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The influence of land use on nutrient regime in a tropical stream

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ABSTRACT

Pollution of inland waters by agricultural, industrial and municipal wastes is a global problem and a common phenomenon in developing countries. These anthropogenic activities within the landscape facilitate the transfer of nutrients into aquatic ecosystems, sometimes leading to eutrophication which has adverse effects on aquatic ecosystems. Deposition of nutrient-rich sediments washed into rivers and stream is common during rainy season in places where the riparian buffer zones have been destroyed. River Isiukhu watershed land use comprises sugar-cane farm, forested, peri-urban and mixed agriculture from upstream to downtream. The research employed stratified random sampling. Nitrate-nitrogen was determined through ultra-violet screening spectrophotometric method while phosphate-phosphorus through ascorbic acid method. Data analyses were done using Statistical Analysis System, version 9.1. Land use had a significant effect of both nitrate-nitrogen (F=1372.25, p<0.05) and phosphate-phosphorus concentrations. Peri-urban and mixed agricultural land uses recorded higher concentrations of these two nutrients while the forest land use recorded the lowest. The study showed that the type of riparian land use land cover influences nutrient concentrations in a water body and is an important area to be focused on by watershed managers.

Introduction

Physicochemical conditions of rivers and streams are controlled by numerous natural and anthropogenic activities within a watershed (Ahearn *et al.*, 2005). Human activities including deforestation, agriculture, urban run-off and discharge of untreated waters from sewers result into alteration of riparian zone leading to changes in nutrient content and overall river water quality (Townsend *et al.*, 1997; Shivoga *et al.*, 2005; Shivoga *et al.*, 2007 and Njiru *et al.*, 2008). This is because riparian vegetations are believed to be important in protecting river ecosystems from excessive sedimentation, surface run-off, pollutants and contaminants from the landscape (Enanga *et al.*, 2011).

Riparian buffer strips are important in filtering nutrients e.g. nitrogen, phosphorus and carbon from the water flowing over a landscape through biological (nutrient absorption by riparian vegetation, microbial assimilation and denitrification for N-based nutrients and microbial respiration for C) and physical–chemical (e.g., nutrient adsorption for phosphorus which binds to clay particles and sediments) processes (Enanga *et al.*, 2011). For example, in undisturbed forested areas, streams are believed to have generally good water quality with low concentrations of dissolved nutrients and suspended sediments (Andrea *et al.*, 2009) because these areas are thought to efficiently cycle water with very minimal losses to the surface and ground water. Surface drainage water, from paddy fields and other agricultural lands, is influenced by numerous factors such as spatial and temporal distribution of rainfall, land topography and soil characteristics (Young Kim *et al.*, 2006).

The nature of riparian zone tends to vary from one watershed to another depending on the type of land use that is practiced in a particular region. Such land uses activities (e.g. agriculture, municipal, peri-urban and industrial) have different influences on nutrient levels of rivers and streams that may be point or spatially diffuse (Ahearn *et al.*, 2005). Therefore, in order to understand the effects of riparian land use on the physicochemical conditions of a river, studies of spatial and temporal changes in water quality are essential (Raburu and Okeyo, 2010).

River Isiukhu drains an area of diverse gradient of land uses ranging from agriculture (mainly sugar-cane farming in the upper course and mixed farming in the lower course), undisturbed forested area within the Kakamega Tropical Forest and peri-urban surroundings within the Kakamega Municipality to become a tributary of River Nzoia which eventually drains into Lake Victoria, Kenya. This study postulated that these various land use practices on a spatial scale, have an effect on the concentration of nitrate-nitrogen and phosphate-phosphorus along the river course.

Similar studies on the impact of riparian land use on the nutrient loads in some Kenyan rivers have been done (e.g. Shivoga, 2001; Shivoga *et al.*, 2005; Shivoga *et al.*, 2007; Kibichi *et al.*, 2007; Kibichi *et al.*, 2008; Kigen *et al.*, 2009; Raburu *et al.*, 2009; Raburu and Okeyo, 2010 and Enanga *et al.*, 2011). However, no previous study has clearly compared the impacts tropical forest remnant, peri-urban, sugar-cane and mixed agricultural land uses (as evident in river Isiukhu watershed) on the nutrient content of rivers, which this study intended to investigate and document.

