Bottom Sediment Chemistry, Nutrient Balance, and Water Birds in Small High Altitude Tropical Reservoirs in the Rift Valley, Kenya

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Abstract: Water bird characteristics, nutrient loadings, and the levels of bottom sediment silicon oxide (SiO_2), aluminium oxide (Al_2O_3), ferric oxide (Fe_2O_3), calcium oxide (CaO), copper (Cu), phosphorus (P) and organic carbon (C) was studied in eight high altitude (2040-2640m) small shallow (0.065-0.249 km^2; 0.9-3.1 m) reservoirs in the central rift valley of Kenya. The general aim was to assess the nature of the bottom sediments in relation to nutrient balance in the water bodies and their birdlife from a geographic perspective of spatial comparative analysis. The findings showed positive correlation between the levels of SiO_2, CaO and P with the levels of total-N and total-P. In addition, there was an inverse correlation between C, Al_2O_3, Cu andFe_2O_3 in the bottom sediment and two nutrients. A total of six water bird counts across the eight sites recorded 49 species for all the reservoirs and an overall average of 60 individuals per reservoir. The counts of nine water bird species were established to increase significantly with increase in the levels of total-N and total-P. The results indicated a correlation with the levels of SiO_2, C, P, Fe_2O_3, and CaO in the bottom sediment for 12 water bird species, namely, African Fish Eagle, African Jacana, Black-headed Heron, Brack Crake, Common Teal, Great Egret, Great White Pelican, Grey Crowned Crane, Knob-billed Duck, Purple Gallinule, Ringed Plover, and Yellow-billed. The most sensitive species were the African Fish Eagle, Brack Crake, Common Teal, Great White Pelican, and Purple Gallinule. The actual impact of sediment chemistry on the utilization of reservoirs by water birds was not established and should, therefore, be an important subject for further investigation.

Keywords: Bottom Sediments; Total-N; Total-P; Tropical Reservoir; Waterbirds

1. Introduction

According to the International Commission on Large Dams (ICOLD, 1998), over 300 new dams were constructed in the world each year between the 1950s and 1980s. Although this number dropped to about 250 dams a year in the 1990s, the rate continued increasing particularly in developing countries. By the late nineties, the total area occupied by reservoirs worldwide was about 384 000 km^2 or roughly the size of Zimbabwe (Tundisi, 1993; WWF, 1999). Apart from the large reservoirs, there are an estimated 800000 small reservoirs worldwide (WWF, 1999). The construction of man-made reservoirs results in the establishment of artificial wetlands around the world. Presently, some of the world's most important wetlands including some Ramsar and World Heritage Sites are associated with the construction of dams and reservoirs. The rapid colonization of reservoirs by wetland birdlife provides good opportunities for recreation and ecotourism in an increasingly congested world. In the USA, constructed wetlands are managed to benefit waterfowl by mimicking the state of natural wetlands (Duffy &LaBar, 1994).

Water quality in reservoirs is an important aspect which determines the ecological character and spatio-temporal dynamics of aquatic life in water bodies including birdlife. The bottom sediments are known to have a significant influence on the state of water quality in reservoirs because they constitute an important internal storage for incoming materials and can provide an environmental chronological snapshot of what has been happening in a reservoir and its catchment. Large amounts of nutrients in lakes and reservoirs can be accumulated in the bottom sediments due to natural binding as explained by Keller *et al.* (1998). Widespread transfer of phosphorus to bottom sediments is, for example known to occur in water bodies through deposition of organic debris and particulate matter (Grobbelaar & House, 1995). In a study of the nitrogen cycle in a Brazilian floodplain lake, Howard-Williams *et al.* (1989) established that the bulk of the nitrogen storage for the lake existed in the sediments (87%) and only about 3% was in the water column. Nutrients in the bottom sediments can recirculate back into the water column depending on the prevailing environmental condition especially wind and the level of dissolved oxygen. In this way, bottom sediments can contribute to occasional internal loading of nutrients through fluxes at the sediment-water interface thereby affecting nutrient budgets, trophic systems and the entire ecology including birdlife. Melack (1995) identified and summarized the key environmental drivers of nutrient release from the bottom sediments to the water column in water bodies as water pH, temperature and dissolved oxygen.

Some previous studies have attempted to investigate the connection between bottom sediment and nutrient balance in aquatic environments. However, the majority of these have been undertaken in the temperate water bodies (e.g. Søndergaard *et al.*, 2003; Small *et al.*, 2013). A few studies have been done in Asia such as the study on Bukit Merah Reservoir in Malaysia by Ismail and Najib (2011) and the one on Jagadishpur Reservoir in

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Nepal by Gautam & Bhattarai (2008). These kinds of studies are quite rare in Africa with the study on the freshwater reservoirs in Mauritania as an exception (Segersten, 2010). Similarly, there has been very limited work on the linkages between reservoir bottom sediments, nutrient balance and birdlife which makes this a major gap in aquatic research both in Africa and beyond. Yet most water bodies in the region are currently experiencing accelerated sedimentation as a result of widespread environmental transformations in the catchments. A few studies such as Gwiazda *et al.* (2010) have attempted to investigate this linkage from a top-to-bottom perspective by considering the impact of waterbirds on water quality and nutrient balance through *bird* fecal *droppings*. There has been very limited effort to consider the bottom-up impacts by considering the indirect influence of bottom sediments on balance and birdlife.

The link between bottom sediments, nutrient balance and biodiversity is therefore an important subject for understanding reservoir ecosystem dynamics. The general aim of this study was to assess the nature of the bottom sediments in relation to nutrient balance in the small high altitude tropical reservoirs in Kenya and their birdlife. The key research question was whether there were statistically significant relationship between reservoir bottom sediment chemistry, nutrient levels and bird characteristics. Given that these are young water bodies (< 100 yrs) it is interesting to know whether sedimentation which commences immediately after dam construction can be used to predict the expected nutrient balance and birdlife characteristics of new reservoirs. The findings were expected to indicate whether there is need to pursue this line of focus in future research.

2. Materials and Methods

The eight reservoirs selected for investigation in the study are located at the distance of 100-200 km northwest of the city of Nairobi in the rift valley escarpment zones of Nyandarua County (3,500 km^2) and Nakuru County (7,200 km^2). Figures 1 & 2 shows the location of the study sites and Table 1 gives their general characteristics. All the reservoirs are located within the watersheds of three Ramsar Sites in the rift valley, namely Lake Naivasha (3,400 km^2), Lake Elementaita (600 km^2) and Lake Nakuru (1,800 km^2). The reservoirs are located within two key physiographic zones, namely, the flat rift plateaus (Muruaki, Kahuru, Murungaru and Kanguo) and the rift escarpments (Gathanje, Kiongo, Rutara and Gathambara).

