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Physicochemical and Microbiological Water Quality of Lake Sagara in Malagarasi Wetlands

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Abstract: The physicochemical and microbiological water quality parameters of Lake Sagara in the Malagarasi ecosystem, Tanzania, were studied between September 2003 and January 2004. Standard methods of analysis were used to elucidate the levels of the main water quality parameters. The Lake was found to be shallow (maximum depth 6.5 m) with encroaching hydrophytes and floodplain grasslands. High turbidity values ranging from 20-126.5 NTU recorded in the studied sites was attributed to vigorous wind mixing of the Lake water. The temperature, pH and chlorides values were 24.4-27.0°C, 6.8-8.8, 7.9-17.4 mg L^{-1}), respectively. These values are within the standard water quality requirements. The values of conductivity (89-212 is/cm), phosphates (1.0-4.5 mg L^{-1}), organic nitrogen (0.8-2.2 mg L^{-1}); abundant sediments and algal blooms suggest that Lake Sagara is eutrophic. Values of dissolved oxygen (6.2-7.3 mg L^{-1}), COD (22.1-42.6 mg L^{-1}) and BOD (3.8-7.1 mg L^{-1}) show that so far, the levels of oxygen-demanding wastes in Lake Sagara can still sustain aquatic life. The high counts of enteric pathogenic microorganisms including fecal coiliform (10-66 MPN/100m), *Vibrio* sp. (2-6 CFU mL^{-1}) and *Salmonella* sp. (1-4 CFU mL^{-1}) as a result of surface runoff and direct contamination depict poor hygienic practices by the local fishermen and the surrounding communities. This work provides the first ever scientific research on the microbiological status of Malagarasi-Muyovozi wetland ecosystem.

Key words: Organic pollutants, lake water, water quality, wetland ecosystem

INTRODUCTION

Wetlands are important water bodies in terms of ecological balance because they provide breeding areas for different types of flora and fauna and act as active and natural treatment systems, which in turn gives rise to improvement of water quality[1]. They are transitional areas between land and water and are distinguished by wet soils, flora and fauna that are adapted to wet soils and water depth that maintains these characteristics. Studies have shown that wetlands are natural purifiers of wastewaters due to their ability to remove or reduce contaminants including organic matter, inorganic matter and pathogens. The reduction is due to sedimentation, filtration, precipitation adsorption, microbial interactions and uptake by vegetation[2]. However, there has been concern over long-term degradation of wetlands due to additional nutrients and hydraulic loading from wastewater from industrial effluents and surface runoff [3,4].

The Malagarasi-Muyovozi wetlands covers an area of 3,250,000 ha. in Kigoma, Shinyanga and Tabora regions. It is a vast and complex riverine floodplain wetland in the basin of the Malagarasi River in northwest Tanzania, one of the largest and most important wetlands in East Africa. The basin has five main rivers, the Malagarasi, Moyowosi, Kigosi, Gombe and Ugalla, which drain an area of 9.2 million ha (about 30% of the Lake Tanganyika catchment system). The core area of the Ramsar site comprises shallow lakes and open water in the dry season covering about 250,000 ha, together with a permanent papyrus swamp of about 200,000 ha with large peripheral floodplains that fluctuate widely on a yearly basis depending on the amount of rainfall, but cover up to 1.5 million ha[5].

Sagara is a fresh water lake which lies within the central portion of the Malagarasi floodplain wetland ecosystem (5°13'S/31°10'E) covering a total of 93,000 ha. The socio-economy of the population of 85,000 people (year 2002 census; population growth rate is 1% per annum) in the surrounding villages and Nguruka town depends on Lake Sagara for fresh water for domestic use while the fishing industry provide employment to more then 70% of the local community. The lake is rich in fresh