Nevertheless, despite the evidence of agricultural non-point pollution sources, there exist a little data in regard to the extent to which they participate in the deterioration of water quality. Particularly, the dynamic interactions between nutrients and runoff water have been a worldwide concern for many years because run-offs directly transfer dissolved and fixed forms of total nitrogen and phosphorus into water bodies (Steinheimer *et al.*, 1998). Specific relationships permitting predictions of in-

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stream physicochemical processes of such rivers are still poorly understood, especially during the rainy season.

The objectives of this study were therefore to investigate the impact of spatial variation in riparian land uses of the concentration of nitrate-nitrogen and phosphate-phosphorus during rainy season and their relationship between these two nutrients in River Isiukhu watershed. This study was conducted during the long rainy season when the dynamic interactions between physicochemical conditions and land use gradient could be investigated.

Study area

River Isiukhu watershed lies between 0.40 and 0.17 decimal degrees north of the equator and 34.4 and 35.00 East with altitude ranging from 1291 to 1573 m.a.s.l. in Kakamega County, Kenya (Figure 1). The underlying rock within this region is made up of basalt, phenolites and ancient gneisses of the Kavirondo and Nyanzian systems, which are associated with gold-bearing quartz veins (KWS, 1994). This region enjoys some of the highest rainfall in Kenya (2000 mm per annum) that is well distributed. Most of this rain falls between April and November, with a short dry season from December to March. Temperature does not vary greatly throughout the year, with a mean maximum temperature of 27°C and a mean minimum of 15°C (KWS, 1994). The river is a major tributary of River Nzoia which flows into Lake Victoria.

The river traverses four different major land uses (sugar cane plantation, forested area, peri-urban and mixed agriculture). In the upper course, it drains an area dominated by sugar cane farms and the Kakamega Tropical Rain Forest while middle and lower courses are characterized by peri-urban and mixed agricultural land uses respectively.

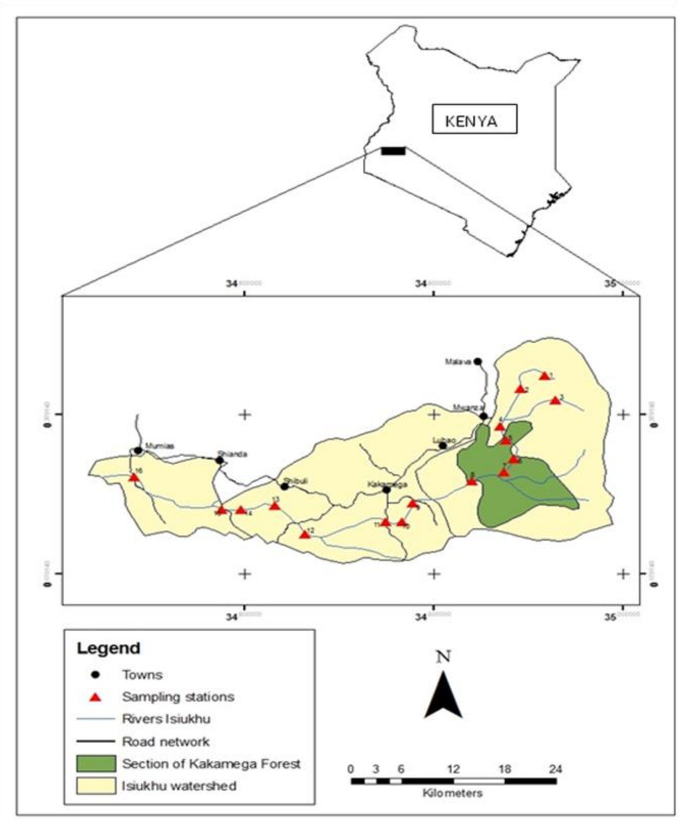


Figure 1: Map of River Isiukhu watershed showing the sampling stations (1 – 16)

