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Water Quality in and around Lake Edward Basin of the Greater Virunga Landscape, D. R. Congo Side

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Abstract

A systematic study has been carried out to assess the water quality in and around Lake Edward basin in D.R. Congo Side. Fifty four water samples were collected and analyzed for physicochemical parameters, including: temperature, discharge, pH, electrical conductivity, transparency, dissolved oxygen, COD, BOD, Carbonate, Bicarbonate, alkalinity, total hardness, turbidity, calcium hardness, calcium, magnesium hardness, magnesium, total nitrogen, ammonium, nitrate, total phosphorus, soluble reactive phosphorus, chloride, sulphate and total suspended solids. For bacteriological parameters: fecal bacteria, enterococcus bacteria, vibrio and salmonella shigella bacteria were considered. For macroinvertebrates assemblages all taxa using standards methods for each parameter. A comparison of data from dry (June to August) and wet (September to May) season was done in and around Lake Eduard watershed. The analytical data of various physicochemical parameters indicates that water characteristics in the watershed were in the limit of WHO standards for drinking water and aquatic life. Bacteriological water quality of some ecosystems in the watershed revealed the infestation of water with bacteria which make the water unusable for drinking by the surrounding population near and within Lake Eduard watershed. Longtime period sampling in the watershed is needed to understand the variation and composition of water quality and aquatic macroinvertebrate environment of the watershed.

Keywords

Water Quality, Lake Eduard, Greater Virunga, Landscape, D. R. Congo

1. Introduction

Water is one of the most important and most precious natural resources of the ecosystem. It is essential in the life of all living organisms from the simplest plant and microorganisms to the most complex living system known as human body [1]. All living organisms on the earth need water for their survival and growth. But due to increased human population, industrialization, use of fertilizers in agriculture and man-made activity, water is highly polluted with different harmful contaminants. Therefore it is necessary that water quality be checked at regular time intervals to avoid human diseases and biodiversity losses [2] [3] [4] [5].

Natural water contains different types of impurities as well as introduced impurities in different ways such as weathering of rocks and runoff of surface soils, atmospheric deposition of aerosol particles and from several human activities [6] [7]. High levels of pollutants mainly organic matter in river water cause an increase in biological oxygen demand [8], chemical oxygen demand, total dissolved solids, total suspended solids and fecal coli form. They make water unsuitable for drinking, irrigation or any other use [9].

The increased use of heavy metal pollution in agriculture and industry could result in a continued rise of the concentration in freshwater and production of chronic poisoning in aquatic animals and human [10]. Furthermore, fecal pollution of water causes water born disease, which has led to the death of millions of people and can affect also other biodiversities in water bodies [11]. Therefore, water quality concerns are often the most important component for measuring access to improved water sources. To ensure the safety of drinking water, acceptable quality in terms of its physical, chemical and bacteriological parameters should be checked [7]-[12].

Lake Edward is a large watershed with varied ecosystems, rich in biodiversities such as a wide variety of fish species and other aquatic resources [13]. However, the excessive use of various agrochemicals in the nearby lands of the rivers, uncontrolled urbanization, lack of well-planned development on the river banks and population growth are increasingly polluted the watershed water ecosystems. The surrounding lands are used for agricultural activities and water of these ecosystems is generally used for irrigation purposes and drinking water for the population as well as animals. People nearby the rivers and Lake use these water ecosystems for washing their clothes, bathing, washing their cattle, etc. These anthropogenic activities may degrade the quality of water in Lake Edward basin. According to Kilham [14] and Lehman [15], despite their ecological, evolutional and geological roles, the real ecology and chemistry of the rivers in the broad south-eastern plain, and others that flow across the western Mitumba escarpment into Lake Edward are essentially unknown and unmeasured.

However, no water quality or water quantity data exists for tributaries rivers and the lake itself, except the work of Talling and Talling [16] and Bagalwa *et al.* [17], who studied the water quality in some rivers feeding Lake Edward. The re-

sults of their studies showed that water quality was suitable for aquatic life and some selected microorganisms consisting of total coliform, fecal coliform (*Escherichia coli*) and *Vibrio cholera* were present. Nevertheless, they didn't consider in their studies heavy metals and anions concentrations, which also play a vital role in assessing water quality along with physicochemical and bacteriological (microorganisms) parameters.

A basic understanding of Lake Eduard watershed is necessary for park managers to preserve the high quality of water resources and the biodiversity using the water [13]. This includes not only Lake Eduard, but the inflows to the lake as well. It is hypothesized that the quality of water in the catchment of the lake Eduard is deteriorated by anthropogenic activity taking place actually. Obtaining knowledge of the entire watershed could lead to a better understanding of the spawning habitat of fish and other unique biodiversities in the Lake but also in the entire Virunga National Park catchment.

The present study was conducted to assess the water quality of the ecosystems in and around Lake Edward watershed with respect to physicochemical parameters and major heavy metals concentrations, bacteriological parameters as well as macroinvertebrates assemblages.

