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Modelling of Nonpoint Source Pollution in Akagera Transboundary River in Rwanda

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Abstract: In this paper, we to assess the level of pollution in the Akagera Transboundary River. The followings parameters namely NH_4-N, NO_3-N, PO_4-P, Total Dissolved Solids (TDS), conductivity, pH, Temperature, and Turbidity were identified and quantified. Sampling was conducted a monthly basis from March 2008 to February 2009 at eleven sampling points on the Akagera River system. The landuse and land form characteristics were studied using satellite imagery and ground truthing. From this pollution reduction factors in terms of kg/ha.yr of pollution load were developed for each landuse type and used for developing the model. Rainfall and river flow data were obtained from gauging stations in and around the river. Water quality parameters particularly values of NH_3-N changed from 0 to 2.36 mg/l, NO_3-N from 1.8 mg/l to 314.4 mg/l and PO_4-P from 0.02 mg/l to 19.3 mg/l. Field observations supported with computed export coefficient values showed that bare soils are the most influencing negative factor on water quality in the Akagera River.

Keywords: Akagera river, nutrients, water pollution, water quality modelling, lake Victoria.

1. INTRODUCTION

Environmental issues such as climatic change, ozone depletion, biodiversity, erosion, and deforestation point source and non-point source pollution (NPS) pollutants are problems of global concern. These problems are exacerbated by the basic trends in world population and consumption. World population has doubled since 1950 and is expected to reach 9.4 billion by the middle of this century. The foremost global issue is satisfying the ever-growing need for natural resources to meet food and living standard demands, while minimizing impacts upon an environment that already shows signs of serious levels of degradation [1]. Barring unexpected technological breakthroughs, sustainable Agriculture is viewed as the most viable means of meeting demands of the projected world's population. The concept of sustainable Agriculture is predicated on a delicate balance of maximizing crop productivity and maintaining economic stability while minimizing the utilization of finite natural resources and the detrimental environmental impacts of associated NPS pollutants.

Without question, Agriculture and poor land-use are currently acknowledged as the biggest contributors of NPS pollutants to water resources. The most common NPS pollutants include eroded sediments, fertilizers, pesticides, organic manures, trace elements and sewage sludge. This presents a dilemma because on one hand, there is the growing pressure of meeting the food demands of a constantly growing world population, but in so doing, the likelihood of detrimentally impacting the environment with NPS pollutants seems inevitable. The ability to assess and understand the fate of NPS pollutants in water bodies is a key concern in maintaining the delicate balance between crop productivity and the detrimental environmental impacts of NPS pollutants, which is the cornerstone of sustainable Agriculture. There is strong and ever-growing awareness of NPS pollution, most of this concern has historically been focused on the contamination of surface water resources. The significance of the NPS-pollution lies in the ramifications to human health. The acute health effects attributed to the consumption of high dosages of contaminants have been well known, but now chronic health effects from low dosages of NPS pollutants are becoming more apparent as their effects surface (International Joint Commission, 1993). Numerous researchers e.g., [2-10] over the past decades have sought to study NPS pollution. Globally, 30 to 50 % of the earth surface is believed to be affected by NPS pollutants [5]. As noted by researchers, such as [10], Lake Victoria has undergone substantial and very negative changes, especially over the last 30 years. One of the driving factors is nutrient enrichment of the Lake from human activities in the catchment, which is causing eutro-

