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Research Article

Spatial and Temporal Variations in Physico-Chemical Parameters and Nutrients, Along a Gradient of Anthropogenic Activities within Kapsabet River, Kenya

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Abstract: Anthropogenic activities can affect the quality of materials discharged into such systems. Pollutants enter the aquatic environment via water from the catchments originating from settlement areas and from areas with anthropogenic activities including from industrial sources. Sediments then act as repository for the metals and can be remobilized to be available in the water column and disturb the aquatic biota. Therefore prudent management of aquatic environments require information on their quality status that can be estimated by monitoring water quality and presence of other pollutants. To this purpose, water, soils and sediments samples were collected along four sites and characterized for the physico-chemical parameters and nutrients in the dry and wet seasons. The parameters analyzed were: temperature, pH, chemical oxygen demand (COD), biological oxygen demand (BOD), total dissolved solids (TDS) and total suspended solids (TSS) while phosphates and nitrates were the nutrients analyzed. TSS and TDS were determined by gravimetric method, COD titrimetrically, BOD by incubation, phosphates and nitrates by colorimetric method. Data was analyzed statistically using SPSS computer package. Their spatial and temporal values were: in water, pH (7.2 -10.3), TSS (110 -1301 mg/L), TDS (868 - 2990 mg/L), COD (6.0 – 67 mg/L), BOD (3.0 - 33.7 mg/L) PO_4^{3-} (0.2 - 2.1 mg/L) and NO_3^- (0.6 - 4.5 mg/L), in soil and sediments, PO_4^{3-} mean values were: 0.5-1.8 mg/L and 0.7 – 2 mg/L, respectively, while NO_3^- in soil and sediments were: 5-5.2 mg/L and 8-8.0 mg/L, respectively. The physico-chemical parameters and nutrients displayed significant ($p < 0.06$) temporal variations. pH was highest in site S2, TSS, COD and BOD were highest in site S4 while TDS was highest in site S1. highest values of physico-chemical were recorded in the rainy season. Further, there were significant ($p < 0.05$) spatio-temporal variation in the physicochemical parameters.

Keyword: physico-chemical parameters, total nitrogen, total phosphorus

1. INTRODUCTION

Human activities including indiscriminate use of inorganic fertilizers during agriculture, disposal of waste products such as detergents and discharge of pollutants from the mining zones, transport of nutrients and pesticides have resulted in changes in water quality of rivers resulting in increased the levels of pollutants into recipient water bodies resulting in drastic changes in the watershed health[1]. As such, water quality problems are not new in most ecosystems of the world but have been recently aggravated by these adverse anthropogenic impacts[2].

The point and non-point source pollution arising from sources that are normally associated with agricultural and silvicultural, and human activities within the catchment are transported from land by atmospheric, surface water and ground water pathways[3]. It is these changes in quality of water parameters that continue to pose problems of increasing environmental concern. As a result of these perturbations, there is an increased interest in holistic evaluation of the quality status of water in both lentic and lotic systems. For many years, Africa was considered safe from heavy metal pollution[4]. However, rapid population growth and high urbanization rates have resulted in a recent expansion of cities in the absence of proper planning and without adequate waste disposal facilities[5] and as such increased reports of adverse changes in water quality are reported and may not be further ignored by the environmental managers.

There are numerous studies that have been conducted in Kenya. Based on these studied, ominous signs of water quality changes have been documented due to agriculture, urbanization, human settlement, motor vehicle wastes and industrial activities[6- 8]. Yet, most of these studies have been conducted in large basins and rivers in Kenya, ignoring the potential of water quality and heavy metals problems in the upstream water bodies, which have continued to be exposed to myriads of anthropogenic activities. Kapsabet in the Rift Valley Province in Kenya is an agricultural urban area and information available in grey literature indicates that there is extensive use of chemical fertilizers in the catchments and livestock production, yet there is lack of studies on how these activities continue to affect the quality of water in the recipient Kapsabet River. For this, the current study was therefore undertaken to document the water quality along an upstream Kapsabet River through an analysis of the physico-chemical parameters and nutrients. The physico-chemical parameters analyzed were; temperature, pH, total dissolved substances (TDS), Total suspended solids (TSS), Chemical Oxygen demand (COD) and Biological Oxygen Demand (BOD). Nutrients analysed were phosphates and nitrates in the three environmental media.

