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Full Length Research Paper

Microbial safety assessment of recreation water at Lake Nabugabo, Uganda

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This study assessed the microbial safety of Lake Nabugabo beaches for recreation. Faecal microbial indicators and physico-chemical characteristics of beach recreational water were determined. Water sampling was done between 10.00 and 11.30 h and 1700 and 18.00 h. Data was analysed using student t-tests, ANOVA and spearman correlation (at 95%). Results were: total coliform (10.5-15.8 CFU/100 ml), faecal coliform (10-12.5 CFU/100 ml), *Escherichia coli* (0-2.63 CFU/100 ml), faecal streptococci (0-1.5 CFU/100 ml), all significantly different (P<0.05) from the control and electrical conductivity (27-32.6 µS/cm), pH (7.1), turbidity (12.6-26 NTU), total dissolved solids (13.2-15.4 mg/l), total suspended solids (12.6 - 13.4), colour (10.3 Pt-Co), alkalinity (29.3 mg/l), hardness ($CaCO_3$) (32.5 mg/l), total nitrogen (1.3 mg/l), ammonium-N (0.6 mg/l), nitrate (0.05 mg/l), total phosphorus (0.8 mg/l), orthophosphates (0.02 mg/l), iron (0.2-0.3 mg/l), calcium (1.2-1.8 mg/l), magnesium (0.4-0.6 mg/l), sodium (1.2-2 mg/l), potassium (1.8-2.6 mg/l), all not significantly different (P > 0.05) from the control. Total coliforms and faecal streptococci exhibited significant correlation with TSS (r = 0.9, p = 0.04). Results indicate that Lake Nabugabo water is safe (WHO, US-EPA) for recreation.

Key words: Lake Nabugabo, microbial safety assessment, recreation water, water quality.

INTRODUCTION

Contamination of water bodies is on the increase and is causing major public health concerns in developing countries where water regulations are lacking. Pathogenic microorganisms are introduced into aquatic ecosystems from the catchment via different agents that include humans, animals and effluents. The microbial composition of aquatic ecosystem depend on the type, nature of the aquatic ecosystem, microbial profile of effluents (Jaiani et al., 2013) and the contaminating agents (for example, humans, wild animals). Organisms of public health concerns in recreational waters include *Salmonella* spp., *Escherichia coli*, *Shigella* spp., *Clostridium* spp.,

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Vibrio spp and various human enteric microbes and protozoa (Wade et al., 2003; WHO, 2005). Therefore, the most significant threat of contamination is autochthonous microorganisms that may be triggered to multiply when the environment is favourable for growth (Jaiani et al., 2013). Water contamination can be assessed by various methods (APHA, 1998; WHO, 2001, 2003) depending on the intended use of the water.

Swimming and bathing in inland waters are recognized forms of full contact recreation activities but due to poor management, waters may easily be contaminated by humans as a result of people defecating in the water and possible sewage discharges or overflows (EPA, 2001). It is therefore useful and necessary to monitor recreational waters continuously for human pathogens as a way to prevent swimming associated infections (Wade et al., 2008).

A study in the USA (Wade et al., 2010) found that gastro intestinal illnesses were associated with swimmers as compared to non- swimmers. Information on microbial safety classification of recreational water is important to the public and managers from public health and economic perspectives (Abbott et al., 2011).

Lake Nabugabo and its wetland system form the second biggest Ramsar site in Uganda after Lake George (Byaruhanga et al., 2006). The lake attracts a number of bird watchers and researchers. Besides research, the lake has for long been used as a site for recreation including parties, picnics, boat rides, swimming and bathing. This has resulted in business developments along the lake shores. Consequently, the lake has experienced transformation from a pristine water source to a more developed recreational site with two beaches and additional sites under development. With the increasing rate of recreational activities in the lake and the physical development (structures and sanitation facilities) at the shores, contamination potential of the lake has increased.