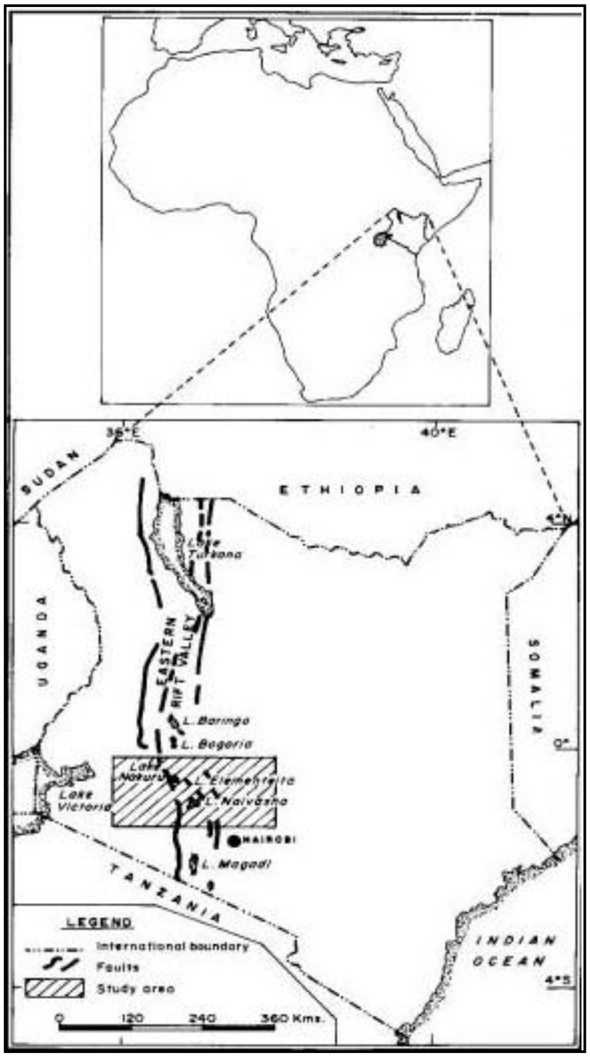


Figure 1. Map of the the study reservoirs.

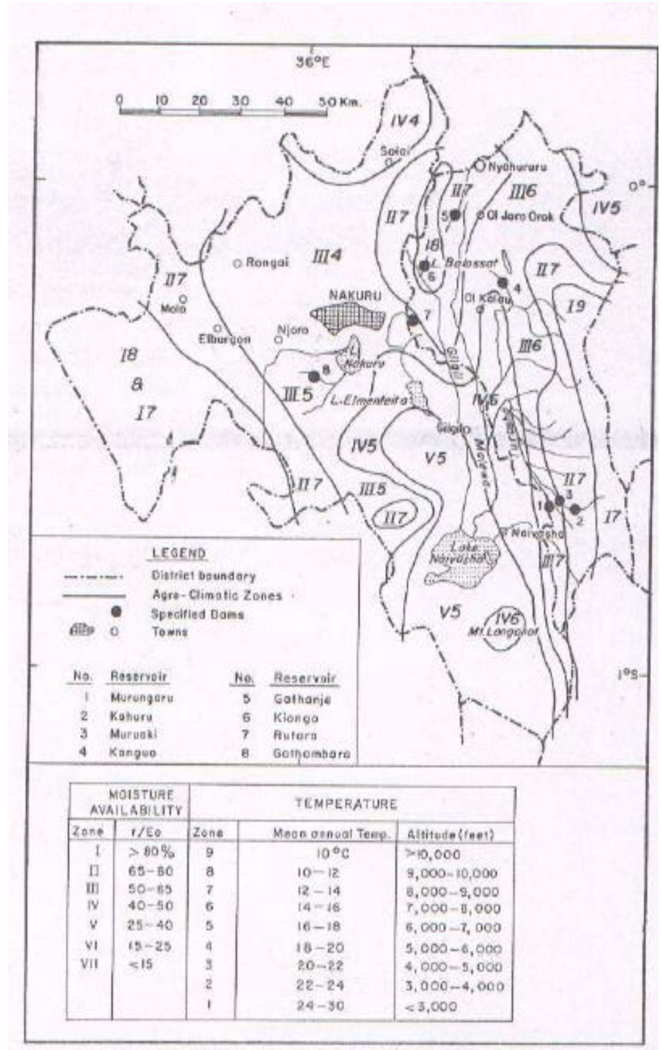


Figure 2. Map of the study area.

Table 1. The geographic and morphometric characteristics of the study reservoirs.

Reservoir	Location	Altitude (m)	Age (yrs)	Catchment area (km^2)	Estimated volume (10^3 m^3)	Water depth (Z_{max}, m)
Muruaki	0°38'S,36°33'E	2440	45	29.1	230	3.5
Kahuru	0°37'S,36°32'E	2420	46	31.4	240	4.5
Murungaru	0°36'S,36°30'E	2360	48	57.3	280	3.8
Kanguo	0°12'S,36°25'E	2340	45	14.1	240	2.2
Gathanje	0°03'S,36°19'E	2460	45	22.4	400	6.0
Kiongo	0°10'S,36°15'E	2640	48	0.05	580	3.3
Rutara	0°17'S,36°15'E	2400	46	1.50	230	3.6
Gathambara	0°27'S;36°02'E	2040	40	50.0	50	1.5

The plateaus reservoirs were characterized by pyroclastic rocks and soils dominated mainly by an assortment of clays especially humicplanosols, vertisols, andosols and phaeozems. The escarpment reservoirs were characterized by volcanic rocks with largely soft volcanic ashes and tuffs and loamy soils dominated by lithic leptosols with nitosols and luvisols. All the reservoirs were constructed in the 1940s by colonial European farmers in the former White Highlands as sources of year-round water supply. After independence in 1963 they became shared communal assets. The plateau reservoirs were mostly situated in open moorland environments consisting mainly of *Pennisetum-Eleusine* grasslands while the escarpment reservoirs were associated with natural forest and woodland zones. The littoral habitats of most of the eight reservoirs had a wide range of emergent macrophytes such as *Kyllingaodorata* and *Cyperus immensus*. Some of the reservoirs like Kiongo, Kanguo and Kahuru were characterized by a substantial cover of submersed plants such as *Ceratophyllum demersum* (Planch*), Potamogeton richardii* and *Crassulagrainkii.* Both Gathanje and Gathambara had distinct stands of *Cyperus immensus* and *Jussiae repens* at the river mouth. The land use around all the reservoirs was small scale agriculture while Kiongo reservoir was located near the OlJororok town (Figure 2).