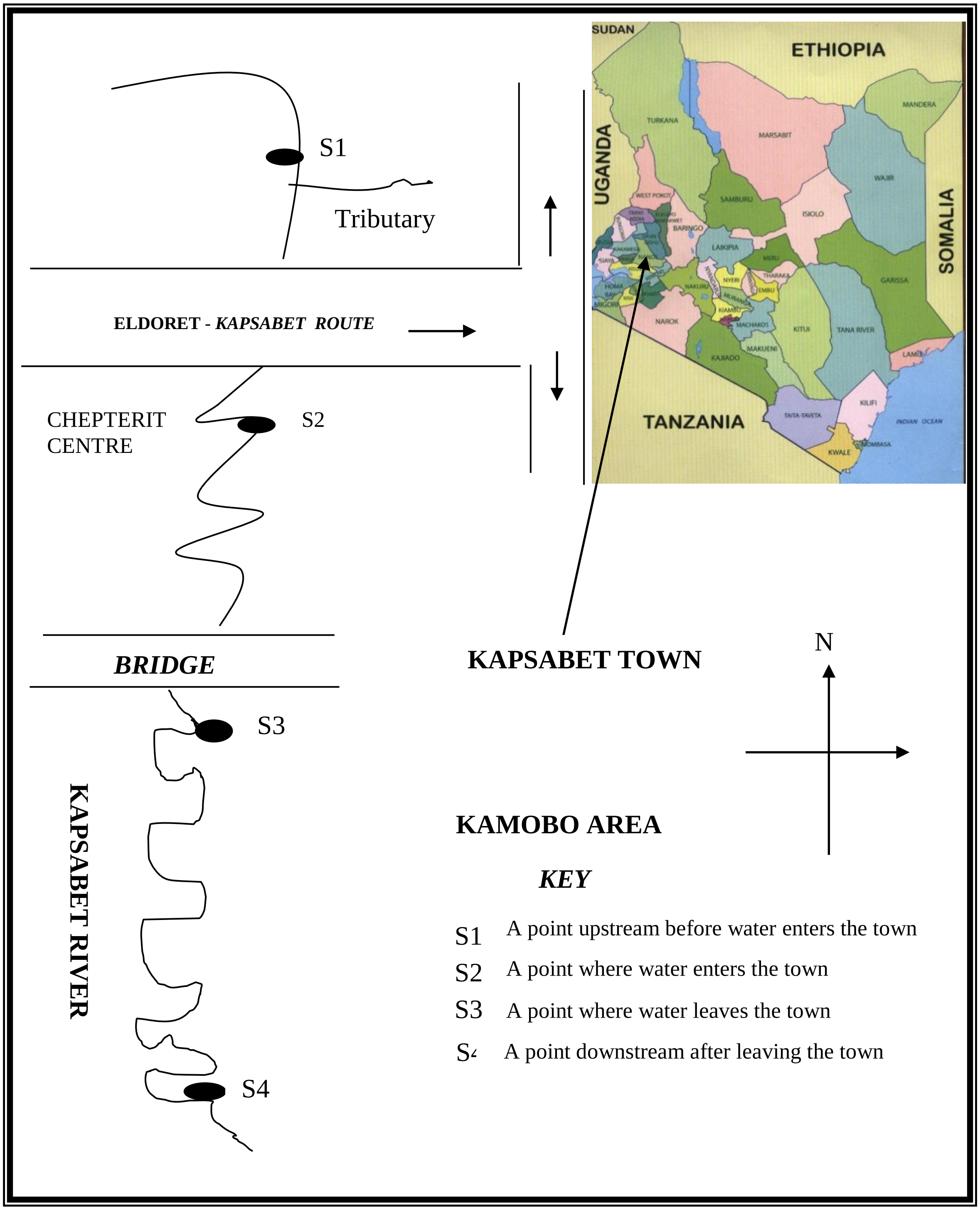

Figure 1: Sketch Map of Study Area (Source: Author, 2012)

2.0 MATERIALS AND METHODS

2.1 Study area and sampling sites: The study area was at Kapsabet River which is within Kapsabet town. There is ongoing construction of water treatment plant for Kapsabet municipality along this river. Water from this river is meant to serve the residents of the rapidly growing Kapsabet town. It is bounded by the latitudes; 34° - 36° E, longitude; 0°03'- 1°15'N and lies between 1134-2700 m above sea level with average slope of 4 per 1000. The region receives an average of 1350 mm/year of rain and is an important cereal and sugarcane- farming region of Kenya producing at least 30% of the national output of both maize and Tea [7]. Potential major sources of pollution for the Kapsabet River basin are the agricultural chemicals, urban effluents of, Kapsabet and industrial wastes of the Chebut tea factory at Kapsabet. The polluting role played by any of these factories is unknown.

Four sampling sites were selected for this study based in the anthropogenic gradients of the catchment. The sites were S1, S2, S3 and S4 and their description are as provided. S_1; this is the remote point upstream Kapsabet River before the river enters the town. This point is expected to be the control point of this research since there will be no contributions from the runoff from the town and farming activities within town. S_2; this is a point closer to Eldoret –Kapsabet route and an entrance point of water into town. It will assist in monitoring of lead metal contamination from exhaust fumes and runoff from farms. The difference between S_1 and S2 shows pollution from the runoffs from the Eldoret –Kapsabet route, surrounding farms and town. S_3; this is a point where water leaves the town. It assisted in evaluating progressive contribution of runoffs from the town and farms around. S_4; this is a point which is approximately 300 M downstream after the river water has left the town. The difference between S_1 and S_4 will provide total contribution of town runoff and soil erosion to the river water.

2.2 Sample collection and analysis

2.2.1 Water sampling*:* Fieldwork consisted of collecting water samples at three pre-determined sites at each of the sampling stations. The river water samples were obtained using the Grab Technique using half litre metal free Van Dorn bottle. All water samples were drawn from about half meter (0.5 m) below the water surface at each of the two opposite sides of Kapsabet River. This depth was considered to represent a homogeneous water layer, free from riverbed sediment or atmospheric air interference. A total of 20 water samples were collected for this study, with 5 samples from each of the four sampling sites. Water samples were acidified to pH 2 with concentrated nitric acid according to APHA[9]. After the preliminary treatment, the samples were placed into an ice box and transported to laboratory for temporary storage in a refrigerator at 4°C before analysis.