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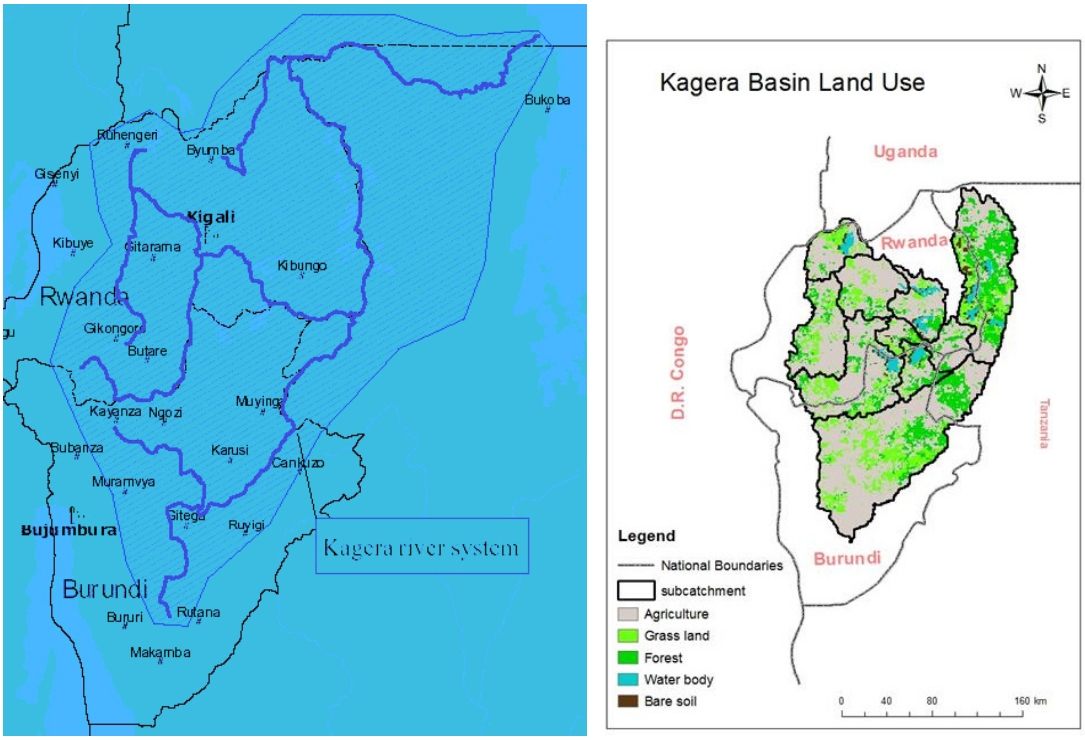

Fig. (1). Akagera River basin (**a**) location, and (**b**) land-use.

phication. This has been associated with, among others, the rapid proliferation of water hyacinth, alga blooms, and with general disruption of the lake ecosystem [11]. Nutrients input in Lake Victoria appear to originate mainly from atmospheric deposition and land runoff through its tributary rivers [12].

The complexity of assessing NPS pollution in the Lake Victoria basin necessitates a measurement of this kind of pollution in the context of individual tributary that feed into the lake. The Akagera River is the main tributary of Lake Victoria. The River has a total length of 785 km. Its average flow is estimated at 261 m^3/s at the point where it enters Lake Victoria and it contributes about 33.5% of the total inflow of Lake Victoria [9]. In comparison, with other tributaries inflows; contribute approximately 778.3m^3/sec corresponding to 66.5%. Despite the importance of the Akagera River to the Lake Victoria basin, there appears to be no comprehensive studies on its contribution and/or NPs pollutants loads and dispersion into Lake Victoria. It is critical that this knowledge gap be filled in order to ably predict the impacts such pollutant on water quality, aquatic life and livelihoods in the lake basin. Therefore, the main objective of this research is to assess the level NPS pollution in the Akagera Transboundary River. In a further step, an export coefficient model is proposed in this research so as to give an insight into the processes related to non-point source pollution on the River in the short and long term periods. Export coefficients represent the quantity of nutrients generated per unit area per unit time (kg/ha/yr). Use of export coefficients is based on the assumption that a given land use activity (e.g., agricultural, urban, or forest) will yield a specific quantity of nutrients to a downstream water body [13, 14]. The used export coefficient to determine the contribution of nonpoint source nutrient to the rivers is an important watershed management tool. The outputs of these type models gives a clear nature and trend for the contribution of each land use activity in a given watershed and are valuable information that policy makers could use in planning strategies for watershed management to improve and control surface water quality.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The Akagera River is the largest of the 23 rivers that drain into Lake Victoria and it is the most remote head stream of the Nile River [15]. The River is formed by the confluence of two rivers: Nyabarongo and Akanyaru Rivers. The Akagera River crosses the Eastern part of Rwanda before forming the border between Rwanda and Tanzania. Further downstream, it forms the border between Uganda and Tanzania before flowing into Lake Victoria as shown in Fig. (**1**). The Akagera River Basin has an area of about 57,364 km^2 and is distributed between different countries notably Burundi, Rwanda, Uganda and Tanzania as shown in Table **1**, and is estimated to have a population of 14 million people [16].