Compared to other Ugandan lakes such as Victoria, Kyoga, Edward and George, Lake Nabugabo has been most preferred for swimming and bathing because it is believed to be safe from Bilharzia due to the absence of snails, the intermediate hosts of Schistosomes (Ogutu-Ohwayo, 2002). There is little information about microbial safety of East African lakes for recreation activities, while most studies concentrated on the suitability of water for drinking (Matano and Anyona, 2013; Olapade, 2013). Although available information is on drinking water quality, results obtained indicate serious contamination with total coliforms, faecal coliform and faecal streptococci, implying that the water is unsafe for use. While a number of studies have been carried out on Lake Nabugabo on aspects such as benthic macro-invertebrates (Efitre et al., 2001), nutrient dynamics (Okot-Okumu, 2004), environmental history of the lake (Stager et al., 2005), there is lack of information on the microbial safety of the lake. The microbial safety of recreational water users of Lake Nabugabo is still unknown. Understanding the lake's microbial safety for recreation is paramount and was the motivation of this study.

The overall objective of the study was to assess the suitability of Lake Nabugabo water for recreation with respect to microbial safety.

MATERIALS AND METHODS

The study was carried out on Lake Nabugabo in Masaka District, Central Uganda (Figure 1). Lake Nabugabo is a shallow ($\bar{x}$= 2.5 m) lake lying near the equator, about 100 km south-east of Kampala City. Lake Nabugabo is a satellite lake of Lake Victoria and is separated from the latter by a sand bar of only two kilometres wide. The lake is about five kilometres long with a surface area of 24 square kilometres. It is situated at an altitude of approximately 1140 m, average minimum temperature for this part of Uganda does not drop below 15°C and the average maximum temperature varies little between 25 and 30°C (Cheng, 2006).

Water samples were collected from two beaches of Lake Nabugabo [Sand Beach (Beach 1) and Holiday Centre (Beach 2)]. For sampling location consistency, coordinates of the sampling sites were obtained using a Garmin GPS within zones of recreation along the beaches and control point in the middle of the lake. Samples were collected once a month for a period of five months covering the last Friday, Saturday and Sunday when the beaches had heightened recreation activities. Sample collection and preservation were done in accordance with Standard Methods for Examination of Water and Wastewater (APHA, 1998).

The water samples were collected just below surface twice a day, in the morning between 10.00 and 11.00 h and in the afternoon between 17.00 and 18.00 h at waist height depth of approximately 0.65 m (near shore) and breast height of approximately 1.0 m depth (offshore). Control samples were collected by boat in waters towards the middle of the Lake, the lake zone that is not normally used for swimming. Samples were kept in an icebox at temperatures of 4°C during the time before laboratory analysis. *In situ* determinations were: temperature (°C) and pH using electrode probe WTW TA 197pH/T, electrical conductivity (μScm^{-1}) and total dissolved solids (mgl^{-1}) using Hach 4460000 conductivity meter, turbidity (NTU) using HACH 2100A turbidity meter.

Laboratory bacteriological analysis was done for total coliforms, faecal coliform, *E. coli* and faecal streptococcus following Standard Methods for Examination of Water and Wastewater (APHA, 1998), sections 9221 B, 9221 E, 9221 F and 9230 C, respectively. Membrane filtration (0.45 µm pores), growth media used, incubation procedure and bacteria enumeration were according to APHA (1998). Physico-chemical parameters: total suspended solids (TSS), colour Ptco, NO_3^-, PO_4^{3-}, total nitrogen (TN), ammonia, total phosphate (TP), Fe^{2+}, Ca^{2+}, Mg^{2+}, K^+, alkalinity and hardness ($CaCO_3$) were all analysed in the laboratory following APHA (1998).

Statistical analysis

Data was analysed in Excel 2010 and SPSS (21st edition). All statistics were computed at a 95 percent confidence level ($p \leq 0.05$). A one sample student t-test was used to compare the recreational water samples with controls, two sample student t-test was used to compare microbial counts between the two beaches, ANOVA was used to compare mean values of all samples collected