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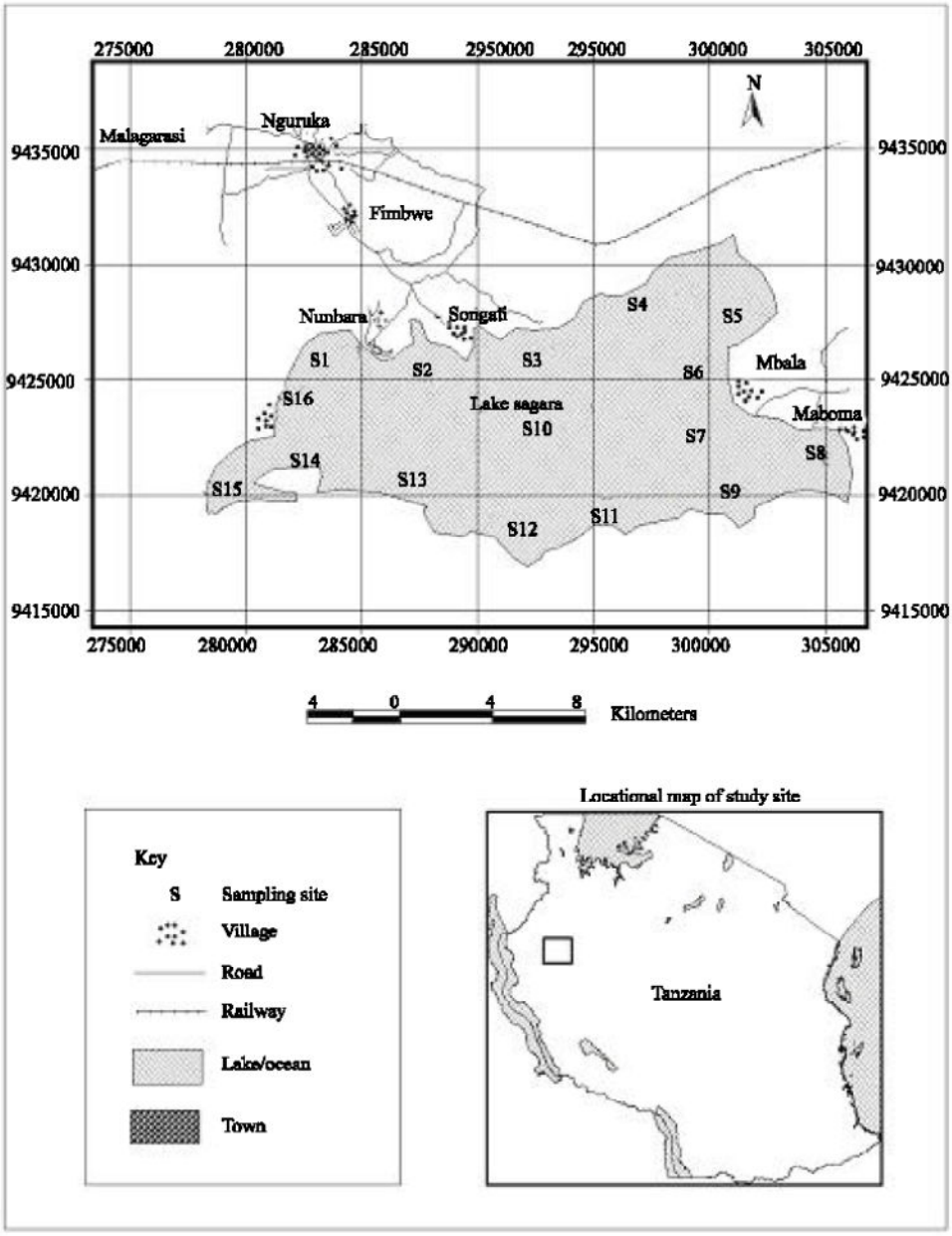


Fig. 1: The map of Lake Sagara showing the sampling points and the main features of the neighboring settlements

water fish including cichlids, cat fish, characids, carps, momyrids, lung fish, birch and citharinids. *Pollimyrus nigricans* and *Bryconaethiops boulenger* are some of the rare fish species found in Lake Sagara Furthermore, the lake supports a number of vulnerable or endangered bird species including shoebill (*Balaeniceps res*), Wattled Crane (*Bugeranus carunculatus*) and African Slender-Snouted crocodile (*Crocodylus cataphractus*). The lake also plays an important hydrological role of water storage, flood control, ground water recharge, sediment retention and water purification[5].