2.2.2 Sediment sampling and analysis*:* A pre-cleaned Ekman Grab Sampler was used to collect the river bottom sediments. A total of 5 grab sediment samples (up to 10 cm depth) were collected from the four sites. They were then transferred to acid rinsed polypropylene bottles. All samples were collected in triplicate. The depth of water at each sediment-sampling site was measured using a meter rule. The wet sediment samples were kept separately in appropriately marked black polythene bags and transported to the laboratory for chemical analyses.

2.2.3 Sampling of Soil: Within each of the sampling sites, four (4), an auger sampler was used to scoop soil in the organo-mineral layer (0 – 25 cm) at each sampling point. The soil was then kept in black polythene bags, labelled and placed in an ice box and transported to the laboratory for chemical analyses.

2.3. Determination of physico-chemical parameters and nutrients: DO concentration, salinity, temperature, electrical conductivity and pH were measured in situ at each of the sampling sites, using a calibrated JENWAY 3405 electrochemical analyzer (Barloword Scientific Ltd, Essex, UK), with independent probes for each variable. Water samples for nutrient determination were collected with a 3-L calibrated van Dorn sampler at the water surface (0 m). Portions of the water samples were used to determine nitrite–nitrogen (NO_2–N) by the sulphanilamide diazotizing method, nitrate–nitrogen (NO_3–N) by the diphenylamine sulphonic acid chromogene method, ammonia–nitrogen (NH_3–N) by the indophenol blue method, soluble reactive phosphorus (SRP) by the standard ascorbic acid method, after filtration of the sample through a 45-lm pore size membrane, and TA by the acidimetric method, with sulphuric acid as the titrant. The analyses were carried out at Eldoret water treatment plant following the standard analytical procedures detailed in APHA[9].

2.4 Statistical Analyses: All data collected were entered, organized and managed using EXCEL spreadsheet for Windows XP. Statistical analyses were performed with either a version of STATISTICA 6.0 (StatSoft,[10] or GenStat 4.24 Release. Data collected were subjected to apriori test to determine the homoscedasticity[11] before subjecting them to statistical analysis. The normality of the data distribution was checked by means of skewness and Kurtosis when performing analysis of variance. However, before conducting t-test, Levene's test on homogeneity of variance was conducted. Data on physico-chemical parameters and nutrients were calculated as means (± S.D) for each site on each sampling occasion. Mean differences among sites were analyzed using a one-way ANOVA; the differences between dry and wet seasons being analyzed by student t-test. Spatial variations in physico-chemical parameters and nutrients were examined by Two-Way ANOVA. Where significant differences were discerned among attributes analyzed by ANOVA, Duncans Multiples Range test (DMRT) was used to discriminate between the means[11].

3. RESULTS AND DISCUSSION

Physico-chemical parameters measured at the four sampling sites are presented in **Table 1.** All the physico-chemical parameters except temperature varied significantly at the sampling sites (Type III, One-Way ANOVA; $p < 0.05$). The ranges of most of the physico-chemical parameters are within normal ranges of fresh water with some deviations. Generally, a range of 7.1 to 8.0 is considered pristine environment, however in the current study, the pH ranged from 7.12 to 10.1which was above the WHO standard limits of 6.5-8.5 (WHO)[12], indicating sometimes extremely alkaline conditions reminiscent of external inputs of alkaline substances into the aquatic environment. Site S2 had the lowest and a near neutral pH probably because it's undisturbed. TSS was highest in site S4 attributed to the dissolution of substances from the nearby Kapsabet town as was reported in earlier studies for areas situated near urban centres[6,13]. The input of substances into the waterbodies can be confirmed by high concentrations of TDS in the water ranging from 800-3000 mg/L, which are higher than those reported[8] in river Nyando of 110.1-142 mg/L. However, the amount of TDS was significantly the highest at S1 which can be associated with discharge of large number of allochthonous materials in water from the decomposing litter in the forest. The concentration of COD and BOD were highest in site S4, due to the presence of large number of organic substances such as humic substances that decompose and therefore consuming a lot of oxygen from the water column[14]. Generally, the water flow in Kapsabet River starts from the upstream before Kapsabet, and then flows towards Lake Victoria. Under normal hydrological flow regime, it is normally expected that a defined gradient of temperature, pH, TSS, TDS, COD and BOD would be obtained defined by downstream flows from the rithron to the potamon [15-17]. However, when there are deviations with sudden decline and increase of these nutrients then, it is normally an indication of inputs from external sources.

Table 1: Mean values (± SEM) of the physico-chemical parameters in four sites of Kapsabet River water.

Parameters	**Sampling sites**				**Statistical**	
	S1	S2	S3	S4	F	p-value
pH	7.91 ± 0.71^a	9.79 ± 0.14^c	9.06 ± 0.52^b	8.88 ± 0.67^b	24.551	0.0002
TSS (mg/L)	355 ± 90.4^a	590.5 ± 82.1^b	627.5 ± 101.1^b	730 ± 89.7^c	13.224	0.0211
TDS (mg/L)	2456 ± 293^c	2147 ± 318^b	2062 ± 272^b	1613 ± 363^a	19.112	0.0012
COD	29.2 ± 6.5^a	26.7 ± 9.4^a	35 ± 7.2^b	44.0 ± 9.7^c	9.433	0.0431
BOD	5.2 ± 3.2^a	10.7 ± 3.1^b	12.5 ± 3.6^c	18.5 ± 4.2^d	25.675	0.0000
Temperature	19.5 ± 0.8	20 ± 0.6	20.1 ± 0.5	20.5 ± 0.3	2.113	0.0971

Similar lettering represents concentrations that do not differ significantly (p > 0.05) based on one-way ANOVA test followed by post-hoc Duncan's Multiple Range Test.