The Akagera River contributes about 33.5% of the annual inflows into the lake, over twice as much as the next largest river, the Nzoia in Kenya [17]. The River is very important in terms of hydrological regime within Rwanda. The Akagera Basin covers 67% of the total surface area of Rwanda which is equivalent to 20,977 km^2, it has a surface area of about 5 km^2, with an average river depth of about 6 m. The land-use of the basin is predominantly agriculture, grassland and forest as shown in Fig. (**1b**). The altitude in the Akagera Basin varies from 1,200 m to 1,600m above sea mean level in the east and rises above 2,500 m in the west with peaks reaching 4,500m in the north. The area generally has four seasons: a short dry season from January to February; a rainy

Table 1. Summary of Selected Sampling Stations and Rationale for their Selection

Sampling Station	Latitude	Longitude	Description and Rationale
Nyabarongo Bridge	1.96^{0} S	30.00^{0} E	Located at the bridge along Kigali–Butare Road. This is expected to capture pollution from the City of Kigali and the area upstream part of Nyabarongo River. Acted as a control site.
Nyabugogo	2.07^{0} S	30.02^{0} E	Located on Nyabarongo River just before it meet with Akanyaru River it is intended to capture pollution change in cultivated plains between it and Site 1.
Akanyaru	2.08^{0} S	30.02^{0} E	Located on Akanyeru River just before it meet with Nyabarango River. This site is expected to give an indication of pollution in Akanyaru catchment.
Akagera	2.07^{0} S	30.02^{0} E	Located about 200 m away from the confluence of Nyabarongo and Akagera Rivers. It is expected that at this point the water from the two rivers has completely mixed up and the parameters mesured here could be consisidered as average of the mixure of the two rivers.
Akagera- Kanzenze	2.05^{0} S	30.09^{0} E	Located under the main bridge along Kigali Nyamata Road to give an indication of pollution change due to the an agricultural plain between that point and site no. 5.
Akagera- Gashora	2.20^{0} S	30.28^{0} E	Located in the Bugesera District at a highly intensive agricultural activities point with the intention to find out how agriculture influences the water quality at that poin.
Akagera- Rusumo	2.38^{0} S	30.78^{0} E	Located just before Rusumo Falls and the border of Rwanda and Tanzania. Here a small village around the River discharges its sewage directly in the Akagera River without pretreatment
Akagera- Mahama	2.31^{0} S	30.85^{0} E	This site is located at the entrance of Akagera National Park after complete mixing of pollutants from Rusumo village and high aeration from Rusumo Falls.
Akagera- Kabanyana	1.16^{0} S	30.49^{0} E	This site is after the Akagera National Park, Rwanda to capture the effects of the wetland and plat land of Akagera Park.
Akagera- Kanyonza	1.05^{0} S	30.45^{0} E	Located at the Rwanda-Tazanian boarder just before the river enters Uganda. This site gives an indication of the level of pollution of the River when it leaves Rwanda without taking into consideration the pollution contribution of Muvumba River.
Muvumba	1.05^{0} S	30.47^{0} E	This point on Muvumba River the last tributary of of Akagera River in Rwanda. It captures an ditional pollution contribution to Akagera River from Rwanda after site no. 10.

season from March to May; a long dry season from June to September; and another rainy period from October to December. Annual rainfall varies from less than 600 mm over the eastern part of the basin up to 1,800 mm and above in the west, where most of the runoff is generated. Steep slopes and heavy rainfall result in erosion and high river sediment loads [18]. However, the river flows are attenuated by a number of lakes, and in particular by floodplains and associated lakes above and below the Rusumo Falls. The peak flow occurs in April in the upper tributaries, in May at Kigali and Rusumo Falls. The terrain is mountainous, declining eastward toward the Tanzanian border [19]. The central part of the basin in Rwanda is covered by rounded hills and large valleys with an altitude between 1,500 and 2,000 m. In the east, the hills give way to a large region with numerous lakes and marshes.