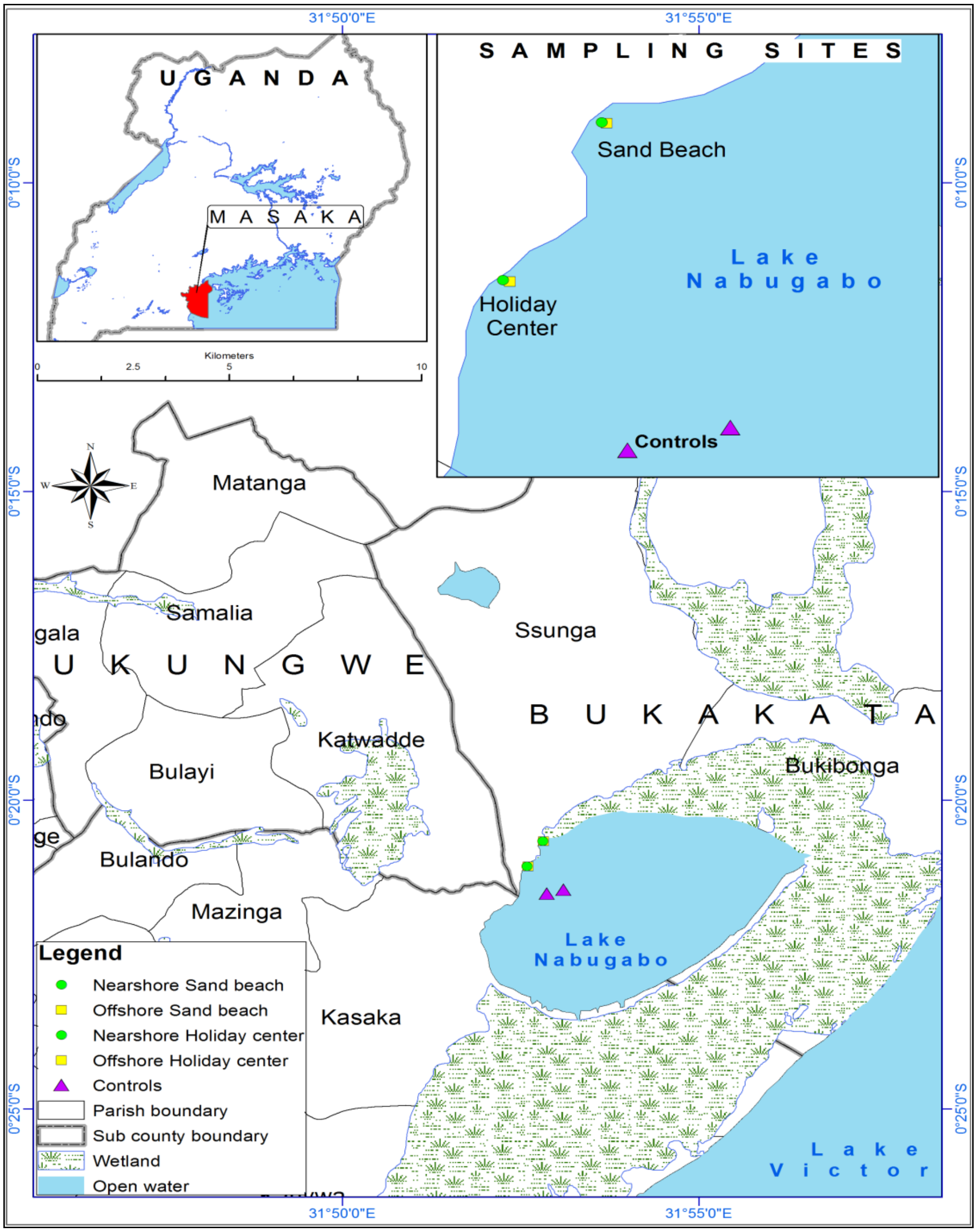

Figure 1. Map of Lake Nabugabo showing sampling sites.

throughout the study period and Spearman correlation analysis 'r' was conducted to determine relationship between microbial and physico-chemical water quality aspects.

RESULTS AND DISCUSSION

The microbial quality (mean values) of Lake Nabugabo water is presented in Figure 2 for the two beaches assessed. Sand beach faecal coliform, total coliform, *E. coli* and faecal streptococci counts were 10-11.5, 10.5-14.8, 2-2.5 and 0.3-1.2 CFU/100 ml, respectively. Holiday Centre beach faecal coliform, total coliform, *E. coli* and faecal streptococci were 10-12, 12-15, 1.7-2.2 and 0.8-1.3 CFU/100 ml, respectively.