A total of twenty-one sampling sites with at least two in each of the eight reservoirs were considered and field measurements undertaken at different seasons between 1998 and 2001. Water depth was estimated by sending a weighted line to the bottom of every reservoir. Bottom sediment samples were collected thrice in 2001 in the months of March, June, October and December using an Ekman Grab. The samples were dried at 105°C and ground in a ball mill after which approximately 1g of sediment was shaken with 40 cubic centimetres of 0.5 M hydrochloric acid for 16 hours and the solution centrifuged and the supernatant filtered through 0.45 μm membranes. Sediment analysis was then conducted at the University of Nairobi using an atomic absorption spectrophotometre (AAS) to establish the levels of silicon oxide (SiO_2), aluminum oxide (Al_2O_3), ferric oxide (Fe_2O_3), calcium oxide (CaO), copper (Cu), phosphorus (P) and organic carbon (C).

Nutrient analysis for both nitrogen and phosphorus was determined from 500 cubic centimetres of integrated surface to bottom samples which were collected using a MacVuti water sampler (Litterick & Mavuti, 1985). The samples were collected in March (dry season), June (wet season) and December (intermediate season). Phosphorus as total-P was determined using the molybdenum blue-ascorbic acid technique after digestion of 25 or 50 cubic centimetres samples with 30% hydrogen peroxide and readings made from a Bausch and Lomb spectronic 88 spectrophotometer (Mackereth *et al*., 1989). Nitrogen as total-N was determined using the Kjeldahl method after digestion of 25 cubic centimetres duplicate samples with 30% hydrogen peroxide (Kalff, 1983).

Seasonal observations of reservoir water birds were undertaken in 6 censuses usually between 10 am and 5pm through both point and transect counts using an inflatable rubber dinghy (Zodiac) according to Rumble and Flake (1982). Between 3-5 point counts lasting 15 minutes were undertaken in the inflow, middle and outflow zones of the reservoirs along a designated transect. At each point, the types and numbers of birds both in the open water and the riparian environment were recorded at different times using the sight and call method. Only positively identified birds were recorded and flying birds were not recorded unless they landed near the reservoir, or took flight from the reservoir. Species identification was done according to Williams and Arlott (1980). Data analysis for the study included computation of summary statistics, correlation and regression analysis.

3. Results

The results of reservoir bottom sediment analysis are shown in Table 2. They showed that the sediments were quite rich in both SiO_2 and organic C, moderately rich in Al_2O_3, Cu and Fe_2O_3, and quite poor in CaO. The plateau reservoirs especially those in Kinangop contained more sediment SiO_2 and less sediment C, Al_2O_3 and Fe_2O_3 when compared with the escarpment reservoirs. The highest content of organic carbon was found in the bottom sediments of Gathanje Reservoir (Table 2).

Table 2. The quality of reservoir bottom sediments.

Variable	R1	R2	R3	R4	R5	R6	R7	R8
Altitude (m)	2440	2420	2360	2340	2460	2640	2400	2040
Depth (Z_{max}m)	2.3	2.6	2.3	2.0	3.3	2.3	3.1	0.9
SiO_2 (%)	65.3	61.7	61.7	52.7	34.7	63.5	52.5	55.5
C (%)	10.82	14.22	14.18	16.9	36.03	26.09	22.16	17.23
Al_2O_3 (%)	13.3	13.7	13.3	16.5	18.3	16.9	14.6	14.5
Cu (ppm)	7.0	8.0	7.0	9.6	10.4	7.5	8.0	5.3
Fe_2O_3 (%)	4.6	5.4	5.0	7.3	7.4	7.6	7.9	7.8
CaO (%)	0.43	0.48	0.54	0.56	0.43	0.41	0.40	0.85
P (%)	0.8	0.2	0.13	0.29	0.22	0.42	0.20	0.19

Key: R18 for Muruaki, Kahuru, Murungaru, Kanguo, Gathanje, Kiongo, Rutara and Gathambara.

Figure 3 shows the total-N levels in the reservoirs with the nutrient loadings for the eight reservoirs in the three monthly measurements shown in different shades in the legend. The range of mean total-N concentration was 220-16 800 μg/l with an increase during the long rains and a maxima in the short rains towards the end of the year. There was no consistent spatio-temporal pattern for total-N concentration because the levels varied greatly from site to site and season to season (Figure 3). The highest concentration occurred in December and the lowest occurred in March. Some of the reservoirs with a high total-N loading included Kahuru in March, Kanguo and Gathanje in June and Gathambara in December.

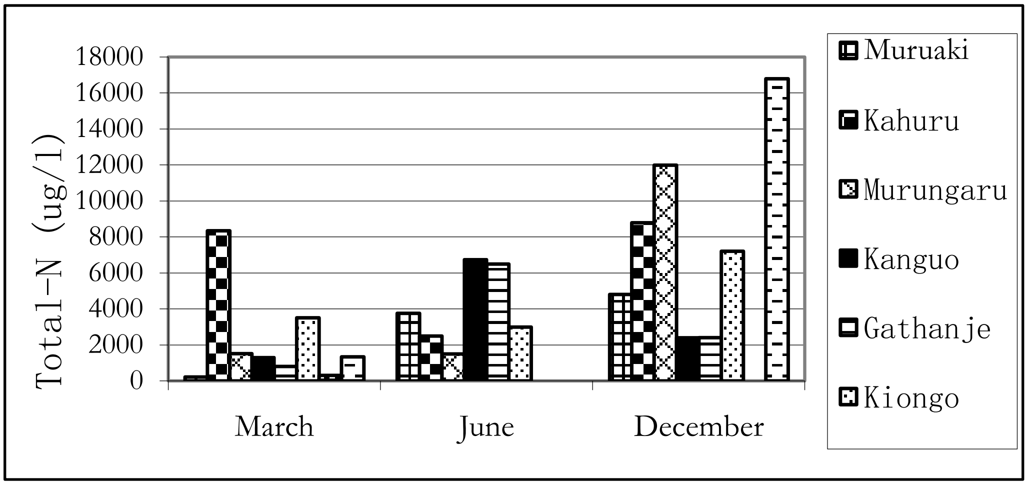


Figure 3. Seasonal total-N levels in the reservoirs.

Figure 4 shows the total-P levels in the reservoirs with the nutrient loadings for the 8 reservoirs in the three monthly measurements shown in different shades in the legend. The concentration of total-P ranged between 30-700 μg/l with the highest loading at the on-set of the long rains in March and the lowest after the short rains in December (Figure 4). There was a spatially consistent pattern whereby the rift plateau reservoirs especially Muruaki and Murungaru had the highest levels compared to the rift escarpment ones like Gathanje and Rutara which had the lowest levels throughout the study period. However, Gathambara reservoir was an exceptional escarpment site with high total-P.