The Malagarasi ecosystem has been the least studied area among the East African wetlands. There is little or no information in the literature regarding the major and trace elements and nutrient inputs due to surface runoffs. Also, little is known about the types and nature of organic pollutants sipping into the wetlands and are being taken

up flora, fauna, sediments and waters. Although some limited studies have been done in the Malagarasi-Muyovosi Wetlands[6-10], no specific research has ever been done on the microbiological water quality of the main lakes, namely Lake Sagara and Lake Nyamagoma. The inadequate scientific knowledge on this ecosystem makes it an important site of research. The current study investigated the quantitative and qualitative physicochemical and microbiological parameters of lake Sagara in the Malagarasi ecosystem and elucidated their interrelationships.

MATERIALS AND METHODS

Study site: The study, carried out in September 2003 to January 2004, covered a total of 16 sampling locations in the Lake Sagara subdivided into four sampling blocks: North Sagara: Numbara, Fimbwe, Mkwajuni and Sisa (S_1-S_4); East Sagara: Kasozi, Migungani, Songati and Sole (S_5-S_8); South Sagara: Ukala, Msindeni, Mihamingi and Katumba (S_9-S_{12}) and West Sagara: Sibwe, Mabwe, Ugalla and Kigulwe (S_{13}-S_{16}). Figure 1 illustrates the geographical positions of the sampling locations and the main features of the surrounding villages.

Sampling: Water samples were taken at the surface (0-30 cm depth) under aseptic conditions. Sterilized sampling tubes with water samples were preserved in ice-boxes at 3°C and immediately brought to the laboratory for analysis.

In situ measurements: Water turbidity, pH, temperature, Dissolved Oxygen (DO) and conductivity were measured *In situ* by using standardized portable equipment while other physicochemical tests were carried out in the laboratory.

Laboratory and microbiological analyses: All the water samples were analyzed in triplicate using standard methods[11,12]. Chlorides in the form of Chloride Ions (Cl^-) were analyzed by Argentometric method whereby in alkaline solution, silver chloride was precipitated quantitatively. Total phosphates was determined by ion chromatography. Total organic nitrogen was determined by Kjeldahl method. Chemical Oxygen Demand (COD) was determined by using closed, reflux method while 5-day biochemical oxygen demand (BOD_5) test was determined by initial and final DO measurements based on the Iodometric titrimetric (Azide modification) method. All microbiological analyses were carried out according to standard methods[12-15]. Total Plate Counts (TPC) was determined by using homogenized and serially diluted samples incubated at 37°C for 48 hrs. The TPC count was reported in Colony Forming Units (CFU) per mL. In the determination of coliform bacteria, presumptive test was carried out using sets of five tubes inoculated with 10 mL of Laury Sulphate Tryptose Broth (LSTB) with sample dilutions of 10, 1 and 0.1 mL. All tubes for total coliform test were incubated in a water bath at 35°C while tubes for fecal coliforms were incubated at 44.5°C for 48 hrs. Tubes were examined for gas formation, either by observing displacement of liquid media in the gas vials or observing vigorous effervescence when tubes were shaken gently. Any gas observed was noted as a positive presumptive test for coliform organisms.

In the confirmed coliform test, 1 mL of positive presumptive tubes from LSTB were transferred to a separate media tube of Brilliant Green Lactose Bile (BGLB) broth and incubated at 35°C for total coliform and 44.5°C for fecal coliforms, respectively, for 48 hrs and the gas positive tubes were recorded. Results were reported as Most Probable Number (MPN) per 100 mL of the sample. In the completed test, positive BGLB samples were streaked in MacConkey agar plates and incubated at 35 and 44.5°C for total coliforms and fecal coliforms, respectly, for 24 hrs and then examined for colony growth. Pink, gram negative colonies which were positive in LSTB test were considered a completed test for coliforms. In the determination of Enterobacteriaceae, preparations of the test samples were the same as that given for TPC.

A series of 1/10, 1/100, 1/1000 dilutions from the test samples for analysis of Enterobacteriaceae was prepared. Violet Red Bile Glucose Agar (VRBGA) was used as growth medium. Incubation was carried out at 30°C for 48 hrs. Red purple colonies with the precipitation zone of bile salts confirmed the presence of enterobacteriaceae.

In the detection of *Salmonella* sp. samples pre-enriched with peptone water was further enriched with selenite tetrathionate broth at 3°C for 48 hrs and then inoculated on solid XLD agar by surface streaking and then incubated at 37°C for 24 hrs. All colonies appearing in red with black centers were presumed as Salmonella colonies. Suspected Salmonella colonies were further incubated in Brilliant green media for a confirmatory test.