Coliform bacteria

Total coliform data was a general indication of the microbial contamination of Lake Nabugabo. According to

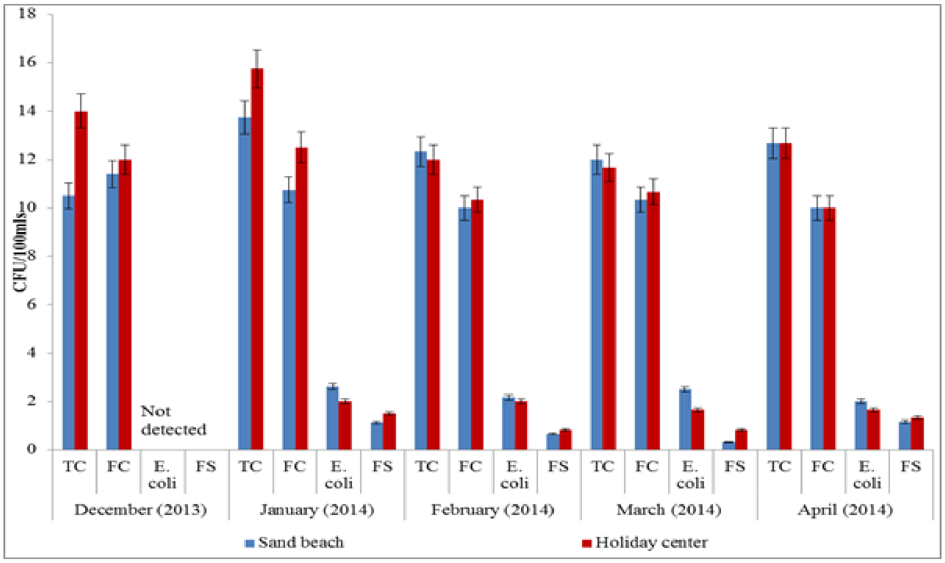

Figure 2. Microbial counts at the beaches of Lake Nabugabo. TC- Total coliforms, FC- faecal coliforms, *E. coli*- *Escherichia coli*, FS- faecal streptococci.

DWA (1996), total coliform gives an indication of the general sanitary quality of water since this group includes bacteria of faecal origin. Lake Nabugabo total coliform counts was low as compared to findings of studies of coastal waters (Abbu and Lyimo, 2007; Mwakalobo et al., 2013) in Tanzania and urban lakes (Shirude et al., 2014) in India. This can be attributed to variation in number of recreational users and the frequency of use of the various lakes/beaches studied.

Faecal coliform bacteria which are more specific indicator of human contamination of water in Lake Nabugabo exhibited counts lower than total coliform that is similar to finding by Mwakalobo et al. (2013) on Pangani, Ruvu and Mzinga creeks along the coast of Tanzania. Faecal coliform is part of the total coliform counts and therefore as expected is lower than total coliform counts taken from the same point of assessment. Faecal coliform counts obtained in Lake Nabugabo were comparable to findings at Rasi Dege in Dar es Salaam, Tanzania (Abbu and Lyimo, 2007) but very low as compared to findings of Lake Kivu in Rwanda (Olapade, 2013). The low values of faecal coliform counts in Lake Nabugabo could be due to low pollution inputs from near shores areas of the lake catchment.

According to information obtained from the beach owners at Lake Nabugabo, the recreational use of the lake was mostly during weekends. The number of recreational water users varied between 50 people during rainy season months (November, March and April) and 600 people during dry and sunny months (December, January and February). The number of recreational water users and frequencies of beach water use was lower at Lake Nabugabo as compared to other water bodies (Abbu and Lyimo, 2007; Mwakalobo et al., 2013), that also had higher faecal bacterial counts. This could be an indication of human population influence on faecal coliform contamination of recreational waters.

Lake Nabugabo is a rural fresh water body where human settlements are approximately 500 m away from the shores implying that direct pollution input from the catchment settlements is very low if any. It is therefore presumed that the recreational water users at the beaches were the main source of bacterial contamination of Lake Nabugabo. Animals like donkeys and cattle although not in very big numbers were observed entering the shallow waters of Lake Nabugabo to drink and waterfowls were also common. According to Choi et al. (2003), although humans or sewage effluents are sources of faecal indicator bacteria in water, wildlife and waterfowl may also contribute to the observed total coliform counts. Results of total coliform and faecal coliform counts indicate that Lake Nabugabo has not yet been exposed to immense faecal contamination.