2. Materials and Methods

2.1. Sampling Site

The study area covers Lake Edward and its catchment area in DR Congo side. The catchment of Lake Edward covers 15,840 km^2. The lake is fed primarily by rivers draining the surrounding mountains. In addition, the Kazinga Channel, a 30 km-long, 1 km-wide, drowned river valley that flows from Lake George (914 m a.s.l.) to the east, is a major inflow. Lake George is mainly fed by streams draining the Rwenzori Mountains [18]. Currently, Lake Edward overflows into the Semliki River, which runs northwards into Lake Albert and hence to the White Nile like **Figure 1** shows.

The annual rainfall varies from 650 - 900 mm [19]. The monthly mean maxima of temperature vary from 26.3˚C in January to 30˚C in September, while the minima vary from 15.5˚C to 17.8˚C. The absolute maximum temperature is of 32˚C generally in February, and the absolute minimum temperature is of 14˚C generally recorded in January, February, June and July [13] [20].

2.2. Physicochemical Analysis

Two methods were used to determine the quantity of water at the sampling sources. Discharge from rivers was measured by determining the velocity of a floating object and the total cross-sectional area of the river following the Floating Method procedure [21] [22]. For source and borehole bucket and stopwatch method was used. Very easy method to estimate discharge by simply measuring the time it takes to fill a container of a known volume. This method only works for systems with fairly low flow volume. A bucket of 10 liters was placed

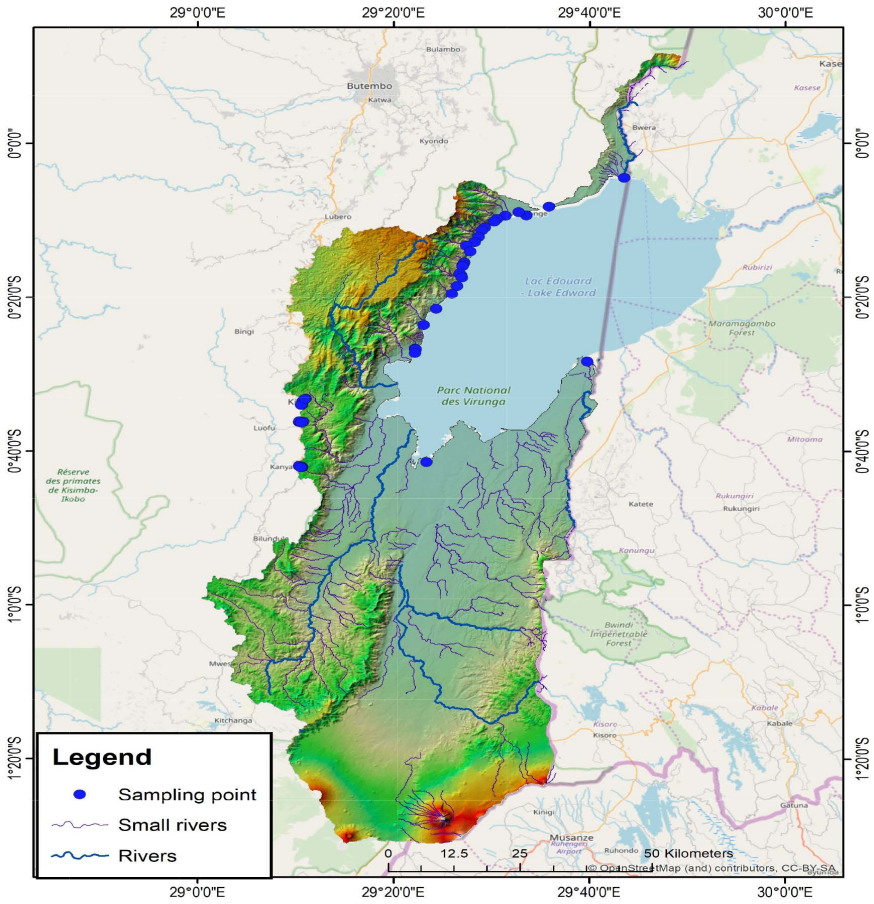

Figure 1. Study area and sampling sites, Lake Edward Basin Congo side.

underneath in order to capture all the discharge and a stopwatch was used to estimate the time necessary to fill the bucket [23].

Surface water temperature, pH, Conductivity, Transparency, Dissolved Oxygen (DO), five-day Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Hardness, Calcium, Magnesium, Chloride, Sulphate, Fluoride, Hydro-carbonate, Free CO_2, Total phosphorus, soluble reactive phosphorus, Total nitrogen, Ammonium, Nitrate and Total Suspended Solide (TSS) were measured in different sites and analyzed following the procedures described in Golterman *et al.* [24], APHA [25], Wetzel and Liken [26].