Materials and methods

The study used stratified random research design, in which the four land uses formed the strata. Samples were collected in 16 stations (Figure 1). Four sampling stations were randomly selected in each stratum where three replicates were collected weekly seven weeks. A total of 84 water samples were collected for the laboratory analysis of the two nutrients. Phosphate-phosphorus (PO_4^{3-}-P) and Nitrate-nitrogen (NO_3^--N) analysis was done through ascorbic acid and ultraviolet screening spectrophotometric methods respectively as described in APHA (1992). Data was analysed using Statistical Analysis System (SAS), Version 9.1. One way analysis of variance (ANOVA) was used to test for any significant differences between the means and the Difference of the Least Squares (LSD) used to separate the means. Pearson Correlation analyses were performed to determine the relationships between the concentrations of the two nutrients within the watershed.

Results

There were spatial variations in the concentrations of phosphate-phosphorus and nitrate-nitrogen along land use gradient within the watershed. The concentrations of phosphate-phosphorus and nitrate-nitrogen within the river Isiukhu watershed varied spatially with land use (Table 1).

Table 1: Mean (±SD) values of physicochemical variables of water in River Isiukhu during the long rainy season from March to June 2013 (N = number of samples)

			Land use		
Variable	**N**	**Sugar-cane**	**Forest**	**Peri-urban**	**Mixed agriculture**
PO_4^{3-}-P (Mg L^{-1})	84	0.08±0.05	0.07±0.06	0.15±0.1	0.21±0.18
NO_3^--N (Mg L^{-1})	84	2.75±1.67	2.25±1.09	5.01±0.99	5.66±1.88

The highest concentration of PO_4^{3-}-P was 0.21 MgL^{-1} and recorded in the mixed agricultural land use and the lowest concentration 0.07 Mg L^{-1} was within the forest (Table 1). There were significant differences between the means of PO_4^{3-}-P in the forest and sugar-cane land use (t=4.91, p<0.05) and peri-urban and mixed agricultural areas (t=20.33, p<0.05). The concentration of NO_3^--N showed a similar trend to that of PO_4^{3-}-P. The lowest concentration of NO_3^--N was recorded within the Kakamega Forest upstream and increased downstream with the highest concentration being observed in the mixed agricultural area (Table 1).

ANOVA showed a significant impact of land use on the concentration of NO_3^--N within the river watershed (F=1372.25, p<0.05). The concentrations of nitrate-nitrogen in sugar-cane and forest land uses were statistically different (Table 1). Peri-urban and mixed agricultural land uses also had significantly different concentrations of nitrate-nitrogen. Also observed was that within the forest land use, sampling stations recorded varying concentrations of both nitrate-nitrogen and phosphate-phosphorus (Figure 2). The first and second sampling stations, boarding sugar land use, recorded the highest concentration of these two nutrients. However, as the water flows through third and fourth sampling stations, the concentration of these two nutrients declined considerably (Figure 2).

Contrastingly, the concentrations of these nutrients increased downstream along sampling stations within the peri-urban land use (Figure 3). The first sampling station bordering the forest land use recorded the lowest concentration of the two nutrients while the fourth sampling station located towards the mixed agricultural land use recorded the highest concentration (Figure 3).

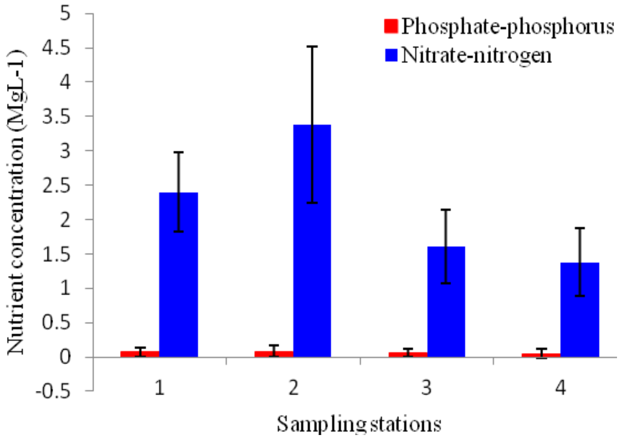


Figure 2: Variation in the concentration of nitrate-nitrogen and phosphate-phosphorus within the forest land use during the long rainy season (March-June 2013).