Escherichia coli

E. coli counts obtained in Lake Nabugabo water were low as compared to findings for other water bodies like Lake Kivu in Rwanda (Olapade, 2013), bathing beaches in Durban, South Africa (Mardon and Stretch, 2004), coastal waters in Greece (Vantarakis et al., 2005) and natural recreation waters of Southern Portugal (Valente et al., 2010). The low counts of *E. coli* in Lake Nabugabo can be attributed to the presumed low contaminant input from the catchment. Although sanitation facilities like septic

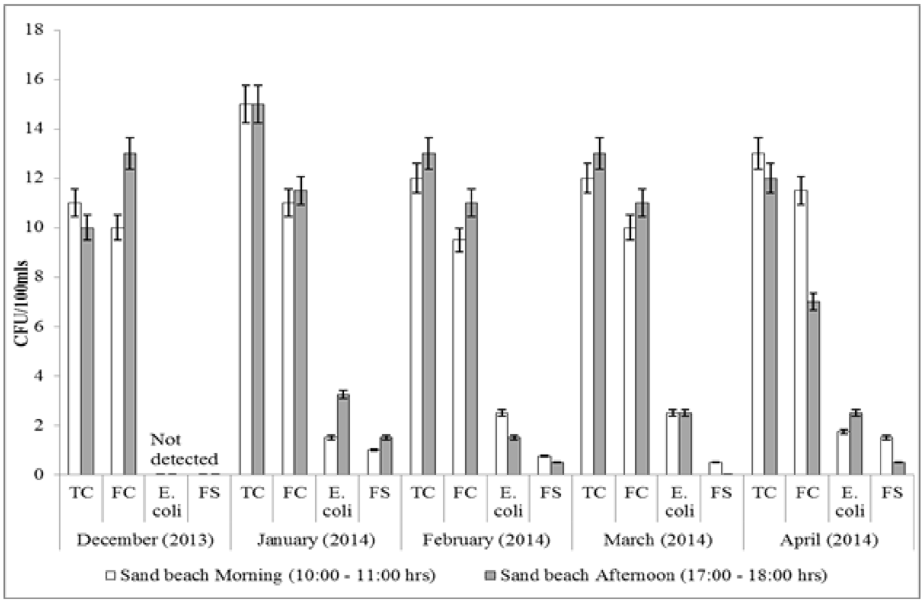

Figure 3. Microbial variations with sampling time in different months at Sand Beach, Lake Nabugabo. TC- Total coliforms, FC- faecal coliforms, *E. coli- Escherichia coli*, FS- faecal streptococci.

tanks and pit latrines are located less than 250 m away from Lake Nabugabo shores, the *E. coli* counts indicated that these facilities currently do not have any significant contamination impact on the lake. However, environmental factors such as high irradiation levels and visible light typical of tropical climate such as at Lake Nabugao, have bactericidal effects (Vermeulen et al., 2008). According to Vermeulen et al. (2008), the proportion of the surviving *E. coli* cells decreases exponentially with increase in radiation dosage at a given wavelength.

Faecal streptococci

Faecal streptococci counts in Lake Nabugabo as in many other water bodies (Mardon and Stretch, 2004; Valente et al., 2010; Olapade, 2013; Mwakalobo et al., 2013), were found to be far lower than any other bacterial indicators. Faecal streptococci is normally low in number in faeces of humans and other warm-blooded animals as compared to other bacteria indicators (Mwakalobo et al., 2013). Faecal streptococci rarely multiply in polluted water and are more resistant to disinfection than coliform organisms (UNESCO/WHO/UNEP).

Temporal variation in microbial contaminants

Microbial counts were also compared with respect to time of sampling to check whether time of sampling contributed to variation in counts of faecal indicator microorganisms. Figure 3 shows variation in microbial counts with sampling time at Sand Beach while Figure 4 shows variation in microbial counts with sampling time at Holiday Centre.

Generally, afternoon sample microbial counts were higher ($p < 0.05$) than morning sample counts. This is due to the fact that afternoon samples were normally collected during and after swimming and other recreation activities. The increased contamination level therefore can be attributed to human contamination of the lake water during the afternoon recreation activities. This observation at Lake Nabugabo is similar to findings of a study in Rwanda (Olapade, 2013).