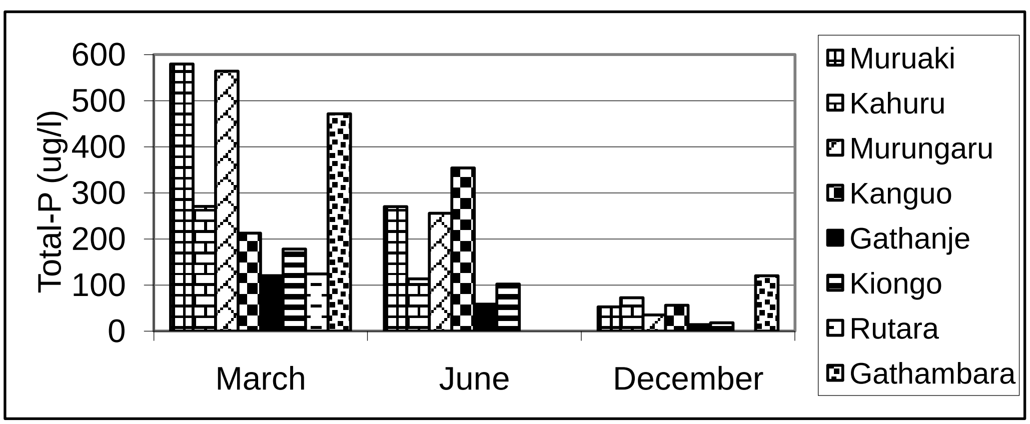
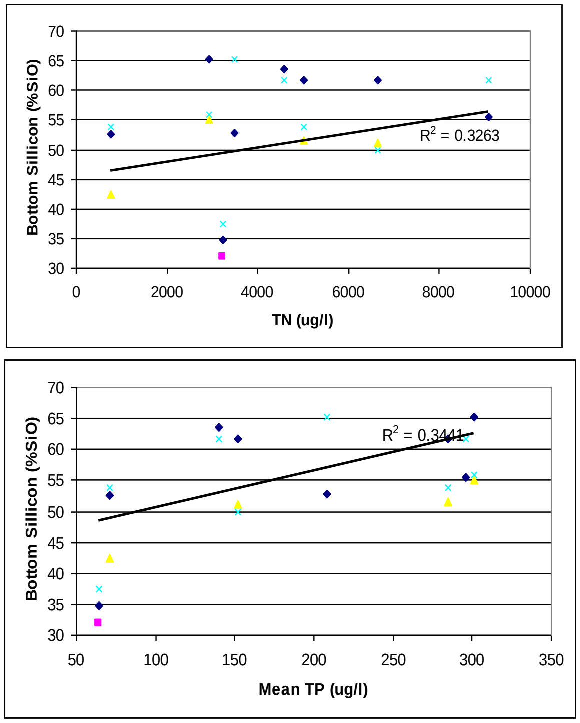


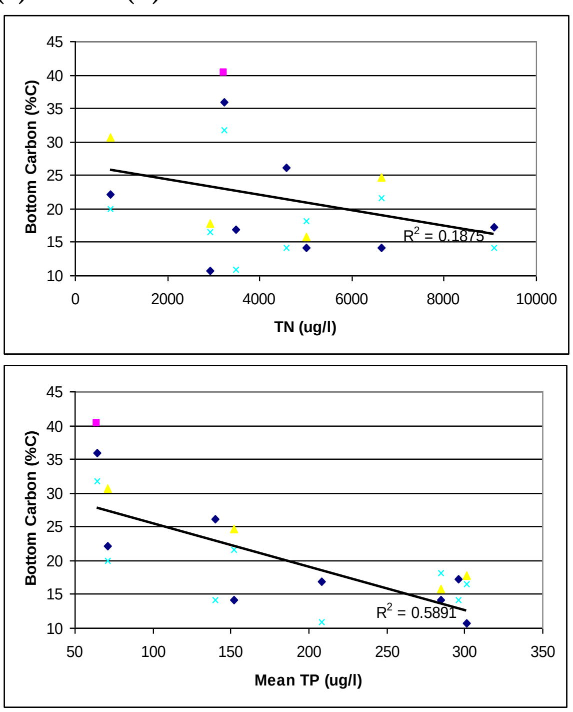
Figure 4. Seasonal total-P levels in the reservoirs.

Correlation analysis between the reservoir bottom sediments chemistry and the levels of total-N and total-P in water indicated positive relationships between sediment SiO_2, CaO and P on one hand and total-N and total-P on the other as shown in Figure 5. It appeared that the higher the level of these parameters in the sediment, the more available the macronutrients. The correlation analysis in addition, established inverse relationships between sediment C, Al_2O_3, Cu and Fe_2O_3 on one hand andtotal-N and total-P on the other (Figure 5). However, the regression analysis between the levels of total-N and total-P and the concentration of bottom sediment parameters established that total-N was only significantly related with the level of CaO (r^2 0.606, df 1, 6, t 3.041, p 0.023) while total-P was only significantly related with the level of C (r^2 0.589, df 1, 6, t -2.933, p 0.026) in the bottom sediments. On the overall, the correlations were very weak between TN in the reservoir water column on one hand and Al_2O_3, Fe_2O_3, P, and C in the bottom sediments. In the case of TP, there was very weak correlation between nutrient loading in the water with Fe_2O_3, CAO and P in the bottom sediments as shown in Figure 5.

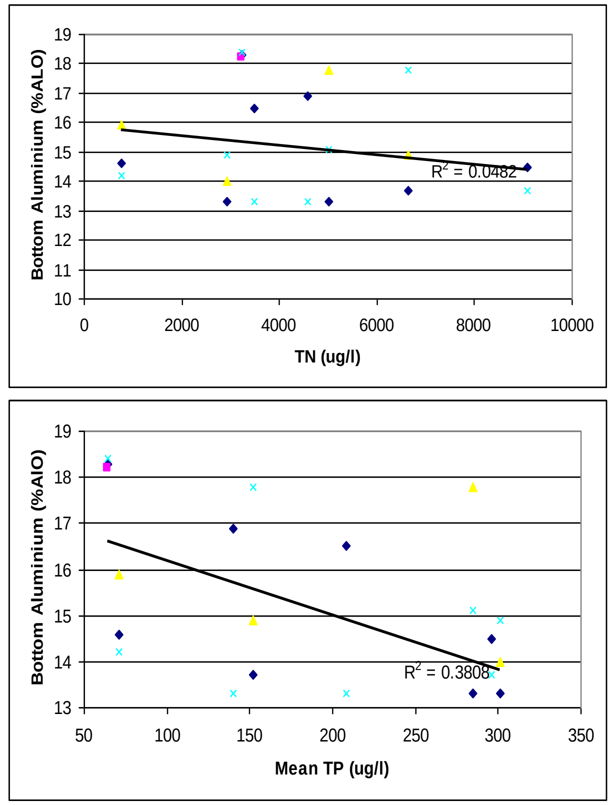
(a) Silicon (SiO_2)