Vibrio were detected using Trypticase Citric Bile Salts (TCBS) as a selective plating medium. The medium contains sucrose and therefore allows the differentiation of *Vibrio* species such as *Vibrio cholerae* (sucrose positive) and *Vibrio haemolyticus* (sucrose negative). To enrich samples for *Vibrio* growth, one percent of Alkaline Peptone Water (APW) was added to the water samples. The mixture was thoroughly mixed and incubated in a water bath at 35°C for 6 to 8 hrs. A loopful from the surface growth of each sample from APW broth culture was transferred to the surface of Bacto Tripticase Citric

Table 1: physicochemical water quality parameters of lake sagara

Location	pH	Temp (°C)	DO ($mgO_2\ L^{-1}$)	Condu-ctivity ($\mu S\ cm^{-1}$)	T.Org.Nitrogen ($mg\ L^{-1}$)	Chloride ($mgCl^{-}\ L^{-1}$)	Total $P0_4$ ($mgPO_4^{3-}\ L^{-1}$)	COD ($mg\ L^{-1}$)	BOD_5 ($mg\ L^{-1}$)
S_1	7.5±0.6	24.4±0.5	7.2±0.1	142±3	1.5±0.2	11.5±2.0	1.5±0.1	25.5±1.2	4.3±0.21
S_2	7.4±0.2	24.5±0.6	7.1±0.1	89±4	1.8±0.2	12.0±1.5	2.6±0.9	22.1±0.4	3.8±0.1
S_3	8.3±0.3	27.0±0.3	6.9±0.2	363±2	1.6±0.1	11.6±1.0	1.3±1.1	31.1±1.6	5.5±1.3
S_4	7.1±0.6	25.0±0.7	6.8±0.3	510±2	0.9±0.3	15.2±0.9	4.3±1.1	30.9±2.1	5.1±0.1
S_5	6.9±0.9	26.0±0.8	7.0±0.2	820±1	1.0±0.1	8.4±0.5	2.6±1.0	32.3±2.4	5.9±0.5
S_6	6.8±0.4	26.5±0.2	6.8±0.3	119±5	1.2±0.2	15.6±0.2	3.1±0.5	25.2±2.5	4.1±1.1
S_7	7.1±0.8	25.5±0.1	6.2±0.1	144±8	1.5±0.4	13.2±0.9	4.0±1.2	26.2±1.6	4.6±0.3
S_8	7.4±0.2	25.0±0.5	6.3±0.1	185±9	0.8±0.4	12.6±0.7	1.0±0.2	30.1±2.8	5.4±0.1
S_9	8.1±0.3	26.5±0.7	6.9±0.2	108±5	0.9±0.3	14.3±0.3	3.8±1.2	33.2±2.6	5.7±0.2
S_{10}	7.7±0.5	26.0±0.6	7.1±0.4	119±6	1.8±0.2	17.4±0.5	3.4±1.3	28.1±2.2	5.0±1.4
S_{11}	7.2±0.6	25.5±0.2	7.3±0.2	152±7	2.2±0.2	11.6±1.2	4.2±1.6	31.2±3.4	5.6±0.1
S_{12}	7.6±0.7	26.5±0.5	6.6±0.3	139±3	1.9±0.3	10.8±1.0	1.3±0.9	27.1±2.5	4.9±0.3
S_{13}	7.5±0.1	25.5±0.4	6.8±0.1	177±2	0.9±0.1	9.6±1.4	2.4±0.8	27.9±5.4	4.9±0.1
S_{14}	8.0±0.2	25.0±0.2	6.9±0.4	212±6	1.1±0.1	7.9±1.3	3.6±1.2	38.3±1.1	6.5±1.0
S_{15}	8.8±0.1	26.0±0.9	7.0±0.2	191±4	1.6±0.4	8.1±1.1	3.8±1.5	40.7±4.5	6.9±0.2
S_{16}	8.0±0.2	25.5±0.7	6.5±0.2	193±3	1.3±0.1	10.9±0.9	4.5±1.6	42.6±3.1	7.1±0.1

Bile Sulphate (TCBS) agar and incubated at 35° C for 24 hrs. *Vibrio* sp. grew on the agar plates as yellowish, round colonies

Data analysis and interpretation: The data were analyzed by the Microsoft INSTAT and Excel Statistical packages and other statistical analyses were carried our according to Zar[16].