The temporal variation of the physico-chemical parameters was also determined **(Table 2).** Based on the table there were significant seasonal differences in the concentration of all the measured parameters in water (*t*-test for all parameters; $p < 0.005$). All parameters tested were found to be significantly higher in the rainy season. Although rains are supposed to bring dilution effects into the water body[18], the exceptionally higher pH during rainy seasons indicate that there is presence of external inputs of substances that affect the levels of pH in the water.

Table 2: Mean values (± SEM) of the physico-chemical parameters in dry and rainy season of Kapsabet River water.

Parameters	Season		Statistical analysis	
	Dry	Wet	*T*	p-value
pH	8.14 ± 0.33^a	9.68 ± 0.31^b	24.551	0.0002
TSS	145.0 ± 14.4^a	956.3 ± 98.8^b	13.224	0.0211
TDS	1537 ± 134^a	2602 ± 107^b	23.105	0.0011
COD	9.81 ± 1.05^a	51.63 ± 3.64^b	17.411	0.0033
BOD	4.25 ± 0.32^a	23.25 ± 2.1^b	54.675	0.0000
Temperature	19.8 ± 0.3	18.8 ± 0.4	12.113	0.0071

Similar lettering represents concentrations that do not differ significantly (p > 0.05) based on t-test

The spatio-temporal variations in the values of the various physico-chemical parameters are provided in **Table 3**. There were significant spatio-temporal variations in the levels of measured physico-chemical parameters in water (Two-Way ANOVA; $p < 0.05$). That means that that seasons and sites of occurrence were main factors that determined the concentration of the measured parameters suggesting that rain and presence of human factors contributed to the occurrence of the these substances in water.

The concentration of total phosphorus (TP) in water, soils and sediment at the four sampling sites of River Kapsabet is shown in **Fig. 2**. Based on the figure, there were significant differences in the concentration of TP among sites in water, sediments and soils (One-Way ANOVA; $p < 0.05$). The highest concentration of TP occurred at site S2 in all the analyzed media and lowest at site S3 in water and sediments and site S4 in the soils. The direct relationships between TP in water and sediments was expected since the sources of phosphorus in water normally settle to the sediments and may be re-mobilized during times of the river mixing regime[16] .

Therefore it appears that there is heavy use of substances that elevated the concentration of TP in soils at site S2. The TP was taken into the water body through overland flow and then accumulated in the bottom sediments. A casual survey of site S2 indicates that there is extensive use of fertilizers in the area than other sites such as S1 which has lower agricultural activities. Again due to the small nature of the river, most of the washing points along the river are located in this site and therefore likely to elevate the levels of TP in water. However, site S2 had lower elevations than other sites and therefore likely to receive a lot of non-point sources of inputs from other watershed into the water body, which is likely to elevate the amount of TP in the sampling site.

The concentration of total phosphorus in water, soils and sediment at the four sampling sites of River Kapsabet during the rainy and dry is shown in **Fig. 3**. Rainy seasons resulted in significantly higher concentration of TP in all the environmental media because of the possible input of phosphorus from the external environment into the River Kapsabet. Previous studies have established that total phosphorus is usually highly adsorbed into the soil and can be transported from the upper parts of the river catchments into the recipient water bodies and may account for the high total phosphorus concentration in local water bodies even if there is no evident point sources of pollution[18,19] .

The spatio-temporal variations of total phosphorus among the four sampling sites are shown in Fig. 4. There were significant spatio-temporal variations (ANOVA; $p < 0.05$) in the concentration of total phosphorus in water soils and sediments with all dry seasons having the highest concentration of total phosphorus in all the media. In water, highest concentration of total phosphorus was recorded in site S2 followed by S1 during the rainy season while in water, the highest concentration of TP in dry season was in site S1.

In the soils, highest TP concentration occurred at site S1 in both the dry and rainy season while in sediments, sites S1 and S2 had the highest concentrations of TP in dry and rainy season with no discernable significant differences in seasons at site S3. These results indicate that at each site, there is relative contribution of external sources of TP that may not be easily detected in the surrounding riparian ecotones and may be overland flow and soil sediment transportation from the upper parts of the catchments.

Table 3: Mean values (± SEM) of the physico-chemical parameters in four sites in dry and rainy season of Kapsabet River water.

