium

Comparatively higher ammonium content (0.47-0.51 ppm) in rainwater was observed during the dry seasons and lower (0.16 ppm) during the intermediate season (March 02). Canopy drip contained a relatively higher ammonium content (1.03 ppm) during the wet season (November 02) and lower (0.40-0.42 ppm) during the intermediate seasons. Comparatively higher ammonium content (0.59 ppm) in stem flow was detected during the dry season (July 02) and lower content

(0.30-0.31 ppm) during the intermediate seasons. River water contained comparatively higher content (0.55 ppm) during the wet season (November 02) and lower (0.32 ppm) during the intermediate season (March 03). While, infiltration water contained relatively higher content (0.64 ppm) during the intermediate season (March 02) (Table 2).

Nitrate

Rainwater contained comparatively higher nitrate (0.07 ppm) during the dry season (July 03) and lower content (0.01 ppm) during the intermediate season (March 02). A relatively higher content (0.07-0.08 ppm) in canopy drip was observed during the wet and intermediate seasons followed by dry seasons (0.05-0.06 ppm). Stem flow contained comparatively higher nitrate (0.08 ppm) during the wet season (November 02) and lower (0.02 ppm) during the intermediate season (March 02). Nitrate content in river and infiltration water varied from 0.01 to 0.03 ppm and comparatively higher content was detected during the dry season (July 02) (Table 2).

Phosphate

Similar content (0.01 ppm) of phosphate was detected in rainwater at the different seasons. Comparatively higher phosphate content (0.09 ppm) in canopy drip was detected during the dry season (July 02) and lower content (0.04 ppm) during the intermediate season (March 03). Phosphate content in stem flow varied from 0.01 to 0.02 ppm and comparatively higher content (0.02 ppm) was detected during the intermediate season (March 02). A relatively higher content of phosphate in river (0.05 ppm) and infiltration (0.11 ppm) water was detected during the intermediate season (March 02) (Table 2).

Potassium

Rainwater and canopy drip contained comparatively higher potassium during the intermediate season (March 02) (0.33 and 4.49 ppm, respectively). Stem flow showed relatively higher potassium content (2.61 ppm) during the intermediate season (March 02) and lower (0.50 ppm) during wet season (November 02). Comparatively higher content (38.1-45.96 ppm) was detected in river water during the dry seasons and lower (20.05 ppm) during the intermediate season (March 03). Infiltration water showed relatively higher content (327.14-348.89 ppm) during the intermediate seasons and lower content (60.12-64.12 ppm) during the dry seasons (Table 2).

Calcium

Relatively higher calcium content was detected in rainwater, canopy drip, stem flow and infiltration water during the intermediate season (March 03) (2.45, 20.12, 8.00 and 926.23 ppm, respectively). Rainwater showed comparatively lower content (1.40 ppm) during the dry season (July 03). While, canopy drip, stem flow and infiltration water showed comparatively lower content of 9.00, 3.00 and 329.56 ppm, respectively during the dry season (July 02). A relatively higher calcium content (76.00 ppm) was detected in river water during the dry season (July 02) and lower content (54.00 ppm) during the wet season (November 02) (Table 2).

Magnesium

Comparatively higher magnesium content (2.50 ppm) in rainwater was detected during the intermediate season (March 03) and lower content (1.30 ppm) during the dry season (July 03). Canopy drip and stem flow contained relatively higher magnesium (7.00 and 4.50 ppm) during the dry season (July 02) and lower content (1.00 ppm) during the wet season (November 02). Relatively higher contents (271.00 and 2356.33 ppm) were detected in river and infiltration water, respectively during the intermediate season (March 02). While, comparatively lower content (163.00 and 2012.00 ppm) was measured for river and infiltration water during the intermediate season (March 03) and dry season (July 02), respectively (Table 2).

Sulphate

Rainwater contained comparatively higher sulphate (14.42 ppm) during the dry season (July 02) and lower content (2.24 ppm) during intermediate season (March 03). A relatively bigher content, 41.19 ppm and 14.56 ppm were detected in canopy drip and stem flow, respectively during the intermediate season (March 02) and comparatively lower content (5.69 ppm and 7.18 ppm) during the wet (November 02) and dry season (July 03), respectively. Sulphate content in river and infiltration water varied from 305.44-908.90 ppm and 1559.23-4460.86 ppm, respectively and comparatively higher content was detected in dry seasons followed by intermediate seasons and wet season (Table 2).