Selection of Sampling Sites

Eleven water quality monitoring stations Fig. (**2**) located along the Akagera River as summarized in Table **1** were selected. Sites were selected to cater for variation in land-uses and land-use patterns. The downstream stations were carefully selected to encompass additional landuse features such as Akagera National Park, grazing and other small agricultural practices. Stations 2 through 6 were characterized by intensive agricultural activities very close to the river whereas stations 1, 7 through 10 are surrounded by a big floodplain which may play an important role of riparian buffer and sediment stripping.

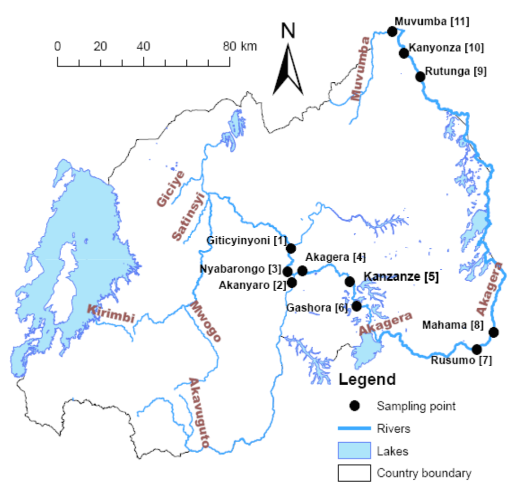

Fig. (2). Location of the sampling points.

Table 2. ANOVA Summary Guide

Source of Variation	Sum of the Squares	Degrees of Freedom	Means Squares	F
Between	SS_B	$d.f._N$	$MS_B = \frac{SS_B}{d.f._N}$	$F = \frac{MS_B}{MS_W}$
Within	SS_W	$d.f._D$	$MS_W = \frac{SS_W}{d.f._D}$	

Table 3. Summary of Land Use with Area and Export Coefficient for Diffirent Nutrients

Initial Land Use	Grouped Land Use	Export Coefficient kg, km^{-1} per year		
		Nitrates	Ammonia	Phosphates
Dry cropland and pasture	Agriculture	285	5	9
Cropland and woodland mosaic				
Grassland	Grassland	90	1	2
Shrubland				
Savanna				
Deciduous bread leaf forest	Forest	23.6	2	1.5
Evergreen				
Barren or sparsely vegetated	Barren land	14	1	1
Water bodies	Water bodies	54	1	1

2.3. Sample Collection and Analysis

The study was conducted during a period of eleven month from February to December 2008. Samples were collected on monthly basis using grab methods and store in 500 ml plastic bottles that has been rinsed first with HCl to avoid contamination and pollutants adsorption and then with distilled water [20]. Before storing the sample, the bottles were rinsed three times with the sample water. Samples were taken from the free flowing section of the stream at each station approximately at the middle of a river and at depth of about 20 cm below the surface. Testes were carried out in the field in the case of temperature, pH, conductivity, turbidity and total dissolved solids. While nitrate, ammonia and phosphates were measured in the laboratory, the samples for their test were transported to the laboratory in a cooler box with ice. All tests were conducted using HACH Calorimeter in accordance to [21]. Where the test was not carried out immediately on reaching the laboratory the samples are preserved in a freezer at a temperature of about 0^oC before the analysis.

As mention earlier eleven sampling points was monitored for twelve months the collected data were then arranged in tables of eleven columns (sampling sites) and twelve rows (sampling months). To test the variability of the collected data the one-way-ANOVA (F-test) was found appropriate, as this give opportunity for testing the variability at one sampling point for the whole period and within the different sampling points. The followed procedure is as details in [22] and the approach for presentation of the result statistics are summaries in Table **2**.