	Sampling sites								Statistical analysis	
	S1		S2		S3		S4		F	p-value
Parameters	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy		
pH	7.3 ± 0.1	8.7 ± 1.1	9.6 ± 0.1	10.0 ± 0.5	8.2 ± 0.1	9.9 ± 0.1	7.7 ± 0.1	10.1 ± 0.2	19.221	0.0172
TSS	135 ± 41	575 ± 45	130 ± 20	1050 ± 142	155 ± 15	1100 ± 100	160 ± 11	1100 ± 201	83.992	0.0000
TDS	1950 ± 50	2962 ± 38	1600 ± 120	2695 ± 423	1600 ± 125	2525 ± 345	1000 ± 132	2225 ± 432	78.112	0.0000
COD	6.5 ± 0.5	61.5 ± 5.5	9.5 ± 0.8	44.1 ± 4.2	14.2 ± 0.6	52.3 ± 5.3	9.4 ± 1.1	49.5 ± 12.3	29.433	0.0001
BOD	3.5 ± 0.5	27.5 ±5.2	4.5 ± 2.1	20.5 ± 3.8	5.5 ± 0.9	24.6 ± 3.8	3.5 ± 0.5	21.7 ± 4.4	87.674	0.000
Temperature	19.5 ± 0.5	17.5 ± 0.5	20.5 ± 0.7	19.5 ± 0.4	20.8 ± 0.9	20.9 ± 1.8	19.0 ± 2.1	18.5 ± 1.1	22.113	0.0078

Sampling sites

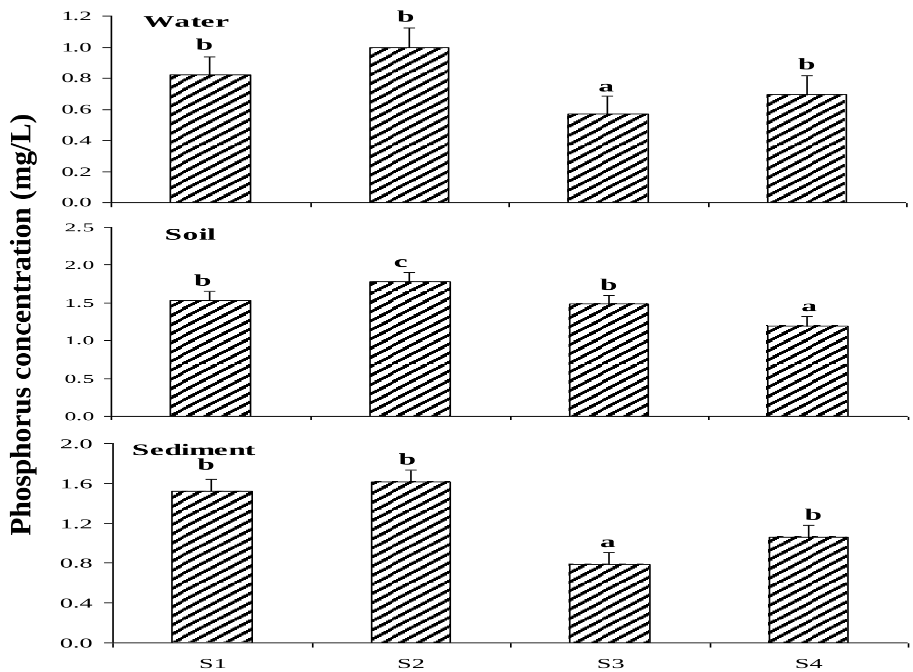

Fig. 2: Concentration of total phosphorus along the four sampling sites in water, soils and sediment of Kapsabet River

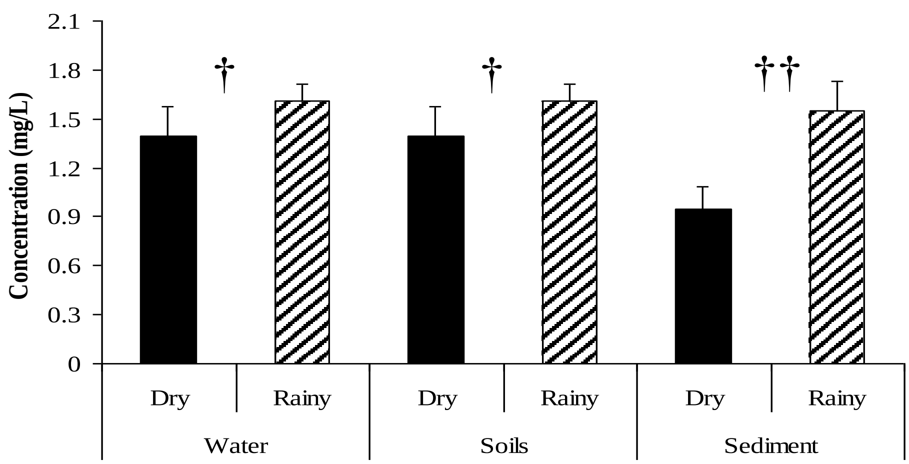

Fig. 3: Concentration of total phosphorus in dry and rainy seasons in water, soils and sediment of Kapsabet River