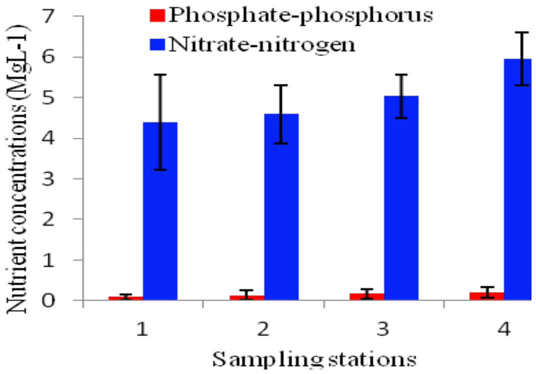
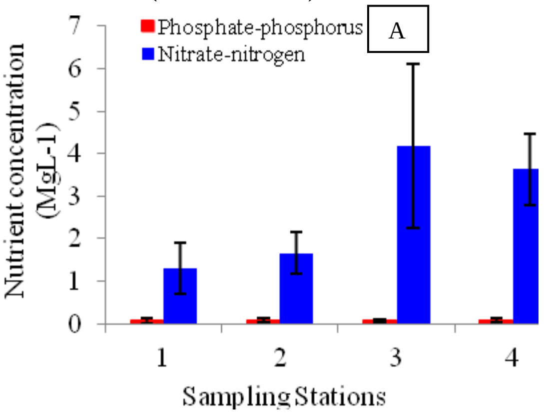


Figure 3: Variation in the concentration of nitrate-nitrogen and phosphate-phosphorus within the peri-urban land use during the long rainy season (March-June 2013).

Within each land use, sugar-cane and mixed agricultural land uses showed similar patterns in the changes in concentrations of nitrate-nitrogen and phosphate-phosphorus. Within these two land uses, nutrient concentrations increased from sampling stations 1 to 3 and significantly decreased at the fourth sampling stations (Figure 4).

Therefore, forest land use recorded the lowest mean concentrations of both NO_3^--N and PO_4^{3-}-P while the mixed agricultural land use showed the highest concentration of these two nutrients. Generally, the concentration of the two nutrients increased downstream with the lowest levels recorded within the sampling stations located in the forest (stations 5-8) as shown in Figure 5. Nutrient concentrations therefore peaked within the peri-urban land use (stations 13-16).



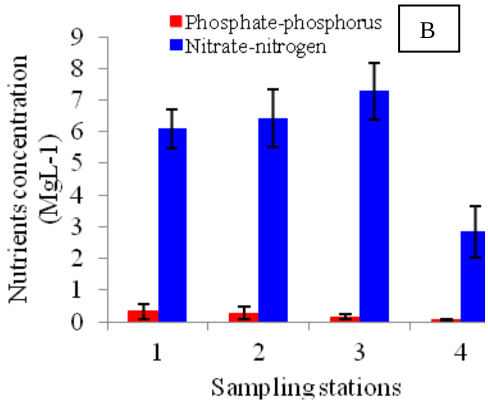


Figure 4: Variation in the concentration of nitrate-nitrogen and phosphate-phosphorus within sugar cane (A) and peri-urban (B) land uses during the long rainy season (March-June 2013).

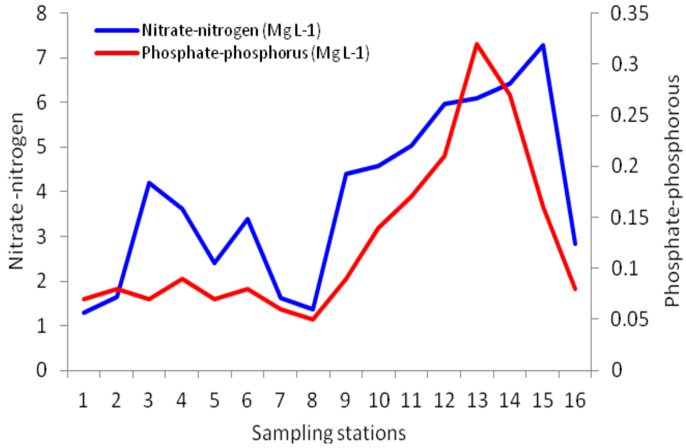


Figure 5: Variation in the concentration of nitrate-nitrogen and phosphate-phosphorus along sampling stations during the long rainy season (March-June 2013).