Samples were collected during different times of the day. At each sampling point, two water samples were collected in prewashed glass bottles. Water was collected at a depth of 30 cm, near midstream in plastic bottles at the same time, for other chemical analyses (heavy metals). The plastic bottles were rinsed before overnight with 1 M HCl and then with distilled water. At the site, bottles were also rinsed thrice with sample water before final collection. The samples were placed in a cooler box with ice for transportation at Goma Volcano Observatory laboratory. Analyses were not done immediately upon arrival at the laboratories; samples were stored in a refrigerator at 4˚C with preservation as appropriate. *In situ*, temperature was measured using an YSI PROFESSIONAL PLUS. The

meter sensor was dipped into the water and the temperature reading was recorded after the meter had stabilized. The pH was determined using the same YSI PROFESSIONAL PLUS, which was first standardized with two buffers (4 and 10). The conductivity was also measured in situ with the same equipment. Transparency of the water was determined with the aid of Secchi disc. The calibrated disc was lowered into the water and the depth at which it disappeared observed and recorded. The level of DO in the water was determined after fixation in the field, following the iodometric Winkler's method [24] [27]. BOD_5 was measured as the decrease in DO after incubation in the dark at 20˚C for five days. The BOD_5 in mg/L of DO was calculated by subtracting the mg/L of DO in incubated sample bottles from the DO in initial bottles [28]. Hydro-carbonate (HCO_3^-) was estimated titrimetrically using 0.1 N HCl with phenolphtalein and bromocresol as indicators (5%). Total hardness determined by complexometric method using EDTA after added a tampon and Eriochrome T indicator. Calcium hardness also was determined by complexometric method using mirixid indicators. Magnesium was determined by subtracting the Total hardness and calcium hardness. The Chloride was determined by titration with silver nitrate and potassium chromate indicator [24]. The sulfate was determined using gravimetrical method. TSS ($mg{\cdot}l^{-1}$) was estimated by filtration of water samples through analytical filter paper (Whatman 589, 185 µm pore size), which was dried at 105˚C and pre-weighed [25]. The nutrients (TN, NO_3^-, NH_4^+, TP and PO_4^{3-}) were determined using a spectrophotometer (UNICO 1200 at 630 nm for nitrogen and 850 nm for phosphorus). All measurements were made in duplicate. Data were compared with UNECE [29]; FEPA, [30] and WHO [31] standards.

2.3. Heavy Metal Analysis

Collected sub-samples were sent to INES regional laboratory for heavy metal testing. Lead, Cadmium, Zinc, Nikel, Chronium, Selenium, Iron, and Mercury-water content were determined. For analysis of Cd, Pb, Ni, Zn and Cu direct determination by flame atomic absorption spectrometry as described in ISO 8288 [32] was used. The test sample was acidified by adding nitric acid in order to obtain a pH of 1 to 2. An acidified sample portion of 100 ml was used for analysis. Calibration solutions were also prepared using standard solutions of 1000 ppm (Sigma Aldrich Inc.) for each element. Absorptions of calibration solutions were measured and standard curves were plotted. Test solutions were also tested and absorptions obtained were projected on the standard curves to get the corresponding concentrations. Results were reported in mg/l.

Mercury was determined using AAS method after tin(II) chloride reduction without enrichment as described in ISO 12,846 [33] and Iron as described in ISO 6332 [34]. Calibration curve were prepared by measuring the absorbance standard solution of respectively mercury and iron at different concentrations. Results were reported in mg/l.

2.4. Bacteriological Analysis

Samples were collected in clean, sterile polypropylene 200 mL bottles. Before the bottles were washed with deionized water and sterilized in the oven at 60˚C overnight. At the field, bottles were washed thrice before collecting sample. All samples were kept in refrigerated cool box and transported to the laboratory. All analyses were completed at the Laboratory of Bacteriology at Goma Volcano Observatory. Analyses for total coliform, fecal coliform and fecal streptococci were made in accordance with standard methods [25]. Nutrient agars (NA), Salmonella-shigella agar, Thiosulphate citrate bile salt sucrose agar were used to determine heterotrophic bacterial, Salmonella and Shigella, *Vibrio cholera* respectively [35].

Due to insecurity reasons in the region, we were not able for streams and rivers to follow an upstream to downstream gradient. Sampling was done both for the wet season (September to May) and the dry season (June to August).

2.5. Macroinvertebrate Sampling and Analysis

The benthic macro-invertebrates were collected using a standard form hand-net of 30 cm wide, 20 cm high and 50 cm long with mesh size of 500 μm. They were collected along the river stretch in a stream direction with an effective sampling effort of 10 minutes per person [36]. The presence of stones in the river bed and water plants were taken in the hand-net and washed in a bucket to collect macro-invertebrate attached. The collected organisms were stored and preserved in formalin 4 % on the field. Identification was made at the malacology laboratory of up to the species level when possible using the keys of determination of Needhan and Needham [37] and Micha and Noiset [38]. If the species were not fund in the key, the identification was restricted to the family or genus level.