Spatial variation in microbial contaminants

Total coliforms can naturally exist in open surface water bodies and so are not considered for this comparison. There was a significant difference between faecal coliform counts at Sand Beach and control ($p = 0.01$ for December (2013), $p < 0.001$ for January, February, March and $p = 0.02$ for April in 2014). Similarly, there is a significant difference between faecal coliform counts at Holiday Centre and control ($p = 0.04$ for January, $p < 0.001$ for February, March and $p = 0.01$ for April 2014). There was no significant difference between *E. coli* counts at Sand Beach and control ($p = 0.2$ for January, $p = 0.4$ for February, $p = 0.13$ for March and $p = 0.4$ for

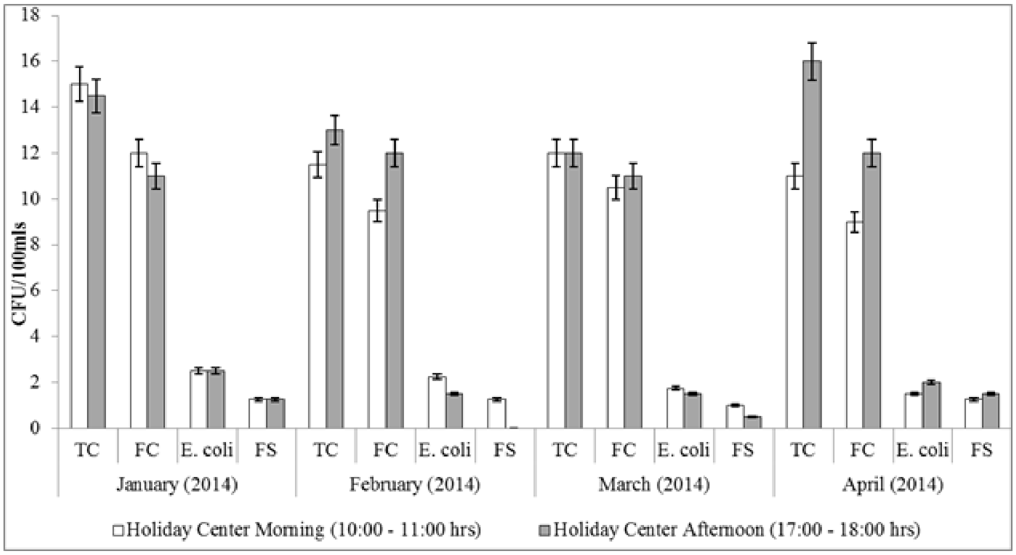

Figure 4. Microbial variations with sampling time in different months at Holiday Centre, Lake Nabugabo TC- Total coliforms, FC- faecal coliforms, *E. coli*- *Escherichia coli*, FS- faecal streptococci.

April in 2014). There was also no significant difference between *E. coli* counts at Holiday Centre and control (p = 0.3 for January, p = 0.4 for February and p = 0.8 for March and April 2014). There was a significant difference between faecal streptococci counts at Sand Beach and control in the months of January and April (p = 0.004 and p = 0.01, respectively) but no significant difference in the months of February and March (p = 0.1 and p = 0.2, respectively). There was a significant difference between faecal streptococci counts at Holiday Centre and the control (p = 0.001 for January, p = 0.04 for February, March and p = 0.01 for April 2014). The observed significant difference in bacterial counts between the control and the beaches indicate the influence of human recreation activities on the level of contamination of Lake Nabugabo water.

Comparing Lake Nabugabo water with recreational water standards

Uganda and East Africa countries do not have recreational water standards, and for purposes of this research therefore, results are compared with internationally recognized standards. Bacteriological counts from Lake Nabugabo recreation water when compared with South Africa, US-EPA, EC and WHO standards indicate that the lake water is ‘very good’ and ‘very safe’ for recreation. Table 1 summarizes comparison of our findings with the various international recreational water quality standards.

From Table 1, the bacteriological counts compared favourably with various standards implying that Lake Nabugabo water is safe for recreational activities. Classification of Lake Nabugabo beaches according to EC guidelines indicates that the beaches achieve an overall “excellent” rating based on the *E. coli* counts. Given the controversies attached to many of the faecal indicator microorganisms, faecal streptococci remain the most doubtable microbial indicators of human faecal contamination of any water source.

Since the bacteriological (Total coliform, Faecal coliform, *E*. *coli*, Faecal streptococci) study on Lake Nabugabo has not demonstrated any substantial contamination, the lake therefore probably still has the opportunity for self-purification to maintain water of environmentally insignificant microbial levels with low risk of infection during recreation. This observation however only applies to the current situation and may change if the pollution threshold is exceeded, which will reduce the capacity of the lake to ameliorate the situation and the water will become unsafe for recreational activities.