2.4. Land-use Data and Analysis

The land use and catchment boundary digitized data for the study was obtained from GeoSFM for Africa [23]. The catchment boundary of the study area was used to extracted land use from the GeoSFM land use map of Africa. The extracted land use for the study area comprises of nine different land uses which were then regroup into five closely related land uses for convenience Fig. (**1b**) and Table **3** using the classification tools of ArcMap in ArcGIS environment and the export coefficient of each land use class for the export of nitrate, ammonia and phosphate were adopted from [24].

$$L = \sum_{i=1}^{i=n} C_i \frac{A_i}{1000}, ...1$$

where L is the nutrient load in kg per annum and C is the export coefficient for the given land use in kg per hectare per annum, A is the in square kilometer and 1000 is the coefficient for conversion of hectares to kilometer square.

3. RESULTS AND DISCUSSION

3.1. Pollution levels along the Akagera River

Table **4** present the summary results of statistical test one-way-ANOVA conducted for the five measured parameters vis: temperature, pH, nitrates, ammonia and phosphates at the 0.5% (α=0.005) level of significance. The results statistic indicate that there is significant variation in the measured values of temperature of pH between the tested samples from different sampling points and within the samples from the same point measured in different months. Though the pH

Table 4. ANOVA Summary for Temperature, pH, Nitrates, Ammonia and Phosphates

	Statistics	Temperature	pH	Nitrate	Ammonia	Phosphates
Sum of squares	SS_B	53.6	5.39	16959.5	2.14	47.0
	SS_W	114.6	8.55	457280.4	23.16	44074.4
Degrees of freedom	$d.f._N$	10	10	10	10	10
	$d.f._D$	62	58	93	96	93
Mean squares	MS_B	5.36	0.539	1696	0.214	4.7
	MS_W	2.01	0.14	4970.4	0.244	479.1
F- value	F	**2.66**	**3.85**	0.341	0.87	0.0098
	F_O	1.99	2.04	1.95	1.95	1.95

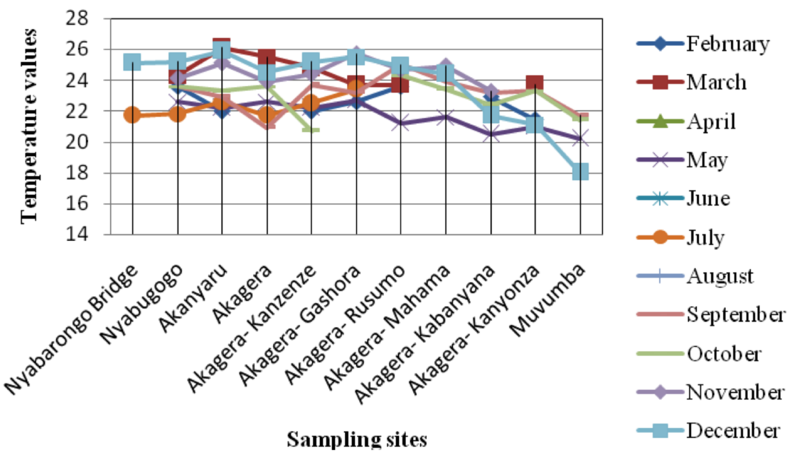

Fig. (3). Temperature values at different sampling points and months.

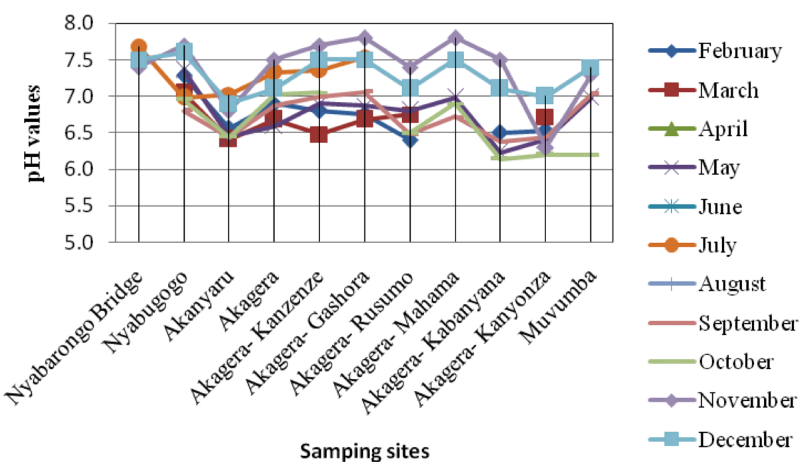

Fig. (4). pH values at different sampling points and months.