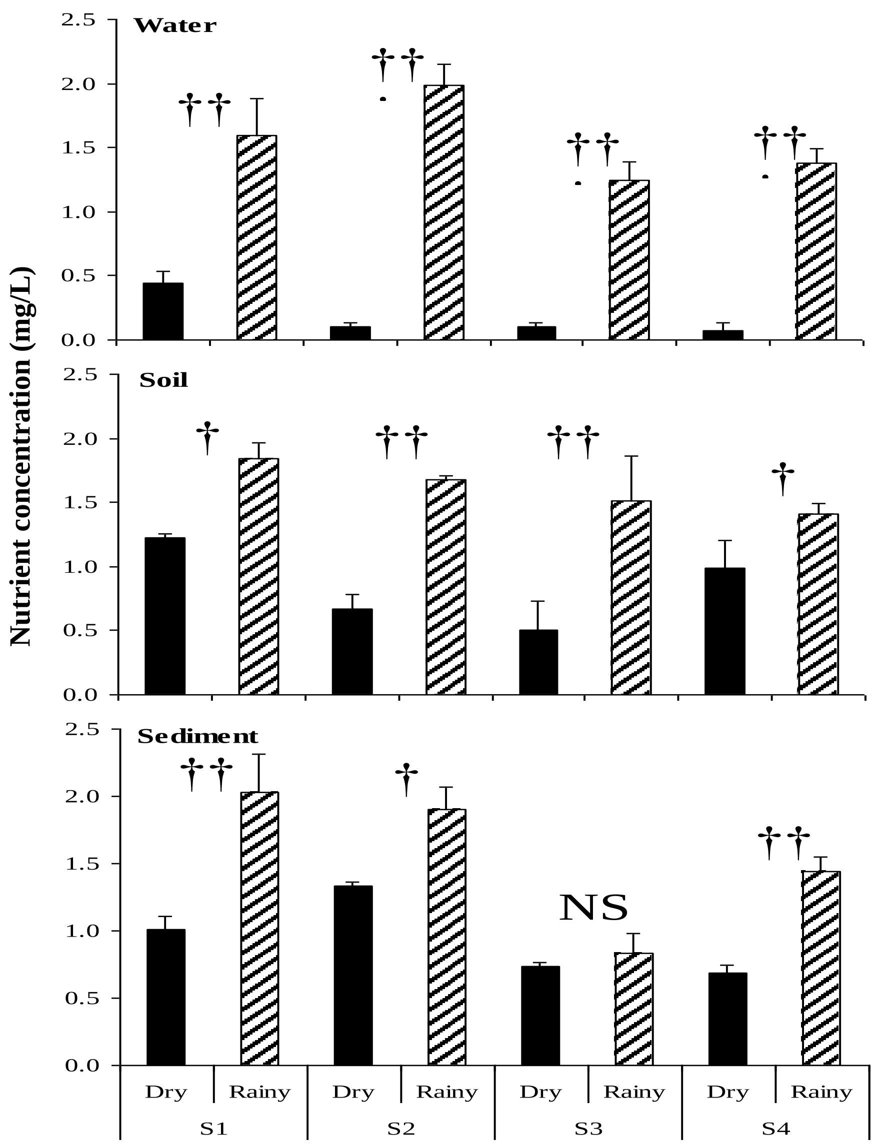

Fig. 4: Concentration of the total phosphorus in the four sites in dry and rainy season in water, soils and sediment of Kapsabet River

The concentration of total nitrogen (TN) in water, soils and sediment at the four sampling sites of River Kapsabet is shown in **Fig. 5.** Based on the figure, there were significant differences in the concentration of TN among sites in water, sediments and soils (One-Way ANOVA; $p < 0.05$). It determined that the concentration of TN increased significantly from site S1 to site S4 systematically. The direct relationships between TN in water and sediments was expected since the sources of nitrogen in water normally settle to the sediments and may be re-mobilized during times of the river mixing regime[20]. Therefore it appears that there is heavy use of nitrogenous fertilizers in the farmers and additional inputs from the nearby urban centres resulted in elevated levels of TN in water and subsequent transference to the sediments. The

TN is normally transported in form of nitrates, nitrites and ammonia[21] and may therefore account for the high concentration of TN in the environmental media. Again due to the small nature of the river, most of the nitrogenous fertilizers will have very strong influence on the nutrient status of the river and likely to elevate the concentration of TN in water[22].