Physical chemical characteristics of Lake Nabugabo water

Table 2 summarises the physico-chemical parameters determined during the study. The results indicate low ions and nutrient (mesotrophic) and low buffering capacity lake water characteristics as illustrated in Table 2.

Lake water turbidity was lower during calm weather as compared to windy conditions that recorded high turbidity values when water was turbulent. High turbidity reduces

Table 1. Comparison of research findings with recreational water standards.

Institution/Country	Standard value	Sand beach (Average value)	Holiday Centre (Average value)	Comment
Faecal coliforms				
South Africa	≤ 130	10.5 CFU/100 mls	10.7 CFU/ 100 mls	Values fall within acceptable ranges of South African recreational water standards. Lake Nabugabo water is safe for recreation activities in reference to faecal coliforms contamination
Escherichia coli				
US EPA	≤ 126	2.4 CFU/ 100 mls	2 CFU/100 mls	Values fall within acceptable ranges of all standards. Lake Nabugabo water is safe for recreation activities as far as *E. coli* is concerned
EC	≤ 100			
New Zealand	≤ 130			
South Africa	≤ 30			
Faecal streptococci				
WHO	≤ 40	0.8 CFU/100 mls	1.1CFU/100 mls	Values obtained fall within acceptable ranges of all standards. Lake Nabugabo water is safe for recreation activities, in reference to faecal streptococci contamination.
US EPA	≤ 33			
EC	≤ 100			
Australian	≤ 40			
New Zealand	≤ 40			
South Africa	≤ 130			

Table 2. Physico-chemical characteristics of Lake Nabugabo.

Parameter	Average value+	Relevance to recreational water
EC (µS/cm)	27.9 ± 0.7	-
pH	7.1 ± 0.0	Eye and skin irritation
TN (mg/l)	1.3 ± 0.0	-
Nitrate (mg/l)	0.1 ± 0.0	-
Ammonia (mg/l)	0.6 ± 0.0	-
TP (mg/l)	0.8 ± 0.1	-
Ortho-P (mg/l)	0.02 ± 0.0	-
Turbidity (NTU)	20.8 ± 1.4	Aesthetics
TSS (mg/l)	13.0 ± 0.4	Aesthetics
TDS (mg/l)	14.9 ± 2.5	-
Colour (Pt co)	10.3 ± 0.6	Aesthetics
Fe^{2+} (mg/l)	0.2 ± 0.0	Aesthetics
Ca^{2+} (mg/l)	1.6 ± 0.1	-
Mg^{2+} (mg/l)	0.5 ± 0.0	-
Na^{+} (mg/l)	1.8 ± 0.1	-
K^{+} (mg/l)	2.3 ± 0.1	-
Alkalinity (mg/l)	29.3 ± 0.8	-
Hardness ($CaCO_3$, mg/l)	32.5 ± 1.1	-

+Average values.

aesthetics value of recreational, since the water becomes unsightly and less attractive for swimming and bathing.

The recorded alkalinity of the lake water indicates low buffering capacity of the lake. The buffering capacity of

Table 3. Spearman's rank correlation analysis for water quality parameters of Lake Nabugabo.

Parameter	TC	FC	*E. coli*	FS	pH	EC	Turbidity	TDS
FC	r = -0.4 p = 0.5	1						
E. coli	r = 0.6 p = 0.3	r = 0.0 p = 1	1					
FS	r = 1** p < 0.001	r = -0.4 p = 0.5	r = 0.6 p = 0.3	1				
pH	r = -0.4 p = 0.5	r = 0.1 p = 0.9	r = 0.4 p = 0.5	r = -0.4 p = 0.5	1			
EC	r = -0.05 p = 0.9	r = -0.8 p = 0.8	r = -0.6 p = 0.3	r = -0.05 p = 0.9	r = -0.2 p = 0.7	1		
Turbidity	r = -0.6 p = 0.3	r= 0.2 p = 0.7	r = 0.2 p = 0.7	r = -0.6 p = 0.3	r = 0.9* p = 0.01	r = -0.2 p = 0.7	1	
TDS	r = 0.1 p = 0.9	r = 0.8 p = 0.1	r = 0.3 p = 0.6	r = 0.1 p = 0.9	r = 0.1 p = 0.9	r = 0.8 p = 0.08	r = 0.0 p = 1	1
TSS	r = 0.9* p = 0.04	r = -0.2 p = 0.7	r = 0.3 p = 0.6	r = 0.9* p = 0.04	r = -0.6 p = 0.3	r = -0.05 p = 0.9	r = 0.8 p = 0.1	r = 0.3 p = 0.6