RESULTS AND DISCUSSION

Physicochemical parameters: Table 1 shows physicochemical water quality parameters of Lake Sagara. The turbidity values ranging from 20-126.5 NTU were recorded in the studied sites of Lake Sagara (data not shown). The high turbidity could be attributed to the vigorous mixing due to winds and shallowness of the lake (maximum depth was 6.5 m). The water temperature range was 24.4-27.0°C, increasing in places of higher disturbance. As for the pH values, the range was 6.8-8.8. The high pH values in disturbed areas, notably Ugalla, Mabwe and Mkwajuni, reflect the intensified human activities such as fishing, bathing and washing. Chloride levels (7.9-17.4 mg L^{-1}) were within the international standard water quality requirements[17]. The values of conductivity (89-212 is/cm), phosphates (1.0-4.5 mg L^{-1}), organic nitrogen (0.8-2.2 mg L^{-1}); abundant sediments and algal blooms depict a profound eutrophication in Lake Sagara. This is due to the high amounts of sediments imported and the amount of organic matter internally generated. The addition of large amounts of phosphorus (in the form of phosphate anion, PO_4^{3-}) from a variety of man-made sources accelerate the process of eutrophication. Such lakes eventually become marshes and ultimately dryland[18,19]. The source of phosphates in the lake could be surface runoff from agricultural practices such as the use of phosphate-containing fertilizers, the spreading of manure in the bare fields and the rearing of livestock around the lake. Figure 2 shows how Lake Sagara is being transformed into a marshland as a result of invasion by hydrophytes and swampy vegetation.



Fig. 2: Effect of eutrofication in Lake Sagara: Liliaceae and cyperaceae encroachment reduce the lake into a swamp at *Sole* sampling site

Dissolved oxygen (DO), COD and BOD value ranges were, respectively, 6.2-7.3 mg L^{-1}), 22.1-42.6 and 3.8-7.1 mg L^{-1}. These parameters, used as indicators of water quality, shows that, for the time being the levels of oxygen-demanding wastes in Lake Sagara can still sustain aquatic life[20]. However, the continued addition of organic matter into the lake through surface run-off and direct human activities will continue to stimulate oxygen consumption, raising the COD and BOD. The dynamics of these parameters need to be monitored periodically in order to determine the rates of oxygen depletion on long-term basis.

Microbiological parameters: As shown in Table 2, the values of TPC and coliforms for samples collected in Lake Sagara were high. The presence of *Vibrio* sp. and *Salmonella* sp. though at low levels (1-6 CFU mL^{-1}), shows that the water is contaminated

Table 2: Microbiological water quality of lake sagara

Location	Total plate count (MPN/100 mL)	Total coliforms (MPN/100 mL)	Feacal coliforms (CFU mL^{-1})	Enterobacte-riaceae (CFU mL^{-1})	*Vibrio* sp. (CFU mL^{-1})	*Salmonella* sp. (CFU mL^{-1})
S_1	292x10^2±90	540±12	55±14	1300±28	2±1	1
S_2	279 x10^2±85	920±17	42±9	1350±32	3±1	4±1
S_3	254 x10^2±70	870±11	30±12	1475±15	4±2	2
S_4	290 x10^2±30	540±6	40±10	1080±10	5±1	3±1
S_5	196 x10^2±25	220±2	42±3	1050±25	4±2	2±2
S_6	238 x10^2±45	370±5	70±15	1400±42	3±1	4±1
S_7	275 x10^2±20	260±12	65±10	952±20	5±2	3±2
S_8	286 x10^2±15	260±16	60±11	1200±10	6±1	0
S_9	271 x10^2±18	350±9	55±5	930±5	4±1	2±1
S_{10}	236 x10^2±21	170±15	71±13	720±17	3±2	4±2
S_{11}	221 x10^2±110	210±18	10±1	630±5	2±1	0
S_{12}	219 x10^2±90	240±17	45±11	810±17	4±2	3±2
S_{13}	242 x10^2±82	260±10	66±8	952±10	6±3	2
S_{14}	230 x10^2±17	530±20	37±2	1275±20	2±1	3±1
S_{15}	195 x10^2±18	210±12	34±2	928±12	3±1	1
S_{16}	206 x10^2±26	220±9	31±9	850±11	2±1	3±1