varies as suggested by the statistical test it is important to note that the ranges are still with the fresh water designated uses and criteria [25]. The However, for the nutrients, Nitrate, Ammonia and Phosphates it is suggested that there is no sufficient evidence to conclude that there is a difference in the concentration of the parameters at the same sampling points in different months and at different sampling points.

To give an indication of values and concentration of parameters at each sampling point and in different months Fig. (**3**) – Fig. (**7**) are presented. The concentration of Nitrates and Phosphates for all the sites and for all the period of the study exceeded the USGS background nutrient water quality in stream and shallow ground water which are 0.6 and 0.02 mg/L respectably [26].

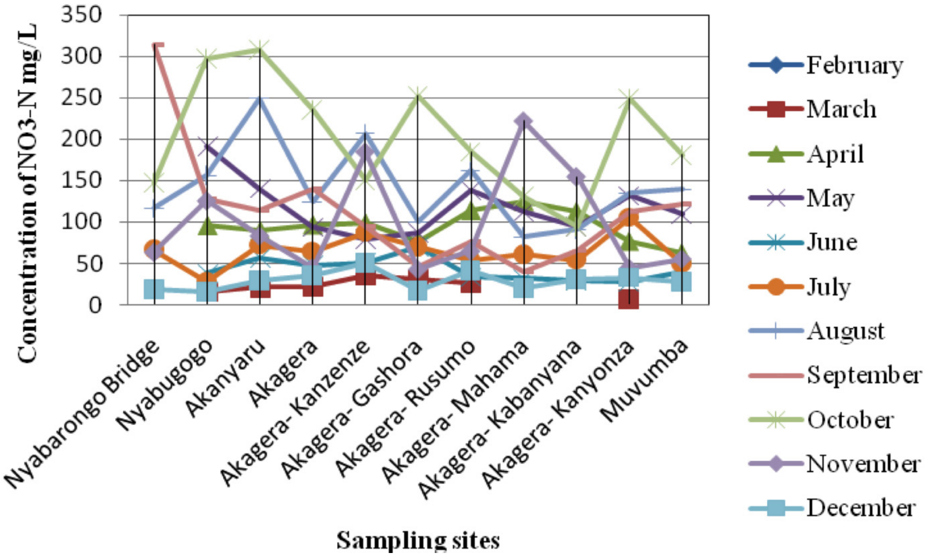

Fig. (5). Concentration of Nitrates at different sampling points and months.