TC = Total coliform, FC = faecal coliform, *E. coli* = Escherichia coli, FS = faecal streptococci, pH = water pH, EC = electrical conductivity, TDS = total dissolved solids, TSS = total suspended solids ** = correlation is significant at 0.01, * = correlation is significant at 0.05, (r ≤ 0.2) = weak linear correlation, (r>0.2≤0.6) = moderate linear relationship, (r≥0.7) = strong linear relationship.

water is strongly related to pH (UNESCO/WHO/UNEP, 1996). Although Lake Nabugabo alkalinity was low, the average pH was almost neutral, that was, favourable for survival of microorganisms. This means contaminant bacteria could survive well unless impacted by external factors such as strong sunshine (UV light) that kills bacteria. Lake Nabugabo had low ions contents. The physico-chemical characteristics of the lake water (Table 2) were all comparable to Okot-Okumu's findings in 1999, which is an indication that the lake has been fairly stable for more than ten years as regards physico-chemical characteristics.

Physico-chemical characteristics of Lake Nabugabo water were studied to understand lake phenomena and determine any significant relationship between physico-chemical and microbial components of the water and also to aid in future reference studies. According to Maipa et al. (2001) survival of most bacteria in water is also dependent on temperature, pH, solar radiation and other factors, all of which have to be taken into consideration when interpreting results. The lake water pH is 7.1 which is recommended for recreational water use (Raibole and Singh, 2011). According to WHO (2003), pH has a direct impact on the recreational users of water only at very low or very high values, which may have effects on the skin and eyes. There are no specific guidelines for physico-chemical parameters for recreational waters. However, parameters such as TSS, turbidity and colour that are visible, certainly do affect aesthetics value of the water. Iron at certain concentrations may cause colouring of the water hence its aesthetic value.

Correlation between physico-chemical and microbial parameters

Spearman's rank correlation analysis (Table 3) shows that among all physico-chemical parameters, TSS was significantly correlated with microbial contaminants [total coliform: (r = 0.9, p = 0.04); faecal streptococci (r = 0.9, p = 0.04)]. According to Muirhead et al. (2006), the strong relationship between microbial contaminants and TSS is reasonable because bacteria are likely to attach to fine suspended particles. Faecal streptococci was also significantly correlated with hardness (r = 0.9, p = 0.005), total phosphorus (r = 0.9, p = 0.005) and total coliforms (r = 1, p < 0.001).

Faecal coliform has exhibited a significant negative correlation with colour (r = -0.9, p = 0.01). There are also significant relationships between physico-chemical parameters like pH and turbidity (r = 0.9, p = 0.01), hardness and colour (r = -0.9, p = 0.005), colour and total phosphorus (r = -0.9, p = 0.005), hardness and total phosphorus (r = 1, p < 0.001). Although not significant, faecal coliforms and *E. coli* was also positively correlated with TSS.

The correlation analysis (Table 3) was done to establish relationships and understand the interaction between individual microbial contaminants and physico-chemical parameters of Lake Nabugabo. This was done to possibly aid future studies to use as dummies, water physico-chemical parameters that demonstrate strong correlation with microbial contaminants. Caution should however be taken when using physico-chemical parameters to explain microbial contamination status of a given water resource because it may not always be the case, since many factors both internal and external (Maipa et al., 2001) interact to determine the survival of bacteria in water.

Conclusions

It has been demonstrated that Lake Nabugabo water has low microbial contamination levels. Although microbial counts within the recreational zones were higher than microbial counts for non-recreational zones of the lake, all microbial populations fall within acceptable limits for recreational water standards implying that Lake Nabugabo water is microbially safe for recreation. Physico-chemical parameters of Lake Nabugabo were found at permissible levels of recreational water quality standards which further contribute to the assertion that Lake Nabugabo is safe for recreation. Notwithstanding, there is need for national guidelines for managing risks in recreational water in Uganda. Guided use of recreational water will create confidence among swimmers and ensure that the water users are safe from contamination.

Conflict of interest

The authors declare that there is no conflict of interest.

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