Copper, Iron and Zinc

Similar content of copper (0.01 ppm) was detected in rainwater, canopy drip and stem flow during the sampling seasons. While, river and infiltration water copper content varied from 0.01 to 0.02 ppm and 0.06 to 0.07 ppm, respectively.

Similar content of iron (0.03 ppm) was detected in rainwater, canopy drip and stem flow during the sampling seasons. While, river and infiltration water iron content varied from 0.02 to 0.04 ppm and 0.41 to 0.84 ppm, respectively. Comparatively higher iron content (0.74-0.84 ppm) in infiltration water was observed during the intermediate seasons and lower (0.41-0.43 ppm) during the dry seasons. Rainwater, canopy drip and stem flow showed similar content of zinc (0.02 ppm) during different seasons. While, river and infiltration water zinc content varied from 0.05 to 0.07 ppm and 0.12 to 0.16 ppm, respectively and comparatively higher zinc content (0.07 and 0.16 ppm) was detected in river and infiltration water during the intermediate season (March 02) and dry season (July 02), respectively (Table 2).

Discussion

Comparatively acidic pH (5.4-6.72) was observed for canopy drip and stem flow than the rainwater. Nutrients and different organic acids usually leaches during the interception of rain water by the forest canopy and this could be the reason for detecting comparatively lower pH in canopy drip and stem flow (Trudgill, 1988). Moreover, comparatively higher conductivity of canopy drip and stem flow may be the evidence of cation leaching from the tree canopy. River and infiltration water pH ranged from 6.32 to 7.05 and showed similar ranges 5.78 to 6.92 and 6.80 to 7.20 with the study of Mahmood *et al.* (2001) at Sepang Mangrove forest, Malaysia and Ashton and Macintosh (2002) at Sematan mangrove forest, Sarawak, Malaysia respectively. Comparatively higher conductivity and salinity of river and infiltration water during the dry seasons and intermediate seasons may be due to the lower amount of rainfall compared to the wet seasons.

The nutrients content in rainwater varies from place to place and also with the time. Places close to the sea have greater influences of sea born spray on nutrients composition of rainwater (Yaalon and Lomas, 1976). Moreover, local sources of pollution may have considerable effect on rainwater nutrients content, such as quarry dust, road dust and the industrial emission (Trudgill, 1988). The source of nitrogen in rainwater is the atmospheric and originates from lightning during the rainstorms and other nutrients in the rainwater probably from the dust (Boto, 1982). Nutrients (N, P, K, Ca and Mg) in rainwater and canopy drip showed seasonal variation and canopy drip contained relatively higher nutrients content under the cacao ecosystem, Bahia, Brazil (Leite and Valle, 1990). Present study showed seasonal variation in nutrients (NH_4^+, NO_3^-, PO_4^{---}, K^+, Ca^{++}, Mg^{++} and SO_4^{--}) content of rainwater, canopy drip and stem flow. Relatively higher content of NH_4^+, NO_3^-, PO_4^{---}, K^+, Ca^{++}, Mg^{++} and SO_4^{--} were detected in canopy drip followed by stem flow and rainwater, but Cu^{++}, Fe^{+++} and Zn^{++}

showed similar content in rainwater, canopy drip and stem flow. However, Ca^{++}, Cu^{++}, Fe^{+++} and Zn^{++} content in rainwater, canopy drip and stem flow showed similar pattern among the different seasons. Macronutrients (except NO_3^-) content in rainwater showed positive correlations with canopy drip and stem flow and Cu^{++}, Fe^{+++} and Zn^{++} showed negative correlations (Table 3). The reason could be the leaching of macronutrients from the tree canopy. Rainwater nutrients are augmented by canopy leaching and result in comparatively higher nutrients content in canopy drip and stem flow (Trudgill, 1988; Leite and Valle, 1990). However, nutrients content in canopy drip and stem flow varied from species to species (Gordon *et al.*, 2000) and also the stages of plant development such as flowering, fruiting and appearance of new leaves (Leite and Valle, 1990), temperature, intensity and duration of rainfall (Tukey, 1970).