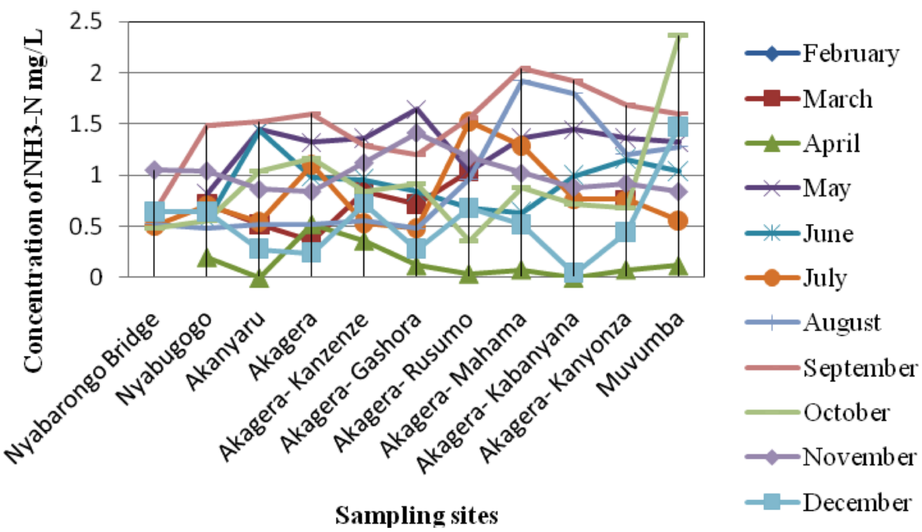

Fig. (6). Concentration of Ammonia at different sampling points and months.

Excessive nutrients (nitrogen and phosphorus) can cause negative ecological impacts to waterbodies by stimulating harmful algal blooms. Algal blooms block sunlight and result in the destruction of submerged aquatic vegetation (SAV). SAV serves as critically important habitat and food for many organisms. Algal blooms eventually die off and consume dissolved oxygen (DO) from the water column. Low DO concentrations lead to die off of aquatic organisms. One result of algal blooms is decreased biological diversity and populations, including smaller populations of game and commercial fish. Excessive nutrients also pose public health risks. Algal blooms can cause taste and odor problems in drinking water. Hazardous algal blooms can cause respiratory distress and neurological problems in swimmers. Excessive nitrates can cause blue baby syndrome [27]. It is therefore recommended that watershed management strategy be developed and implemented for the improvement and control of water quality in the Akagera catchment.

3.2. Pollutants Export

The annual nutrient export into the surface water in the study area for Nitrate, Ammonia and Phosphate are presented in Table **5** in kilogram per square kilometre per year and in percentage for the catchment. Runoff from land cultivation, forestry operations and pasture preparations is often associated with increased phosphate exports, with phosphorus adsorption to soil supplying phosphorus through erosion processes.

The relatively high nitrates and ammonia (NO_3-N and NH_3-N) catchment exports may be associated with catchment based nitrification processes. As nitrogen enters the soils bacteria convert it to gaseous nitrogen that rises out of the soil and into the atmosphere (i.e. reducing TN exports). Another factor that is just as important as nutrient loads is the composition, and reactivity (digestibility), of the organic matter source, that can contain a substantial proportion of the nitrogen and phosphorus exported to the receiving waters.

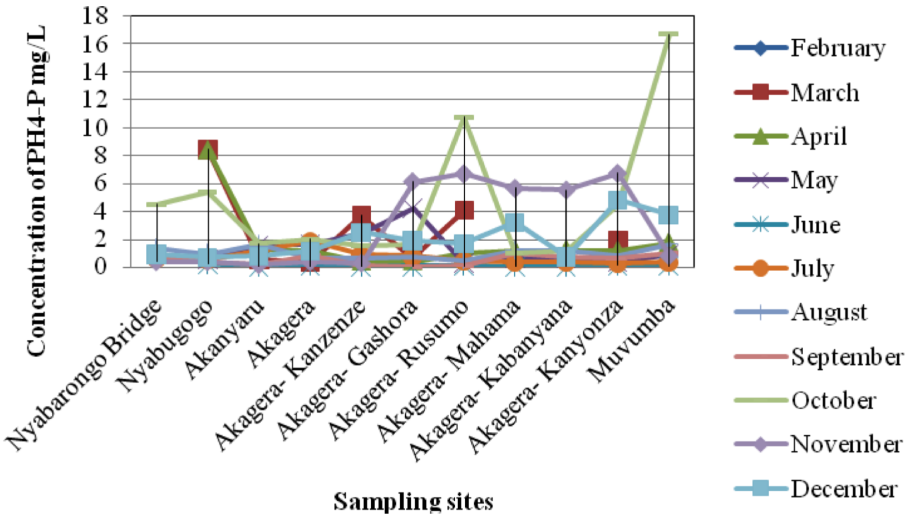

Fig. (7). Concentration of Phosphates at different sampling points and months.