3. Results and Discussion

The highest temperature in the watershed was recorded at Vitshumbi fountain (28.6˚C) and the lowest was recorded at Muwe River (19.2˚C). This temperature is higher than the temperature recorded in Mikeno sector (16˚C to 20˚C) by Karume *et al.*, [39]. Temperature is an important water factor because the rate of chemical reactions increases at higher temperatures, which in turn affects biological activities and growth of aquatic organisms [40]. The temperature was conform to the WHO recommended range of 20˚C - 32˚C and will not constitute any problem to the residents [12]. pH varied from 9.39 in Semuliki river to 3.23 in Biondi ground water. This range is out of range of the WHO standards for drinking water [12]. Ground water sustainability is a major challenge because the ground water is a widely distributed resource that is affected by local users and contamination [41]. Electrical conductibility is high in Rutshuru River (1882 μS/cm) and low EC was recorded in river sans nom (38 μS/cm). These highest values in Rutshuru River show the influence of human activities on the physical quality of water in the living place where river crosses. The variation of EC is

observed in all the sampling sites as also observed in other studies in the same watershed [42] and inrivers in Cote d'Ivoire [43] [44]. Two rivers were dry during this dry season in the watershed and the discharge varied from river to river and springs during the period of study. Turbidity also varied from sampling points, but it is low in spring and fountain except in Vitshumbi fountain where turbidity is high (180 NTU). The highest value was recorded at Lubiriya River sampling site (743 NTU). Chloride varied from 156 mg/L (Katiri fountain) to 24 mg/L (Ancien Muramba). Concentrations of chloride in all the sampling sites were in the range of the WHO standards for drinking water [12]. Dissolved Oxygen (DO) and Chemical Oxygen Demand (COD) varied in sampling sites during the dry season. Water from sampling sites was very well oxygenated. Generally the DO concentration is higher than 5 mg/L. COD and BOD_5 show generally an inverse curve. When BOD_5 is high COD is low. Alkalinity varied from 508 mg/L (Rutshuru River) to 4 mg/L (4 mg/L). The highest value of Total hardness was recorded in the river Lubiriya (12.32 mg/L) and the lowest in the river Kisaka and Ikanga 1 River (1.15 mg/L) but for Calcium Hardness the highest value was recorded in Ikanga 2 River (5.44 mg/L) and at Ancien Muramba (0.29 mg/L). Magnesium Hardness varied all from site to site with the highest value recorded in Lubiriya River (6.36 mg/L) and the lowest value in Kyavinyonge 800 m large (0 mg/L). The highest concentration of Sulfate was recorded in Ancien Muramba River (364.8 mg/L) and the lowest concentration in Muwe River (3.84 mg/L). Except Ancien Muramba, all other sampling sites are in the range of standards for drinking water [12] as indicated in **Table 1**. Total Phosphorus concentration is high in Lubiriya River (2.16 µmole/L) while Soluble Reactive Phosphorus concentration is high in Kisaka spring (1.63 µmole/L). Total Nitrogen and Nitrate concentration are high in Lubiriya River (29.89 µmole/L and 26.68 µmole/L). Total Suspend Solid varied also from sampling sites. The highest concentration of TSS is recorded in Lubiriya River (0.29 g/L).

There were significant occurrences in some physicochemical parameters which call for caution on discharge untreated waste into Lake Eduard. The sampling sites near populated villageson the lake shore were found to have high concentrations of pollutants. It is a common practice for people living along the lake watershed to discharge their domestic waste as well as human excreta into rivers, which transport them in the Lake. Wild and Domestic animals using the same drinking water can also contaminate the water through direct defecation and urination [45] [46] and caused increase of physicochemical parameters. The high loads of pollutants were more prominent in rainy season as compared to dry seasons. Comparative results of physics parameters during the dry and wet seasons in 2015-2016 for rivers, surface lake water, springs, ground water and fountains in Lake Eduard watershed are present in **Table 2**.

There were in general no significant differences in the values between the wet season and the dry season ($P < 0.05$) in Lake Eduard watershed. But some physical parameters values increased and others decreased. Some rivers discharges could not be taken over the two period and others disappear in dry season.

Table 1. Mean chemical characteristics of sites around and in the Lake Eduard during the dry and wet period of sampling (2015-2016).