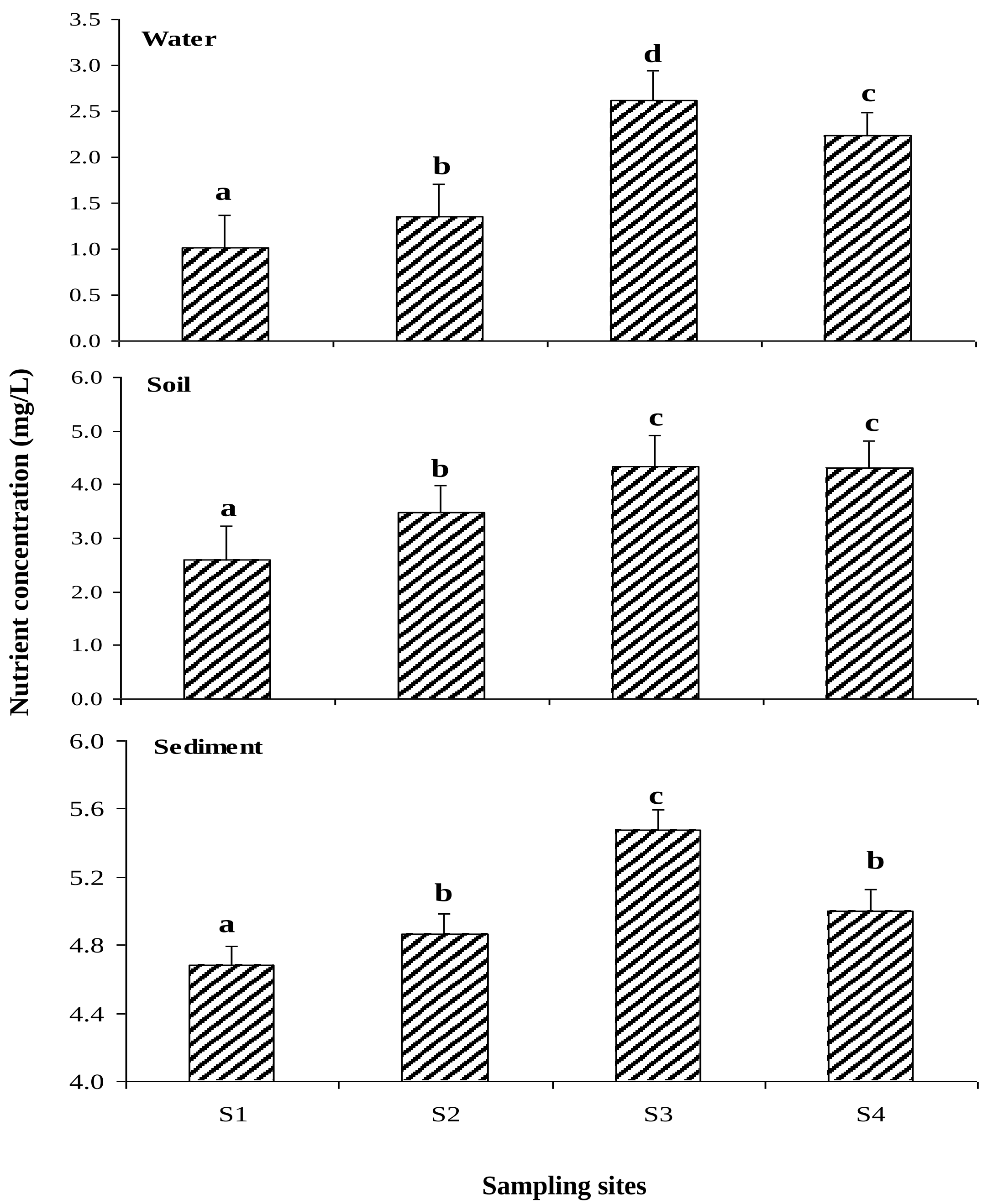

Fig. 5: Concentration of total nitrogen along the four sampling sites in water, soils and sediment of Kapsabet River

The concentration of total phosphorus in water, soils and sediment at the four sampling sites of River Kapsabet during the rainy and dry is shown in **Fig. 6.** Rainy seasons resulted in significantly higher concentration of TP in all the environmental media because of the possible input of phosphorus from the external environment into the River Kapsabet. Previous studies have established that phosphates are usually highly adsorbed into the soil and can be transported from the upper parts of the river catchments into the recipient water bodies and may account for the high phosphates concentration in local water bodies even if there are no evident point sources of pollution[18].

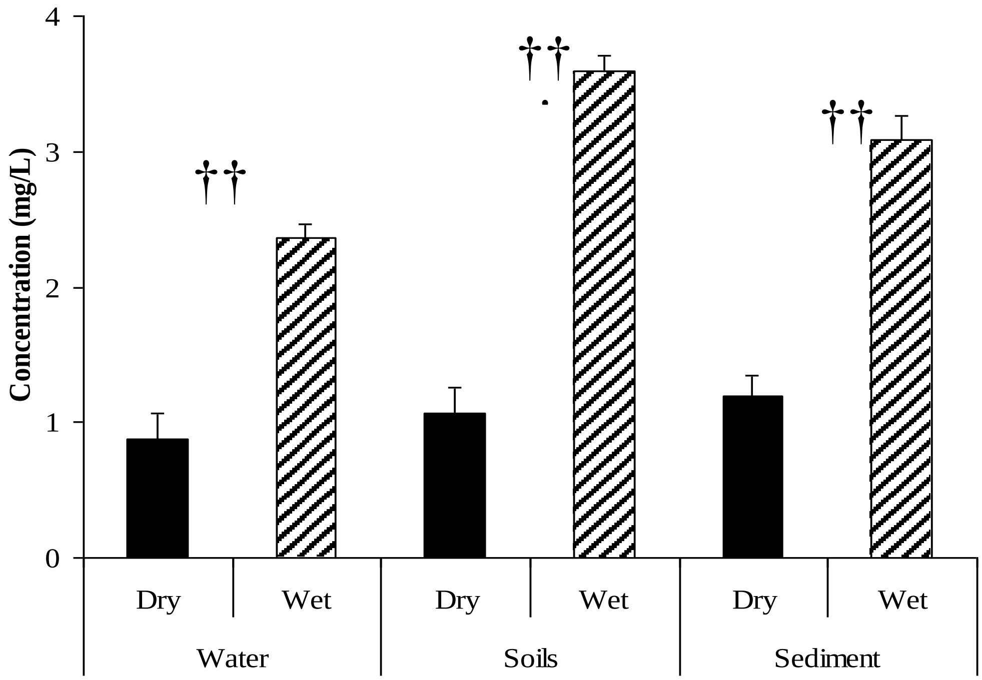

Fig. 6: Concentration of total nitrogen in dry and rainy seasons in water, soils and sediment of Kapsabet River

The spatio-temporal variations of total nitrogen among the four sampling sites are shown in **Fig. 7**. There were significant spatio-temporal variations (ANOVA; $p < 0.05$) in the concentration of total nitrogen in water soils and sediments with all dry seasons having the highest concentration of total phosphorus in all the media. In the three media, there was a systematic increase in the concentration of TN along the sites from site S1 to S4 both in the dry and rainy season and this could be accounted for by systematic increase in the concentration of TN in water due to increased inputs of external contaminants into the water body from both agricultural and municipal centres. These results also signify that at each site, there is relative contribution of external sources of TN that may not be easily detected in the surrounding riparian ecotones and may be overland flow and soil sediment transportation from the upper parts of the catchments.