The tidewater is an obvious source of nutrients in the mangroves and nutrients are usually dissolved and bound to sediment particles. Tidewater is not only the source of nutrients but also exports nutrients from the mangroves (Boto, 1982). Tropical rivers carry massive amount of sediment during the rainy season (Milliman and Meade, 1983). Relatively higher content of NH_4^+, PO_4^{---}, Mg^{++}, Fe^{+++} and Zn^{++} were detected in the river water during the wet and intermediate season. The reason could be the large amount of dissolved sediment in the river water or tidewater exports these nutrients from the mangroves to the river. Tidewater percolated into the soil profile during the high tide and can influence the nutrient content of infiltration water. In the present study, NO_3^-, PO_4^{---}, Mg^{++}, SO_4^{--}, Cu^{++} and Fe^{+++} showed positive correlations between river and infiltration water (Tables 3), which could be the evidence of nutrients exchange among the river and infiltration water. It can be concluded that rain, canopy drip, stem flow, river and infiltration water parameters (pH, redox potential, conductivity and salinity) and their nutrient contents are not static rather fluctuating with the seasonal changes.

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Table 1. Water parameters of Rainwater, canopy drip, stemflow, river water and infiltration during different seasons.

Sample types and sampling seasons	PH	Redox potential (mv)	Conductivity (dS/m)	Salinity (ppt)
Rain water				
Intermediate season (March 02)	6.79±0.05^{A}	9.74±1.29^{B}	0.08±0.001^{D}	-
Dry season (July 02)	6.91±0.04^{A}	3.34±1.13^{B}	0.29±0.001^{A}	-
Wet season (November 02)	6.91±0.03^{A}	1.68±0.37^{B}	0.14±0.001^{C}	-
Intermediate season (March 03)	6.39±0.03^{B}	105.67±5.61^{A}	0.10±0.001^{D}	-
Dry season (July 03)	6.33±0.07^{B}	126.00±20.84^{A}	0.21±0.001^{B}	-
Canopy drip				
Intermediate season (March 02)	6.72±0.03^{A}	11.84±0.74^{B}	0.15±0.001^{C}	-
Dry season (July 02)	6.67±0.08^{A}	12.10±0.55^{B}	0.35±0.001^{A}	-
Wet season (November 02)	6.34±0.07^{B}	35.40±5.43^{B}	0.16±0.001^{C}	-
Intermediate season (March 03)	6.45±0.06^{B}	115.67±6.86^{A}	0.13±0.001^{D}	-
Dry season (July 03)	6.36±0.06^{B}	120.33±10.97^{A}	0.31±0.001^{B}	-
Stem flow				
Intermediate season (March 02)	6.18±0.06^{A}	46.00±0.58^{D}	0.10±0.001^{A}	-
Dry season (July 02)	5.40±0.05^{C}	84.20±1.02^{C}	0.09±0.001^{B}	-
Wet season (November 02)	6.13±0.08^{A}	80.57±2.71^{C}	0.09±0.001^{C}	-
Intermediate season (March 03)	5.98±0.04^{B}	143.00±2.65^{A}	0.10±0.001^{A}	-
Dry (July 03)	5.84±0.04^{B}	105.33±5.18^{B}	0.10±0.001^{A}	-
River water				
Intermediate season (March 02)	6.92±0.03^{A}	2.50±0.67^{D}	20.00±0.30^{B}	30±0.01^{A}
Dry season (July 02)	6.91±0.05^{A}	5.83±1.31^{C}	22.17±0.17^{A}	30±0.01^{A}
Wet season (November 02)	6.56±0.08^{C}	23.01±1.89^{A}	18.17±0.17^{C}	25±0.01^{B}
Intermediate season (March 03)	6.69±0.06^{B}	11.93±3.60^{B}	19.50±0.29^{D}	30±0.01^{A}
Dry season (July 03)	6.92±0.08^{A}	6.17±1.38^{C}	21.17±0.17^{B}	30±0.01^{A}
Infiltration water				
Intermediate season (March 02)	6.32±0.03^{C}	42.00±2.65^{B}	61.67±1.67^{B}	37±0.01^{B}
Dry season (July 02)	7.05±0.06^{A}	-20.93±0.24^{C}	70.17±0.44^{A}	41±0.02^{A}
Wet season (November 02)	6.27±0.08^{C}	48.00±1.73^{A}	55.83±0.44^{C}	34±0.02^{C}
Intermediate season (March 03)	6.52±0.05^{B}	39.47±2.84^{B}	63.33±1.68^{B}	38±0.01^{B}
Dry season (July 03)	7.03±0.03^{A}	-17.30±1.77^{C}	71.00±0.58^{A}	40±0.02^{A}

Same letter indicates there is no significant (ANOVA, DMRT, $p>0.05$) difference.