Sites	Chloride (mg/L)	DO (mg/L)	BOD5 (mg/L)	COD (mg/L)	Alkalinity (mg/L)	Carbonate (mg/L)	Total Hardness (mg/L)	Calcium Hardness (mg/L)	Magnesium Hardness (mg/L)	Sulfate (mg/L)	TP (µmol/L)	SRP (µmol/L)	TN (µmol/L)	NH_4^+ (µmol/L)	NO_3^- (µmol/L)	TSS (g/L)
Semiliki River	50	8.6	5	57.6	224	0	4.30	1.43	1.72	245.76	0.11	0.086	5.886	0.534	0.642	0.18
Kagezi River	32	1.59	0.59	64	44	0	5.44	3.44	1.20	103.68	0.054	0.05	8.73	0.99	0.582	0.14
Ikanga 1 River	20	7.5	1.9	57.6	52	0	1.15	0.57	0.34	119.04	0.114	0.1	4.914	0.426	0.468	0.08
Ikanga Torrent River	32	7.3	1.7	57.6	24	0	2.86	1.43	0.86	145.92	0.107	0.075	4.848	0.492	0.408	0.5
Sans nom River	26	5.63	0.83	60.8	28	0	3.72	1.72	1.20	138.24	0.131	0.121	4.866	0.414	0.594	0.14
Ntungwe River	22	4.71	0.71	60.8	44	0	3.72	1.43	1.37	168.96	0.325	0.304	5.982	0.678	0.552	0.68
Kisaka River	24	5.22	3.22	96	24	0	2.58	1.15	0.86	180.48	0.775	0.515	10.458	1.542	2.67	6.7
Rutshuru River	40	5.21	2.01	35.2	16	0	5.44	1.72	2.23	134.4	0.167	0.159	7.656	0.924	0.438	0.4
Katundu River	20	6.25	3.55	105.6	36	0	2.86	1.43	0.86	241.92	0.223	0.219	9.294	1.086	0.39	0.62
Murhamba 2 River	22	6.68	2.92	67.2	24	0	2.86	1.15	1.03	99.84	0.138	0.114	8.154	1.266	0.396	0.62
Rwindi River	24	3.24	0.76	54.4	44	0	2.86	2.29	0.34	253.44	0.086	0.079	8.016	0.864	0.366	0.56
Butuku fountain	22	6.18		60.8	24	0	5.44	0.86	2.75	84.48	0.159	0.128	5.592	0.348	0.306	0.1
Muwe River	42	6.4	2.4	86.4	80	0.4	2.58	2.29	0.17	184.32	0.268	0.226	3.066	0.354	0.9	0.54
Kyavinyonge Spring	22	ND	ND	64	56	0	7.73	2.86	2.92	176.64	0.226	0.219	2.976	0.804	0.222	0.18
CEBK fountain	28	6.14		51.2	72	0	6.01	4.01	1.20	76.8	0.205	0.131	4.332	0.408	0.186	0.06
Kinawa River	40	5.39	1.41	67.2	28	0	6.59	2.86	2.23	188.16	0.107	0.1	5.946	0.774	0.96	0.42
Katiri fountain	30	6.17		60.8	16	0	5.73	1.72	2.41	184.32	0.043	0.033	4.656	0.444	0.306	0.1
Biondi ground water	56	3.7		54.4	32	0	6.59	4.01	1.55	53.76	0.283	0.184	5.646	0.714	0.72	0.28
Gite 1 fountain	40	6.67		44.8	24	0	3.44	1.72	1.03	92.16	0.145	0.142	5.22	0.54	0.36	0.06
Kavasembe fountain	50	6.24		41.6	52	1.6	2.86	0.57	1.37	99.84	0.058	0.033	3.912	0.348	0.288	0.14
Ikanga 2 River	40	6.85	2.25	54.4	20	0	6.87	5.44	0.86	107.52	0.5995	0.441	1.656	0.204	0.894	0.06
Karukumbwa	60	4.24	0.36	57.6	40	0	6.59	2.86	2.23	149.76	0.093	0.072	2.532	0.528	0.534	0.16
Kyalibwa River	40	5.8	3.8	16	36	0	2.86	1.72	0.69	264.96	0.107	0.054	3.834	0.426	0.954	0.34
Gite fountain	44	4.16		48	24	0	4.30	1.15	1.89	207.36	0.036	0.036	3.288	0.252	0.606	0.02
Katana fountain	50	4.46		12.8	184	4	3.44	2.86	0.34	149.76	0.079	0.065	5.31	0.63	0.384	0.04