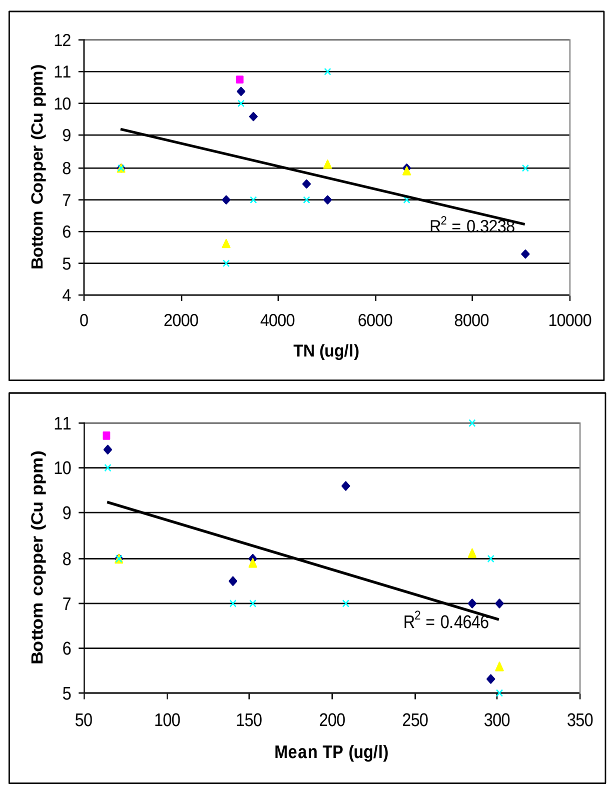
(b) Carbon (C)



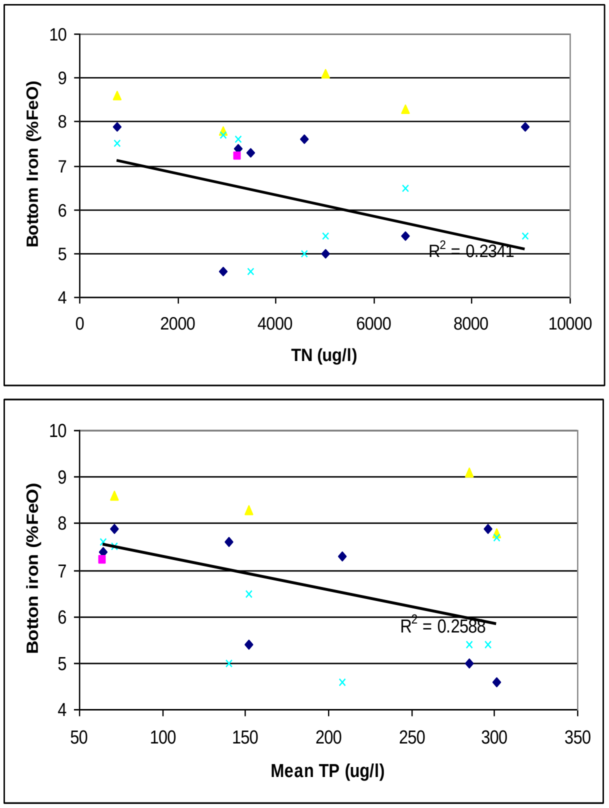
(c) Aluminium (AL_2O_3)



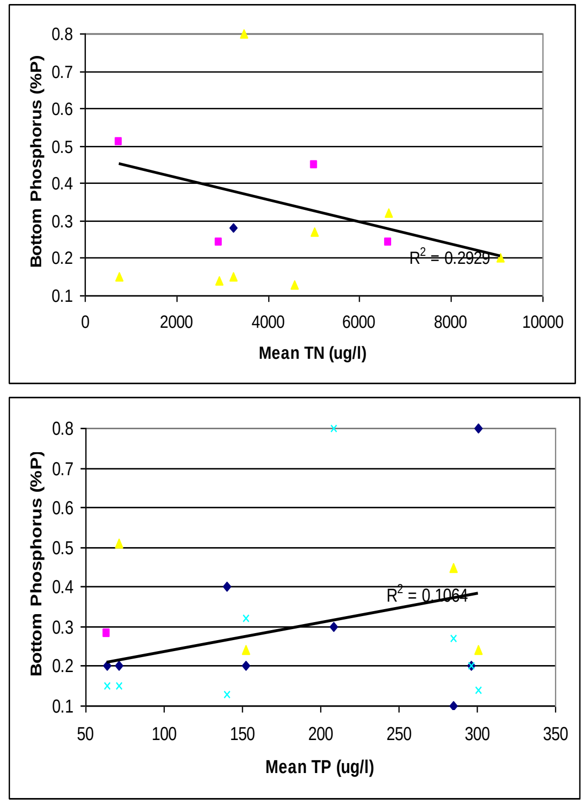
(d) Copper (Cu)



(e) Iron (Fe_2O_3)



(g) Phosphorus (P)



(f) Calcium (CaO)

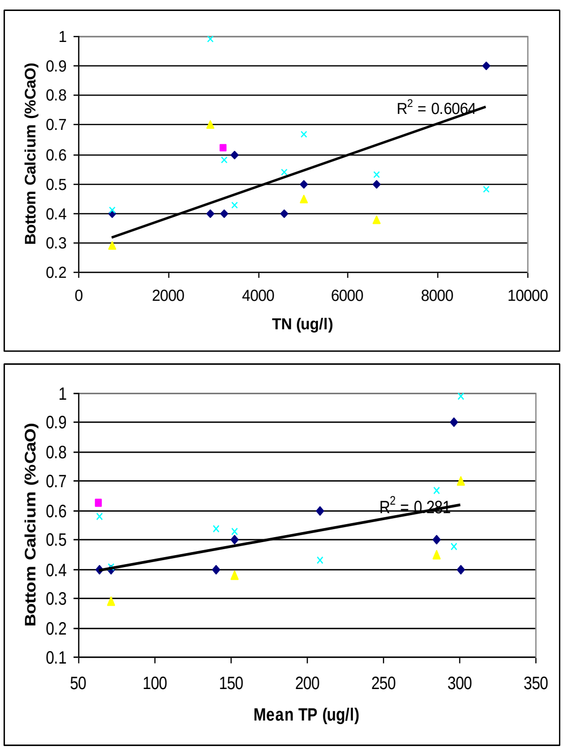


Figure 5. A summary of the relationship patterns between bottom sediment chemistry and reservoir nutrient levels (■ = March, ▲= June, ◊ = October, × = December).