Discussion

Numerous studies have been done on the relations between riparian land use and water quality. The United States Geological Survey (1992) explained out that land use impacts on both the chemical and physical characteristics of streams. The effects of land use on the concentration of NO_3^--N and PO_4^{3-}-P in river Isiukhu watershed can be explained by the difference in deposition rate of materials from the landscape at different land uses. This agrees with Triest *et al.* (2012) and Raburu and Okeyo (2010) who concluded that nutrient loads have a relationship with land use practices in the River Nyando Watershed. Shineni and O'Reilly (2007) also observed that on the northeast shores of Lake Tanganyika, land use had significant effects on physicochemical conditions of tropical streams while Van Orden and Kaushal (2011) in their study of the impact of urbanization and temperature fluctuations in streams also reported that land use significantly impacts on temperature, inflow chemistry and biotic activity of streams.

The dense riparian vegetations within the forest land use are effective buffers in filtering out most of the nutrients from the surface run-off (Shivoga *et al.*, 2007) resulting into lower concentration of NO_3^--N and PO_4^{3-}-P within the sections of the river traversing forest land use. The decrease in nutrient concentration downstream within the forest sampling stations is as a result of forest water cycling itself with reduction of human disturbance. Andrea *et al.* (2009) reported that in undisturbed forested areas, streams have generally good water quality with low concentrations of dissolved nutrients and suspended sediments.

However, the concentration of these two nutrients were both high within mixed agricultural land use as a result of increased intensity of subsistence agriculture involving the use of both organic and inorganic fertilizers to promote crop yields. Sediments containing these nutrients are washed into the river by storm waters during rainy season. United States Geological Survey (1992) also stated that the most common impact of urban and agricultural land uses in watersheds is the release of nutrient-rich deposits into the water channels through point and non-point sources while Wetzel (2001) observed that phosphorus concentration in unimpacted streams is between 0.01-0.05 MgL^{-1}. Shivoga *et al*. (2007) reported similar trends in River Njoro in which the quantity of phosphorus increased with increase in the proportion of disturbed land cover such as mixed small-scale agriculture and bare land. Loading of phosphorus into tropical streams results from accelerated use of their watersheds for human activities, poor recovery of the nutrient from agricultural applications and detergent use (Shineni and O'Reilly, 2007). They further explained that high nitrate levels in streams in deforested regions is due to lack of vegetation that can absorb the nitrate thereby finding its way into the streams. The decline in the concentrations of the two nutrients at the last sampling station within the peri-urban land use is as a result of dilution of the river waters by River Lusumu. This is because river Lusumu is the largest tributary of river Isiukhu at the lower course and drains a watershed that is less impacted by human activities compared to river Isiukhu.

Within mixed agricultural land use, the riparian vegetation has been destroyed massively leaving little or no buffers to filter out excess nutrients contained in storm waters. This agrees with the findings of Shivoga *et al*. (2007) and Enanga *et al*. (2011) in River Njoro watershed. The increasingly high concentrations of nitrates downstream in River Isiukhu is therefore attributed to high levels of disturbances within the watershed as was reported in Havel *et al*. (1999) and Ahearn *et al*. (2005). Raburu and Okeyo (2010) also observed that within a watershed, nitrate concentrations are likely to be affected by several point and non-point release of agro-chemicals containing nitrates i.e. nitrate-based fertilizers in farms close to rivers. Ormanik (1977), Wetzel (2001) and Kibichi *et al*. (2007) also reported that mean concentration of phosphates and nitrates are higher in regions experiencing agricultural run-offs than regions under indigenous forests.

Conclusion and Recommendations

The research concludes that river Isiukhu nutrient regime is a function of the land use with forest and sugar-cane having low impact while urban and agriculture showing the highest adverse impacts on water quality. The study recommendations are to undertake long-term research that can reflect the changing land use, include more variables in nutrient analysis such as the substrate characteristics and development of integrated watershed management plan.

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