Table 3: Correlation matrix of water quality parameters of Lake Sagara. Values shown represent the Spearman rank correlation coefficient, with the probability of a Type I error in parentheses

	Temp.	DO	Conducti -vity	total org. Nitrogen	Chlorides	Total $P0_4^{3-}$	COD	BOD_5	T.P.C.	T.C.	F.C.	E.B.	*Vibrio* Sp.	*Salmonella* Sp.
pH	0.2571	0.1196	0.03100	0.1698	0.03030	0.03030	0.5295	0.5055	0.2566	-0.08080	-0.3323	-0.1889	-002357	-0.1720
	(0.3363)	(0.6590)	(0.9093)	(0.5297)	(0.1921)	(0.9113)	(0.0349)*	(0.058)*	(0.3373)	(0.7661)	(0.2085)	(0.4834)	(0.3795)	(0.5241)
Temp.		(-0.1190)	-0.05835	0.1751	0.09799	-0.08990	0.1929	0.1937	-0.4918	-0.2945	0.03443	-0.1945	0.1593	0.09371
		(0.6607)	(0.8301)	(0.5167)	(0.7181)	(0.7406)	(0.4742)	(0.4722)	(0.0530)	(0.2681)	(0.8993)	(0.4704)	(0.5557)	(0.7300)
DO			-0.1712	0.4609	-0.1008	0.003712	0.01926	0.01186	-0.09334	-0.04170	-0.2478	-0.04003	-0.5737	-0.1751
			(0.5260)	(0.0724)	(0.7103)	(0.9891)	(0.9436)	(0.9652)	(0.7310)	(0.8781)	(0.3548)	(0.8830)	(0.0202)*	(0.5166)
Conducti-				-0.3395	-0.4786	0.1180	0.5931	0.6141	-0.2517	-0.05030	-0.5394	0.1105	0.1357	-0.3357
vity				(0.1983)	(0.0607)	(0.6634)	(0.0155)*	(0.0114)*	(0.3471)	(0.8532)	(0.0310)*	(0.6838)	(0.6164)	(0.2036)
Total Org					-0.04364	0.02741	-0.1922	-0.1746	-3208	-0.2407	-0.2828	-0.3173	-0.5103	-0.1694
Nitrogen					(0.8725)	(0.9197)	(0.4758)	(0.5179)	(0.0058)	(0.3692)	(0.2886)	(0.2311)	(0.0434)*	(0.5306)
Chlorides						0.1438	-0.4371	-0.4742	0.5430	0.1501	0.4775	0.06922	0.2201	0.3720
						(0.5952)	(0.0905)	(0.0635)	(0.0297)*	(0.05789)	(0.0614)	(0.7989)	(0.4127)	(0.1559)
Total							0.4539	0.3945	-0.2255	-0.2785	-0.3107	0.4381	-0.3201	0.1833
$P0_4^{3-}$							(0.0774)	(0.1305)	(0.4011)	(0.2962)	(0.2415)	(0.0897)	(0.2268)	(0.4989)
COD								0.9934	-0.5647	-0.4021	-0.6141	-0.3738	-0.2139	-0.3627
								(<0.0001) ***	(0.0227)*	(0.1226)	(0.0114)*	(0.1538)	(0.4263)	(0.1674)
BOD_5									-0.6019	-0.4379	-6131	-0.3689	-0.2156	-0.3849
									(0.0136)*	(0.0898)	(0.0116)*	(0.1597)	(0.4226)	(0.1410)
T.P.C.										0.7066	0.3417	0.5283	0.3374	-2.621E-24
										(0.0022) **	(0.1952)	(0.0354)*	(0.2012)	(1.0000)
T.C.											-0.03405	0.8550	0.1045	0.1929
											(0.9004)	(<0.0001) ***	(0.7002)	(0.4741)
F.C												0.05748	0.4013	0.3292
												(0.8325)	(0.1234)	(2132)
E.B.													0.09950	0.1263
													(0.7139)	(0.6412)
Vibrio Sp.														-0.09907
														(0.7151)