A total of six water bird counts across the eight sites recorded 49 species for all the reservoirs and an overall average of 60 individuals per reservoir. The range of species number was 5-11 and that of the count was 60-80 birds per site while the density range was 0.3-1.2 birds/m^2. Table 3 gives a summary of the water bird species number, counts and density per square metre. The most dominant birds in terms of cumulative total counts included the Red-knobbed Coot (*Fulica cristata*), Black-headed Heron (*Ardea melanocephala*), Egyptian Goose (*Alopochen aegyptius*), Yellow-billed Duck (*Anas undulata*), Little Grebe (*Tachybaptus ruficollis*), White-necked Cormorant (*Phalacrocorax carbo*), Hadada Ibis (*Bostrychia hagedash*), Blacksmith Plover (*Vanellus armatus*) and Cattle Egret (*Bubulcus ibis*). From the counts, it was evident that the resident avifauna comprised of herons, coots, ducks, geese, grebes, ibises and egrets. The analysis of the monthly patterns for total counts and bird species showed that the bird populations were high in the dry season and onset of the long rains in February and March, decreased during the rains in June and July and peaked again towards the end of the year (Table 3).

The analysis of bird species showed that the reservoirs served as important hot and dry season refugia for the Red-knobbed Coots (*Fulica cristata*), Pink-backed Pelicans (*Pelecanus rufescens*), Little Grebes (*Tachybaptus ruficollis*), Grey Crowned Cranes (*Balearica regulorum*), Egyptian Geese (*Alopochen aegyptius*) and Black-headed Herons (*Ardea melanocephala)* (Figure 3). Figure 3 also shows that in the cold and wet season (June) the dominating birds were Cattle Egrets (*Ardeola ibis*), Grey-headed Gulls (*Larus cirrocephalus*), White-necked Cormorant (*Phalacrocorax carbo*), Red-knobbed Coots (*Fulica cristata*), and Blacksmith Plovers (*Vanellus armatus*).

Table 3 shows that the highest density of water birds occurred in Gathambara and Muruaki which were also the smallest and shallowest water bodies (Table 2). Moderate density occurred in Kahuru and Murungaru which were of medium size and medium depth and the lowest density in Gathanje and Kiongo which were the largest and deepest (Table 2). Although there were no definite regional patterns in terms of the number of species per reservoir, general comparative assessment showed that the plateau reservoirs appeared to have slightly higher number of bird species per site than the escarpment reservoirs (Table 3). Similarly, the bird counts and species numbers were higher in the reservoirs located within the flat plateau rather than rugged escarpment terrain (Table 3).

Table 3. Monthly reservoir water bird counts, density, and species number in 1998-2000.

	Feb	Mar	Jun	Jul	Oct	Dec	Mean
(a) Mean number of species							
Muruaki (plateau, 2440m)	11	8	12	9	10	14	11.3
Kahuru(plateau, 2420m)	8	9	15	8	10	8	10.0
Murungaru(plateau, 2440m)	7	10	12	10	11	24	13.3
Kanguo(plateau, 2340m)	6	7	9	10	10	11	8.8
Gathanje (escarpment, 2460m)	4	6	5	5	10	9	6.5
Kiongo (escarpment, 2640m)	11	5	5	5	12	13	8.5
Rutara (escarpment, 2400m)	5	6	7	6	9	5	5.3
Gathambara (escarpment, 2040m)	5	5	6	7	10	6	6.5
Mean	7.6	7.0	9.0	6.7	9.6	11.8	
(b) Mean of total counts							
Muruaki (plateau, 2440m)	171	35	51	74	82	166	105.8
Kahuru(plateau, 2420m)	58	26	73	49	56	61	54.5
Murungaru(plateau, 2440m)	61	54	57	59	66	128	75.0
Kanguo(plateau, 2340m)	23	77	35	31	24	57	41.2
Gathanje (escarpment, 2460m)	20	97	15	13	19	24	31.3
Kiongo(escarpment, 2640m)	80	54	30	111	146	92	85.5
Rutara(escarpment, 2400m)	30	71	47	46	40	27	49.5
Gathambara (escarpment, 2040m)	6	102	63	16	60	144	83.6
Mean	71.1	64.5	43.5	42.8	57.3	87.4	
(c) Mean density (birds/m^2)							
Muruaki (plateau, 2440m)	1.7	0.3	0.5	0.7	0.8	1.6	1.0
Kahuru(plateau, 2420m)	0.7	0.3	0.8	0.4	0.6	0.7	0.6
Murungaru(plateau, 2440m)	0.4	0.5	0.5	0.4	0.5	1.1	0.6
Kanguo(plateau, 2340m)	0.2	0.7	0.3	0.3	0.2	0.5	0.4
Gathanje (escarpment, 2460m)	0.2	0.8	0.1	0.1	0.2	0.2	0.3
Kiongo (escarpment, 2640m)	0.3	0.2	0.1	0.4	0.6	0.4	0.3
Rutara (escarpment, 2400m)	0.1	1.0	0.5	0.5	0.6	0.4	0.7
Gathambara (escarpment, 2040m)	0.5	1.5	0.8	0.2	0.9	2.2	1.2
Mean	0.7	0.7	0.4	0.3	0.5	0.9	

Table 4 shows the results of curve linear regression between the levels of reservoir bottom sediment parameters and the bird counts. The results indicated that high bottom sediment C, P and CaO was associated with high water bird counts for 14 bird species namely, African Fish Eagle, Common Teal, Grey Crowned Crane, Purple Gallinule, Brack Crake, Great White Pelican, Ringed Plover, Yellow-billed Stork, African Jacana, Black-headed Heron, Knob-billed Duck and Great Egret. On the other hand, high bottom sediment SiO_2, and Fe_2O_3, was associated with low water bird counts for 7 bird species namely, African Fish Eagle, Common Teal, Grey Heron, Purple Gallinule, Brack Crake, Great White Pelican and Pink-backed Pelican. The levels of Cu and AL_2O_3 had no significant impact on the birds.

Table 4. Summary of curve linear regression results between levels of sediment parameters and reservoir birdlife population.