Continued

Apres Muko	42	5.03	2.17	0	80	1.6	4.58	0.57	2.41	184.32	0.191	0.103	2.088	0.252	0.264	0.04
Mulera spring	68	6.38		0	20	0.8	7.16	1.15	3.61	0	0.093	0.054	3.702	0.258	0.276	0.02
Kavutika fountain	50	5.48		9.6	8	0	10.02	2.86	4.30	38.4	0.061	0.043	2.478	0.282	0.246	0.16
Lunyasenge River	30	4.72	3.68	6.4	24	0	5.73	1.43	2.58	238.08	0.585	0.455	4.224	0.576	0.576	0.16
Musenda River	26	5.23	1.17	3.2	24	0	8.02	1.15	4.12	222.72	0.089	0.043	3.756	0.324	0.402	0.24
Kisaka Spring	30	5.42		6.4	24	0	4.58	2.00	1.55	176.64	0.395	0.325	2.754	0.366	1.002	0.16
Kisaka 1 River	42	3.27	1.53	6.4	64	0	9.45	2.00	4.47	211.2	2.104	2.058	2.844	0.276	0.546	0.18
Muko River	30	5.02	2.02	16	56	0	4.01	1.43	1.55	180.48	0.11	0.1	0.69	0.87	0.966	0.62
Lubiriya	32	7.64	4.24	19.2	40	0	12.32	1.72	6.36	49.92	0.332	0.138	7.2	0.36	0.516	0.58
Kyavinyonge 0 m large	40	3.98	2.62	16	200	2.4	4.01	2.86	0.69	126.72	0.124	0.107	1.068	0.312	0.354	0.62
Kyavinyonge 200 m large	48	3.2	2.6	19.2	212	2.4	3.72	2.86	0.52	69.12	0.05	0.043	0.768	0.492	0.378	0.27
Kyavinyonge 800 m large	26	2.34	2	19.2	208	6.4	3.15	3.15	0.00	126.72	0.068	0.065	1.62	0.54	0.432	0.24
Murhamba River	32	6.12	1.08	9.6	52	1.6	6.87	3.72	1.89	103.68	0.142	0.124	3.546	0.714	0.666	1.03
Muko Chute 2	32	5.76	2.76	0	88	2.4	8.88	0.57	4.98	119.04	0.149	0.05	4.266	0.414	0.492	0.04
Ancien Murhamba River	38	5.61	2.59	12.8	124	1.6	4.01	0.29	2.23	172.8	0.276	0.181	10.998	0.822	0.594	0.62
Kalibuta river	ND	6.28	2.72	19.2	ND	ND	6.59	3.44	1.89	ND	2.624	0.268	5.046	0.594	0.678	0.09
Rwessa River	34	6.24	4.76	9.6	128	0.4	7.16	1.15	3.61	176.64	0.29	0.272	5.712	0.648	0.756	0.44
Muharabu spring	36	6.26		6.4	108	0	4.30	0.86	2.06	184.32	1.091	1.01	3.528	0.432	0.3	0.1

Table 2. Physics parameters of rivers, ground water, lake water, springs and fountains in Lake Eduard watershed in dry and wet seasons (2015-2016).

	Temperature (˚C)		pH		EC (μS/cm)		TDS (mg/L)		Tutbidity (NTU)		Discharge (m^3/s)	
Sites	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Semuliki river	25.7	28.2	9.39	7.98	874	79.1	435	158	83	80	40	60
Kagezi river	25.4	25.4	7.64	6.92	92	77.3	46	154	249	45	ND	7.53
Ikanga 1 River	22.8	22.4	8.84	7.84	203	54.6	102	109	94	28	T	T
Ikanga Torrent River	23.1	22.6	8.25	7.69	96	125	48	250	114	Clear	0.004	T
Sans nom River	22.3	23.6	8.32	7.01	38	44.1	19	88	75	Clear	0.02	0.9
Ntungwe River	23.5	22.7	8.22	7.98	187	92.2	94	184	361	12	0.005	0.8
Kisaka River	22.1	23	7.14	7.58	61	25	30	50	107	0	0.09	3.41
Rutshuru River	23.7	21.4	8.35	6.9	1882	1627	944	3250	86	100	40	17.85
Katundu River	22.4	23.1	5.59	7.04	108	67.1	54	134	77	7	0.02	4.85
Murhamba 2 River	ND	21.5	ND	7.87	ND	35.2	ND	70	ND	26	ND	0.9
Rwindi River	21.2	20.5	7.98	6.55	226	679.4	113	1358	233	16	1.5	18
Butuku fountain*	21	21.4	7.4	6.67	96	77.8	48	155	75	ND	ND	0.75
Muwe River	19.2	22.3	7.52	7.66	407	262	204	524	416	Clear	0.0012	0.021
Kyavinyonge Spring	26.9	ND	8.86	7.8	207	ND	104	ND	75	ND	ND	ND
Kasando (CEBK) fountain*	21.2	20.9	7.14	6.35	352	313.3	178	626	75	ND	0.05	0.06
Kinawa Spring	23.6	23.4	7.43	6.91	97	288	48	576	75	Clear	ND	0.015
Katiri (Tsero) fountain*	23	23.4	6.27	6.92	329	71.9	165	143	121	ND	ND	0.37
Biondi (Libulu) ground water	20.8	21.1	3.23	8.21	590	522	295	1044	84	34	ND	ND
Mutikili (Gite 1) fountain*	26.4	25.2	8.04	7.24	168	118.7	84	237	85	ND	ND	0.9
Kavasembe river*	23.7	21.8	3.84	7.35	325	76.3	161	152	167	ND	0.00004	0.99
Ikanga 2 River	23.1	21.4	8.98	8.3	92	27	46	54	79	19	T	T
Kasado (Karukumbwa) river	20.6	21.8	3.98	6.58	347	297.2	173	594	112	Clear	0.2	0.015
Kyalimbwa River	22.3	21.6	7.76	6.7	334	192	167	384	197	Clear	1.6	5
Singamwambe (Gite) fountain*	22.3	23.7	7.66	7.5	138	111.8	69	223	75	ND	ND	0.6
Kinawa (Katana) fountain*	23.6	28.4	7.43	7.88	97	794	48	1588	75	ND	ND	0.43
Apres Muko river	23.4	24.2	8.31	7.99	87	86	43	172	79	Clear	0.0003	0.07
Mulera spring*	26.2	23	5.87	7.45	60	55.2	30	110	75	ND	ND	0.37
Kavutika fountain*	22.9	21.4	5.98	7.1	352	282	176	564	75	ND	0.25	0.3
Lunyasenge River	22.7	24.1	7.2	7.71	141	81.3	71	162	83	14	0.1	ND
Musenda River	21.4	21.8	8.59	7.6	97	57.7	48	115	75	49	0.12	5.86
Kisaka Spring*	25.6	23.1	7.46	6.94	109	98.2	54	196	75	ND	0.18	0.37
Kisaka 1 River	D	22.5	ND	7.25	ND	194.7	ND	389	ND	11	ND	ND
Muko River	23.3	22.5	8.53	8.9	67	49	34	98	75	62	0.015	2.3
Lubiriya river	22.6	23.1	7.74	8.6	183	111.7	92	223	743	23	2.5	18.75