* = significantly correlated, ** = very significantly correlated, *** = extremely significantyly correlated, DO: Dissolved Oxygen, EB: Enterobacteriaceae, FC: Fecal coliform, TC: Total Coloiforms, TPC: Total Plate Count

with potential pathogenic bacteria hence unfit for human consumption[17]. This reflects poor hygienic practices by the local fishermen and farmers in the surrounding villagers. The possible sources of contamination are both man, other animals and the environment, man playing a major role. Surface runoff from the catchment area also accounts for the input of enterobacteriaceae into the lake. TPC is considered to represent the contamination from the natural environment while coliforms and Enterobacteriaceae give an indication of contaminant sources from animals including man. Most of the fishermen in fishing camps have no toilets or if they have, the toilets are so shallow such that when it rains, the rainwater sweeps off the excreta and discharges into the lake water. Coliform bacteria are associated with enteric pathogenic microorganisms and have been shown to be

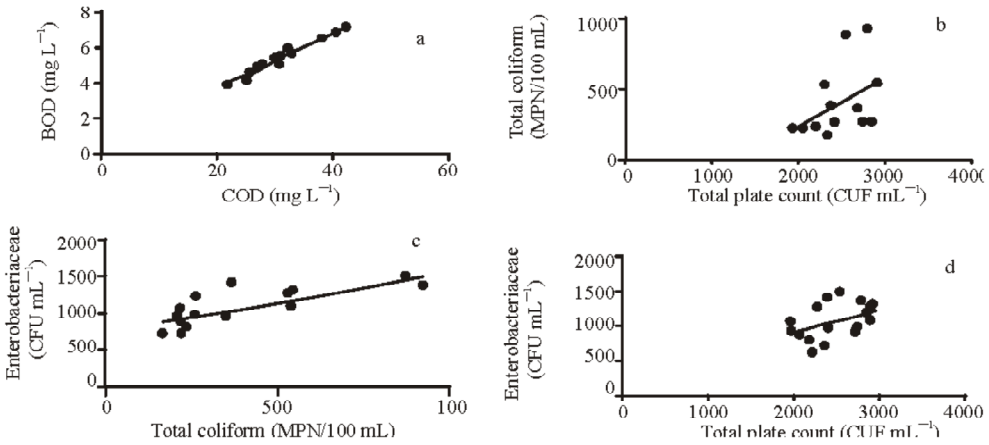


Fig. 3: Positive correlations of some physicochemical and microbiological water quality parameters of Lake Sagara. The correlation coefficient values are shown in Table 3

useful indicators of the presence of fecal contamination. Enterobacteriaceae is a family of many genera including the pathogenic genera such as *Enterobacter*, *Krebsiella* and *Shigella* which are common in animal faeces[21,22]. The presence of high levels of enteric bacteria in the study sites suggests that the lake water should be disinfected or boiled before drinking.

Relationships between physicochemical and microbiological water quality arameters: The inter-and intra-relationships between physicochemical and microbiological parameters are shown in Table 3. Figure 3 shows positive correlations of some physicochemical and microbiological water quality parameters from Table 3. COD and BOD_5 were significantly positively correlated, indicating that there are considerable amounts of both inorganic organic matter in Lake Sagara. BOD_5 was significantly negatively correlated with total aerobic plate count and total coliforms, implying that at high organic loading rates, the ecosystem retards the growth of aerobic microorganisms and favors the growth of anaerobes. Total plate count was very significantly positively correlated with total coliforms and entero-bacteriaceae, indicating that the bulk fraction of microorganisms found in Lake Sagara are related to human and other animals. In 2002, the Nguruka Health Center recorded more than 60,000 cases of water-borne diseases. The high counts of enteric pathogenic microorganisms found in this study confirms that lake water was a source of such infections. Therefore, there is a need for vigorous awareness campaigns and health education programs to the villagers on proper hygienic practices.

CONCLUSIONS

This study revealed that although Lake Sagara is safe from industrial and domestic sewage pollution, its existence is being threatened by high influx of inorganic and organic solids, rapid shallow-up and enteric pathogenic contamination. In order to control the problems of eutrophication, lake shallowing and microbial contamination, health education and training programs for fishermen and villagers in general on proper hygienic practices should be emphasized. The government should enforce laws on proper land-use practices particularly for lakeshore inhabitants to avoid farming and livestock rearing at the vicinity of the lake. It is further recommended that a more intensive and periodic studies on the physicochemical and microbiological dynamics of Lake Sagara should be carried out.

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