Sediment parameter	Impact on TN and TP	Bird species	Df	r^2	b1	F	∞
SiO_2	Positive	African Fish Eagle	1,6	0.556	-0.158	7.52	0.034
		Common Teal	1,6	0.642	-0.200	10.74	0.017
		Grey Heron	1,6	0.577	0.2131	8.20	0.029
		Purple Gullinule	1,6	0.754	-0.124	18.35	0.005
		Black Crake	1,6	0.754	-0.031	18.35	0.005
		Great White Pelican	1,6	0.754	-0.280	18.35	0.005
C	Negative	African Fish Eagle	1,6	0.603	0.200	9.11	0.02
		Common Teal	1,6	0.531	0.221	6.80	0.04
		Grey Crowned Crane	1,6	0.493	0.688	5.84	0.05
		Purple Gullinule	1,6	0.651	0.140	11.17	0.02
		Black Crake	1,6	0.651	0.035	11.17	0.02
		Great White Pelican	1,6	0.651	0.314	11.17	0.02
Fe_2O_3	Negative	Grey Heron	1,6	0.544	-1.473	7.15	0.04
		Pink-backed Pelican	1,6	0.625	-6.053	9.98	0.02
CaO	Positive	Ringed Plover	1,6	0.841	27.725	31.65	0.001
		Yellow-billed Stork	1,6	0.595	31.078	8.81	0.03
P	Positive	African Jacana	1,6	0.840	1.1471	31.58	0.001
		Black-headed Heron	1,6	0.554	327.941	7.45	0.003
		Common Snipe	1,6	0.721	4.118	15.47	0.01
		Knob-billed Duck	1,6	0.840	2.941	31.58	0.001
		Great Egret	1,6	0.615	2.647	9.58	0.02

Table 5 shows the relationships between reservoir water bird counts and nutrient content. The analysis indicated that the relationship between reservoir total-N and total-P and reservoir birdlife was only significant for 9 bird species. The number of birds was found to increase significantly with increase in total-N and total-P for species including the Cape Teal, Grey-headed Gull, Hottentot Teal, Long-tailed Cormorant, Pink-backed Pelican, Red-knobbed Coot, Ringed Plover, Squacco Heron and Yellow-billed Stork (Table 5).

Table 5. Regression results for number of water birds and reservoir nutrient content.

Nutrients	Water birds	df	r^2	b_1	SE	T	∞
TN	Ringed Plover	1,6	0.545	379.513	3.462	109.613	0.000
	Grey-headed Gull	2,5	0.306	128.125	2.633	48.656	0.000
	Squacco Heron	3,4	0.111	-596.467	21.484	-27.763	0.001
	Long-tailed Cormorant	4,3	0.062	365.983	11.335	32.289	0.001
	Red-knobbed Coot	5,2	0.005	-4.058	0.545	-7.440	0.018
TP	Yellow-billed Stork	1,6	0.661	11.607	0.425	27.280	0.000
	Pink-backed Pelican	2,5	0.253	3.723	0.340	10.964	0.002
	Cape Teal	3,4	0.064	15.956	2.487	6.416	0.008
	Hottentot Teal	4,3	0.002	-90.11	1.722	-5.232	0.014

Three bird species namely the Ringed Plover, Yellow-billed Stork and Pink-backed Pelican were found to have significant relationships with both the bottom sediment chemistry and total-N and total-P in water. It seems, therefore, that the reservoir bottom chemistry might have a wider implication on the characteristics of water birds in the water bodies.

4. Discussion

The findings showed that the tropical high altitude reservoirs were quite rich in bottom sediment SiO_2 and organic carbonand poor in CaO. Sediment SiO_2 is a common weathering product of acidic and intermediate igneous and pyroclastics rocks which are quite common in the study area. The rocks in the reservoir catchments are known to be quite rich in oxides especially Al_2O_3, Fe_2O_3 and CaO (Thompson, 1962). This condition is known to enhance the binding of phosphorus in the bottom sediments, which could amplify the process of internal loading as reported in other areas (e.g. Vikhristyuk & Varlamova, 1994). Several recent studies have closely linked the nutrient content in lakes and reservoirs to the physico-chemical profile of the bottom sediments, which can act as sinks, and sources of various elements (e.g. Barko *et al.*, 1991;

Harper, 1992; Daldorph & Price, 1994; Pacini, 1994; Vikhristyuk & Varlamova, 1994; Tiessen, 1995). Such studies have, for example, shown that the accumulation of iron in the sediments should bind the phosphorus and limit the rate of phosphorus release into the water column which can reduce the risk of eutrophication.

The main sources of C in the reservoirs was organic matter and this was more abundant in the escarpment reservoirs probably due to the steeper terrain and more woody vegetation in the riparian zone due to the presence of remnant forest in the catchment. This was a key source of dead litter along the river ways which feed into the reservoirs. Much lower sediment carbon content was recorded in the plateau reservoirs because of their location within a fairly flat meadow or moorland landscape where the release of organic debris was minimized by the gentle gradient and high trapping effect by moorland grass cover which greatly reduced surface transfer of detrital matter into the water bodies. The high level of organic carbon at Gathanje Reservoir was attributed to the raising of the dam which caused the submergence of a section of natural forest in the upper zone. The submergence generated a lot of debris, which accumulated within the reservoir. The burning of natural forests in the catchment also appeared to release a lot of carbon into the reservoir in the form of waste charcoal.

The results showed that the small reservoirs contained higher total-N and lower total-P levels at an average of 220-16 800 μg/l and 30-700 μg/l, respectively, than some large man-made lakes in Africa such as Kariba and Cabora Bassa where the concentration has been estimated at 790 and 1267 μg/l, respectively (Mhlanga, 2001). The three reservoirs in the Kinangop area which were within the Lake Naivasha basin had almost twice as much total-N than in terminal end of the largest river (River Malewa) and almost five times higher than in the open waters of Lake Naivasha (Harper *et al*., 1993). The water bodies were established to be bordering on the point of experiencing a frequent eutrophication which has already been reported by Mwaura, Koyo & Zech (2004). The lower total-N loading in some reservoirs like Gathanje indicated that the macrophyte-shored water bodies are probably better buffered against high nutrient loading than the open grass covered reservoirs. This has been found to occur in other areas. Sharpley *et al.* cited in Tiessen (1995), for example, have reported that forested areas can form suitable riparian buffers around streams or water bodies to reduce nutrient movement from agricultural land. Similarly, Hillbright-Ilkowska *et al.* cited in Tiessen (1995) have reported that zero-tillage along the water ways effectively reduces nutrient loss relative to conventional tillage by reducing soil erosion.