Table 2. Nutrients content (ppm) in rainwater, canopy drip, stem flow, river water and infiltration water during different seasons.

Sample Types	Intermediate season (March 02)	Dry season (July 02)	Wet season (Nov. 02)	Intermediate season (March 03)	Dry season (July 03)
Ammonium					
Rain water	0.16±0.01 D	0.51±0.01 A	0.41±0.01 B	0.31±0.01 C	0.47±0.01 A
Canopy drip	0.40±0.01 D	0.88±0.00 B	1.03±0.02 A	0.42±0.01 D	0.74±0.01 C
Stem flow	0.31±0.00 C	0.59±0.02 A	0.50±0.01 B	0.30±0.00 C	0.50±0.01 B
River water	0.34±0.01 C	0.38±0.01 B	0.55±0.01 A	0.32±0.00 D	0.35±0.01 C
Infiltration water	0.64±0.00 A	0.62±0.01 B	0.51±0.00 C	0.52±0.00 C	0.49±0.01 D
Nitrate					
Rain water	0.01±0.00 E	0.06±0.00 B	0.04±0.00 C	0.03±0.00 D	0.07±0.00 A
Canopy drip	0.07±0.00 B	0.05±0.00 D	0.08±0.00 A	0.07±0.00 B	0.06±0.00 C
Stem flow	0.02±0.00 D	0.03±0.00 C	0.08±0.00 A	0.05±0.00 B	0.03±0.00 C
River water	0.02±0.00 B	0.03±0.00 A	0.01±0.00 C	0.02±0.00 B	0.02±0.00 B
Infiltration water	0.02±0.00 B	0.03±0.00 A	0.01±0.00 C	0.01±0.00 C	0.01±0.00 C
Phosphate					
Rain water	0.01±0.00 A	0.01±0.00 A	0.01±0.00 A	0.01±0.00 A	0.01±0.00 A
Canopy drip	0.05±0.00 C	0.09±0.00 A	0.07±0.00 B	0.04±0.00 D	0.04±0.00 D
Stem flow	0.02±0.00 A	0.01±0.00 B	0.01±0.00 B	0.01±0.00 B	0.01±0.00 B
River water	0.05±0.00 A	0.03±0.00 B	0.02±0.00 C	0.03±0.00 B	0.03±0.00 B
Infiltration water	0.11±0.00 A	0.09±0.00 B	0.01±0.00 E	0.04±0.00 D	0.05±0.00 C
Potassium					
Rain water	0.33±0.00 A	0.21±0.00 D	0.33±0.00 A	0.30±0.01 B	0.25±0.00 C
Canopy drip	4.49±0.10 A	2.34±0.00 C	2.39±0.04 C	2.65±0.02 B	2.65±0.02 B
Stem flow	2.61±0.11 A	2.34±0.00 B	0.50±0.01 D	2.34±0.01 B	2.14±0.00 C
River water	34.06±0.60 C	45.96±0.00 A	21.00±0.00 E	20.05±0.04 D	38.10±0.24 B
Infiltration water	348.89±3.61 A	64.11±0.99 D	154.00±0.00 C	327.14±0.92 B	60.12±0.17 D
Calcium					
Rain water	2.30±0.02 B	1.60±0.00 D	2.00±0.00 C	2.45±0.00 A	1.40±0.00 E
Canopy drip	16.54±0.04 C	9.00±0.00 E	19.50±0.00 B	20.12±0.00 A	10.13±0.00 D
Stem flow	5.91±0.11 C	3.00±0.00 D	7.50±0.00 B	8.00±0.24 A	6.22±0.17 C
River water	68.13±0.12 B	76.00±0.33 A	54.00±0.14 E	63.00±0.17 C	66.45±0.17 C
Infiltration water	568.22±1.57 B	329.56±0.23 E	498.00±0.33 C	926.23±0.17 A	444.23±0.17 D
Magnesium					
Rain water	2.00±0.00 C	1.87±0.00 D	2.10±0.00 B	2.50±0.00 A	1.30±0.00 E
Canopy drip	5.33±0.07 B	7.00±0.24 A	1.00±0.00 E	4.50±0.00 C	3.10±0.00 D
Stem flow	4.11±0.06 B	4.50±0.11 A	1.00±0.00 D	4.00±0.17 B	2.13±0.00 C