Table 5. Nutrients export for Nitrates, Ammonia and Phosphates in kg/km^2/Year and in Percentage for the Catchment

Land Use	Area		Nitrates		Ammonia		Phosphates	
	Square km	%	kg sq_km^{-1} /year	%	kg sq_km^{-1} /year	%	kg sq_km^{-1} /year	%
Agriculture	22823.2	63.1	6504615	89.9	114116	85.5	205409	90.2
Grassland	5872.5	16.2	528524	7.3	5872	4.4	11745	5.2
Forest	6005.8	16.6	141738	2.0	12012	9.0	9009	4.0
Barren land	480.7	1.3	6729	0.1	481	0.4	481	0.2
Water bodies	1011.1	2.8	54599	0.8	1011	0.8	1011	0.4
Total	36193.3	100	7236206	100	133492	100	227654	100

When land use is changed from native vegetation to grassland, the organic matter entering the streams is very different. Grassy organic matter is much more digestible and requires more oxygen as part of the digestion process. This can lead to dissolved oxygen depletion in receiving waters which can lead to major water quality problems which is the high risk threatening the Akagera River. It could be suggested that the influence of land use on River integrity is scale dependent. In-stream habitat structure and organic matter inputs are determined primarily by local conditions such as vegetative cover at a site, whereas nutrient supply and sediment delivery are influenced by regional conditions, including landscape features and land use at some distance upstream and lateral to stream sites.

4. CONCLUSIONS

The result of this study shows that the Akagera River is very highly polluted with nutrient viz: nitrate, ammonia and phosphate beyond the recommended level for aquatic life development in fresh water. The nutrient concentration along the River does not vary for all the sampling sites and for the whole study period. The value of temperature and pH both with site and sampling period, but all are within the recommended value the fresh water designated uses and criteria. As could be expected agriculture is the main source of non-point source pollution in the catchment with about 89.9%, 85.5% and 90.2% for nitrates, ammonia and phosphates respectably.

Based on the findings of this study, the following recommend are suggested: (1) Prepare and execute watershed management strategies for water quality remediation and control. This could be implemented in are regional coordinated efforts. (2) Ensure that municipal wastewater are treatment to the accepted standard level it before disposal into the Akagera River. (3) Further research shall be focus on determination nutrient load and their ascertaining their fate in the Akagera River.

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NOMENCLATURE

%	=	Percentage
^{0}C	=	Degree Centigrade

A_i = Area, km^2

C_i = Export coefficient of the i^{th} land use, kg/ha/year

$d.f._D$ = Degree of freedom for number of groups

$d.f._N$ = Degree of freedom for the total samples

F- value = Calculated F-test value

F_O = Critical F-test value, determine from the table

ha = Hectares

kg = Kilogram

kg/ha/yr = Kilogram per hectare per year

km^2 = Square kilometres

L = Pollutant load, kg/km^2/year

m^3/s = Cubic meters per second

mg/l = Milligram per litre

MS_B = Mean squares between groups

MS_w = Mean squares within groups

NH_4-N = Ammonia -nitrogen

NO_3-N = Nitrate -nitrogen

PO_4-P = Phosphate

SS_B = Sum of the squares between groups

SS_W = Sum of the squares within groups

Greek

α = Level of significance

Subscripts

B = Between

D = Number of groups

i-n = Range of variables

N = Number of total samples

0 = Angle in Degrees

W = Within

Acronyms

ANOVA = Analysis of variance

DO = Dissolved oxygen

E = East of Greenwich meridian

HACH = HACH Company

S = South of the equator

NPS = Non-point source pollution

NUFFIC = Netherlands Universities Foundation for International Cooperation

pH = potential of Hydrogen

SAV = submerged aquatic vegetation

SIDA/SAREC= Swedish International Development Cooperation Agency/ Department of the Swedish International Development Cooperation Agency

TDS = Total Dissolved Solids

USGS = United State Geological Survey

UNESCO-IHE= United Nations Educational, Scientific and Cultural Organization – Institute of Water Education

VICRES = Lake Victoria Research Initiative

WREM = Water Resources and Environmental Management

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