Continued

Lake Kyavinyonge 0 m	28.2	27.1	8.84	8.03	881	792	445	1584	82	8	ND	ND
Lake Kyavinyonge 200 m	26.7	27.5	9.47	8.35	887	799	444	1598	90	15	ND	ND
Lake Kyavinonge 500 m	28.4	27.6	7.45	8.23	888	799	444	1598	82	158	ND	ND
Murhamba River	23.1	22.1	8.36	8.25	74	44.5	37	89	75	15	Delta	12.5
Muko Chute 2	23.3	23.6	8.53	8.14	67	365	34	730	75	Clear	0.015	T
Ancien Murhamba River	22.8	23.6	8.33	8.61	69	65.9	34	131	75	17	0.13	2.9
Kalimbuta river	21.9	22.5	8.71	7.8	42	31.5	21	63	79	Clear	Delta	T
Rwessa River	21.3	23	8.3	7.09	200	117.4	100	234	77	8	0.012	1
Muharabu spring*	26.2	23	7.29	7.19	90	112.9	45	225	75	ND	13	0.43
Vitshumbi fountain*	28.9	ND	4.56	ND	866	ND	433	ND	180	ND	ND	ND
Chahulwa river	20.3	ND	7.56	ND	227	ND	113	ND	173	ND	0.005	ND

Legend: *Discharge in L/sec, T: Torrent, ND: No data, D: Disappeared.

Heavy metal characteristics of water in and around Lake Eduard ecosystem are presented in **Table 3** below.

Results reveal that the concentration of heavy metal is low in water in and around Lake Eduard to standards for natural potable water WHO [12]. That situation is probably due to the nature of the bedrock in the watershed and localization of rivers in a forest where human activities are not common. But with the population increase in the region in search for food this situation may change and water became polluted. Then a regular checking of water quality in the region is recommended to keep the Lake Eduard pristine to diver's heavy metal contamination.

Bacteriological analysis of water in different sampling sites is present in **Table 4** below.

During the sampling period in Lake Eduard watershed, 6 types of bacteria contaminated water in and around Lake Eduard watershed. The results show that, six sampling sites were contaminated with *Escherichia coli*, 8 with Klesbiella, 3 with Citrobacter, 13 with Enterobacter, 1 with Salmonella and 2 with *Vibrion cholera*. Among the sampling points, 27 were found with one or two contaminating bacteria and 14 were found exempts with bacterial contamination. In Dry season two sampling points were contaminated with the *Vibrion cholera* contrary to the sampling in wet season. *Vibrio cholera* and Salmonella were reported in samples in Lake Eduard and its tributaries before in the study conducted by Bagalwa *et al.* [42], their presence in the samples confirms that these bacteria are present in Lake Eduard watershed and these occur in dry season. Bagalwa *et al.* [42] carried out their study in the same watershed (Lake Eduard) collecting water from sites different from the present study, and at different time of the year, but the presence of these bacteria was also indicated. This confirms that these bacteria are present in the watershed. It was reported diarrhea diseases in some villages as Lunyansenge caused by consumption of contaminated water and

Table 3. Heavy metal characteristics (means in mg/L) of rivers, ground water, lake water, springs and fountains in Lake Eduard watershed (2015-2016).