River water	271.00±2.14^A	245.00±0.24^B	188.00±0.17^D	163.00±0.17^E	200.17±0.24^C
Infiltration water	2365.33±8.47^A	2012.00±0.67^E	2123.00±0.00^C	2216.36±0.17^B	2059.00±0.17^D
Sulphate					
Rain water	6.99±0.11^B	14.43±0.36^A	5.32±0.06^C	2.24±0.01^D	7.03±0.36^B
Canopy drip	41.19±0.13^A	33.49±1.86^B	5.69±0.12^E	12.51±0.07^D	23.39±0.68^C
Stem flow	14.56±0.35^A	10.35±0.20^B	9.32±0.18^C	8.28±0.01^D	7.18±0.21^E
River water	611.58±1.18^B	908.90±82.07^A	305.44±3.48^C	511.11±0.52^B	797.78±41.82^A
Infiltration water	2527.46±6.38^C	4460.86±148.21^A	1559.23±8.79^E	1953.59±1.07^D	3129.55±31.17^B
Copper					
Rain water	0.01±0.00^A	0.01±0.00^A	0.01±0.00^A	0.01±0.00^A	0.01±0.00^A
Canopy drip	0.01±0.00^A	0.01±0.00^A	0.01±0.00^A	0.01±0.00^A	0.01±0.00^A
Stem flow	0.01±0.00^A	0.01±0.00^A	0.01±0.00^A	0.01±0.00^A	0.01±0.00^A
River water	0.02±0.00^A	0.02±0.00^A	0.01±0.00^B	0.01±0.00^B	0.02±0.00^A
Infiltration water	0.07±0.00^A	0.07±0.00^A	0.06±0.00^B	0.07±0.00^A	0.07±0.00^A
Iron					
Rain water	0.03±0.00^A	0.03±0.00^A	0.03±0.00^A	0.03±0.00^A	0.03±0.00^A
Canopy drip	0.03±0.00^A	0.03±0.00^A	0.03±0.00^A	0.03±0.00^A	0.03±0.00^A
Stem flow	0.03±0.00^A	0.03±0.00^A	0.03±0.00^A	0.03±0.00^A	0.03±0.00^A
River water	0.04±0.00^A	0.02±0.00^B	0.02±0.00^B	0.04±0.00^A	0.02±0.00^B
Infiltration water	0.84±0.00^A	0.41±0.00^E	0.44±0.00^C	0.74±0.00^B	0.43±0.00^D
Zinc					
Rain water	0.02±0.00^A	0.02±0.00^A	0.02±0.00^A	0.02±0.00^A	0.02±0.00^A
Canopy drip	0.02±0.00^A	0.02±0.00^A	0.02±0.00^A	0.02±0.00^A	0.02±0.00^A
Stem flow	0.02±0.00^A	0.02±0.00^A	0.02±0.00^A	0.02±0.00^A	0.02±0.00^A
River water	0.07±0.00^A	0.06±0.00^B	0.05±0.00^C	0.06±0.00^B	0.06±0.00^B
Infiltration water	0.14±0.00^C	0.12±0.00^D	0.16±0.00^A	0.15±0.00^B	0.14±0.00^C

Mean with similar alphabet in the same row (according to seasons) is not significantly different (ANOVA, DMRT, p>0.05).

Table 3. Correlation coefficient (r) among rainwater and canopy drip, rain water and stem flow, river and infiltration water.

Nutrients	Correlation coefficient (r)		
	Rain water and canopy drip	Rain water and stem flow	River and infiltration water
NH_4^+	0.74*	0.82*	-0.22
NO_3^-	-0.57	0.04	0.40
PO_4^{---}	0.04	0.12	0.76*
K^+	0.51	0.34	-0.55
Ca^{++}	0.87*	0.55	-0.37
Mg^{++}	0.05	0.30	0.27
SO_4^{--}	0.59	0.21	0.88*
Cu^{++}	0.03	-0.14	0.61
Fe^{+++}	-0.22	-0.22	0.97*
Zn^{++}	-0.06	-0.35	-0.48

* Values are significant at $p<0.05$ level

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