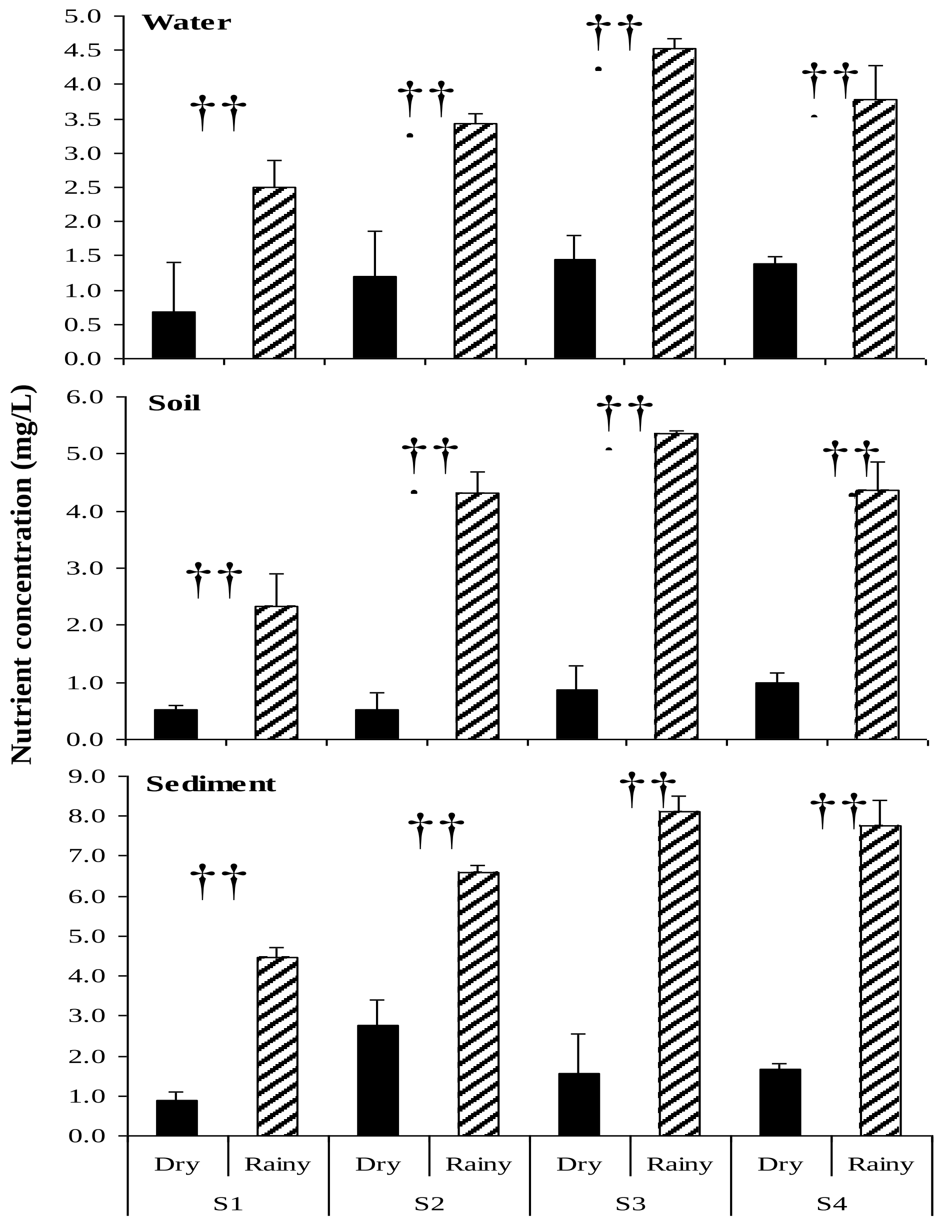

Fig. 7: Mean values (± SEM) of the total nitrogen in the four sites in dry and rainy season in water, soils and sediment of Kapsabet River

4. CONCLUSIONS

The physico-chemical parameters and nutrients analyzed in Kapsabet River indicated a considerable spatio-temporal heterogeneity reminiscent of patterns associated with anthropogenic impacts. Sites near intense anthropogenic impacts appeared to have stronger spatio-temporal variability in the physico-chemical parameters and in the nutrients.

5. RECOMMENDATION

There is need for collaboration between the government and communities staying nearer to the river to avoid pollution of the adjacent water body. Nutrient reduction strategies should be used to control the excessive nutrients load into this river especially during rainy seasons. One such strategy could involve the construction of buffer zones to regulate the inflow of phosphates and nitrogen.

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