The high total-P content in the rift plateau reservoirs was attributed to the slow rate of overland flow within the reservoirs, which maintained longer contact of water with riparian soils. Most of the plateau landscape had higher clay content in the soil, which is known to increase P-binding in bottom sediments. The high content of total-P, which occurred in the reservoirs at the on-set of the long rains in March, indicated that the main route of phosphorus movement was the soil. High leakage of fertilizer from the land to the water was quite possible during the ploughing and planting season in March because of poor land cover, which could enhance rainfall erodibility. The low total-P in the rift escarpment reservoirs was attributed to a low clay content and greater presence of submersed macrophytes especially *Ceratophyllum demersum*. Such plants apart from accelerating nutrient uptake can also elevate the sediment redox potential thereby lowering the concentration of soluble phosphorus.

The high total-P in Kiongo Reservoir was largely attributed to anthopogenic factors because the reservoir is located 50-100 m away from Gwa-Kiongo, a rapidly growing market centre of approximately 5 000 people and whose runoff is flowing directly into the reservoir. With such a population, anthropogenic phosphorus loading can translate to an average export of about 55.1 kgP/person/year at about 2-4 gP/person/day through domestic sewage. The high total-P in Gathambara Reservoir was mainly as a result of heavy siltation. It is possible that re-suspension of phosphorus in the reservoir, which was also the shallowest, was returning large amount of phosphorus from the bottom sediments back into the water column through internal loading. The steeper gradient, high population density and rapid deforestation could explain the high loading of phosphorus in the Gathambara reservoir. A recent study in the area has shown that forest cover in the area has sharply decreased by as much as 19-24% in the 1986-2003 period (Baldyga *et al*., 2007). This is consistent with findings from other parts of the world. A survey of 928 catchments in the USA showed that phosphorus export increased proportionally with decrease in forest cover and increase in agricultural land (Sharpley *et al*., 1995). Rapid land cover change from natural vegetation to agro-ecosystem usually leads to loss of riparian buffer zones along the river ways thereby resulting in greater movement of phosphorus from the catchment into the water bodies especially in steep terrain.

The positive correlation between total-N and sediment calcium in the reservoirs was mostly linked with the movement from the catchment of phosphorus-rich particulate matter. This was attributed to the common use of Calcium Ammonium Nitrate (CAP) and Calcium Nitrate fertilizers for both agriculture and horticulture. This CAP fertilizer contains a mixture of calcium/magnesium carbonate and nitrogen that is often used to raise the soil acidity in the form of lime.

The range of total N: total P ratios in the reservoirs was 10-43. A high ratio above 30 is often associated with oligotrophy or mesotrophy while low values below 30 and in many cases even below 10 characterize the eutrophic and hypereutrophic waters. Based on this, only Muruaki, Murungaru, Kanguo and Gathambara were in the hypertrophic state. The others could to be considered in the oligo-mesotrophic category. The results indicated that both phosphorus and nitrogen limitation are likely to occur in the reservoirs thereby affecting their biological productivy and biodiversity support capacity including birdlife. In June, half of the reservoirs where the total-N:total-P ratio was 10-17, namely Muruaki, Murungaru, Rutara and Gathambara could experience either nitrogen or phosphorus limitation or both as predicted by Forsberg *et al.* (1978) and Hillbricht-Ilkowska *et al.* (1995). In October, 37.5% of the reservoirs including Murungaru, Rutara and Gathambara, where the ratio was < 10 could experience nitrogen limitation. In the rest 50% including Kahuru, Kanguo, Gathanje and Kiongo where the ratio was >17 phosphorus limitation is expected. Finally, phosphorus limitation is likely to occur in all reservoirs during the month of December.

The inverse relationship between sediment carbon and total-P indicated that the former was acting as phosphorus sink. Activated carbon is known to have a strong affinity for many elements including phosphorus (Xie *et al.*, 2014, Newcombe *et al.*, 2010). On the overall, the results of the study indicated marginal influence by bottom sediment Al_2O_3, Fe_2O_3, P, C on TN and Fe_2O_3, CaO and P on TP in the water. The case for the TN is clearly explainable from the point of the nitrogen cycle whose key reservoir is largely atmospheric. But the findings seem to contradict other studies which have indicated positive relationship between iron oxide reduction and organic nitrogen mineralization in tropical wetlands (Sahrawat, 2004). The case of TP and Fe_2O_3 appeared to indicate that Fe(III) oxides can act as a barrier to diffusive P flux as previously established by (Vitousek *et al.*, 1997).

The results revealed that both high TN and TP loading were associated with more vibrant aquatic birdlife due to higher ecological productivity. This was particularly evident for waders, open water and diving birds which heavily depend on the water bodies for food. This pattern has been found elsewhere such in the Jagdishpur reservoir in Nepal where (Thapa & Bahadur, 2012) established that phosphate was positively correlated with bird species richness (r = 0.19) and bird number (r = 0.53). Studies have previously shown that the release of nitrogen and phosphorus from the bottom sediments of lakes and reservoirs to water column plays a key role in influencing the overall nutrient balance (Gautamand Bhattarai, 2008). This will eventually affect the biodiversity including birdlife.

This study established that bottom sediment SiO_2, C, P, Fe_2O_3, and CaO had the strongest positive and negative relationships with the reservoir birdlife community. The most sensitive waterbird species based on the results of a regression analysis included the African Fish Eagle, African Jacana, Black-headed Heron, Brack Crake, Common Teal, Great Egret, Great White Pelican, Grey Crowned Crane, Knob-billed Duck, Purple Gallinule, Ringed Plover, and Yellow-billed out of these, the most sensitive species were the African Fish Eagle, Brack Crake, Common Teal, Great White Pelican, and Purple Gallinule.

5. Conclusion

The findings showed that the chemical state of bottom sediments in reservoirs has a significant influence on the nutrient balance especially the levels of key nutrients such as nitrogen and phosphorus mainly through adsorption and binding of the nutrients at the bottom with occasional release into the ecosystem. The results showed statistically significant relationships between reservoir bottom sediment chemistry, nutrient levels, and bird characteristics. The actual impact of sediment chemistry on the utilization of reservoirs by water birds was not established and should, therefore, be an important subject for further investigation. However, the findings appeared to indicate indirect influence of sediment chemistry on nutrient dynamics, ecological productivity and food availability. The findings indicated that organic carbon litter from forests in the reservoir catchment as well as the riparian zones along the influent streams and rivers will usually influence the state of sediment carbon. This eventually affects the level of influential nutrients such as total-P which can determine the water quality through eutrophication and also affect biological productivity including the typology of species. The findings indicated that the state of reservoir bottom sediments and their influence on nutrient balance and birdlife cannot be de-linked from the landform, land cover, and human activities especially catchment management.

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