	Hg (0.001)*	Cu (1.00)	Cd (0.003)	Fe (0.3)	Zn (5)	Pb (0.01)	Ni (0.02)	Cr (0.05)	Se (0.01)
Ikanga 1 River	0.0012	0.00012	0.00098	0.0007	N.D.	N.D.	0.00058	0.0058	0.0014
Ikanga torrent River	0.0003	0.00012	N.D.	0.0003	0.0004	N.D.	0.00055	0.0223	0.0017
San nom River	0.00195	0.00012	0.00064	0.0007	0.0074	N.D.	0.00055	0.0053	0.0018
Kisaka River	0.0012	0.00004	N.D.	0.0008	N.D.	0.00092	0.00042	N.D.	0.0029
Katundu River	N.D.	0.00004	N.D.	0.0007	N.D.	0.00002	0.00053	0.0075	0.0025
Murhamba 2 River	0.00045	N.D.	0.00081	N.D.	0.0039	0.00029	0.00039	0.0057	0.0014
Rwindi River	N.D.	0.00004	N.D.	0.0008	0.0039	0.00038	0.00055	0.0044	0.0012
Batuku fountain	N.D.	N.D.	0.00013	0.0008	0.0004	0.000137	0.00061	0.0054	0.0014
Kavignonge spring	N.D.	0.00004	0.00021	0.0029	0.0039	0	0.00055	0.0085	0.0013
Kinawa spring	N.D.	0.00012	0.00081	0.0007	N.D.	0.00011	0.00045	0.0074	0.0014
Kavasembe River	0.00045	0.00004	0.00038	0.0022	N.D.	0.00038	0.00042	0.0014	0.0012
Apres Muko River	N.D.	0.0002	0.00047	0.0004	0.0074	0.00043	0.00039	0.0055	0.0012
Kalimbuta River	0.00045	N.D.	0.00064	0.0005	N.D.	0.00038	0.00039	0.0063	0.0013
Kasondo River	N.D.	N.D.	0.00064	0.0005	N.D.	0.00025	0.00039	0.007	N.D.
Kasondo Spring	0.00045	0	0.00047	0	0.0039	0.00092	0.00055	0.0064	0.0012
Kavutika River	N.D.	N.D.	N.D.	0.0014	0.0004	0.00029	0.00058	0.0058	0.0009
Kisaka River	0.0003	0.00012	0.00047	0.0007	0.0039	0.00025	0.00058	0.0093	0.0014
Kyalimbwa River	N.D.	0.00004	N.D.	0.0006	0.0039	0.00029	0.00055	0.0093	0.0016
Kyavinyonge River	N.D.	0.00012	0.00047	0.0028	0.0004	0.00002	0.00058	0.0073	N.D.
Kyavinyonge Spring	0.00045	N.D.	N.D.	0.0003	0.0004	0.00011	0.00045	N.D.	0.0013
Lac 10 m	0.0012	0.00004	0.00047	0.0006	0.0039	0.00011	0.0005	0.0063	0.0045
Lac 200 m	0.0003	0.00012	0.00064	0.0005	0.0039	0.00002	0.00039	0.0057	0.0028
Lac 500 m	N.D.	0.00012	N.D.	0.0004	0.0004	N.D.	0.00053	0.0068	0.0017
Biodi ground water	0.00045	N.D.	0.00047	0.0005	0.0004	0.0043	0.00053	0.0053	0.0013
Lunyasenge River	0.00105	0.00012	0.00064	0.0007	0.0004	0.00025	0.00053	0.008	0.002
Murhamba River	N.D.	N.D.	0.00038	0.0005	0.0039	0.00029	0.00039	0.007	0.0012
Musenda River	0.0003	N.D.	N.D.	0.0029	0.0074	0.00011	0.00039	0.012	0.0014
Mutikili River	0.00045	N.D.	0.00064	0.0002	0.0039	N.D.	0.00055	0.0064	0.0012
Muwe River	0.0012	0.00004	0.00021	0.0025	0.0074	0.00047	0.00042	0.0098	0.0012
Kinawa River	0.00045	0.00012	0.00047	0.0005	0.0031	0.0002	0.0005	0.0064	0.0015
Rutshuru Lb River	0.0012	N.D.	0.00047	0.0007	0.0004	0.00025	0.00053	0.0068	0.0015
Rwindi River	N.D.	0.00012	0.00081	0.0007	0.0039	N.D.	0.00058	0.0054	0.0015
Semliki River	0.00195	0.00004	0.00047	0.0005	0.0039	0.00016	0.0005	0.0061	0.0015
Singamwambe River	0.0012	0	0.00064	0.0013	0.0004	0.00029	0.00053	0.0054	0.0014
Tsere River	0.00045	N.D.	0.00047	N.D.	0.0004	0.00038	0.00061	0.0054	0.0012
Vitshumbi River	0.00045	0.00004	0.00081	0.0016	0.0039	0.00029	0.00042	N.D.	0.0012

*in brackets is the maximum value required by standards for natural potable water, in mg/l; N.D.: Not Detected.

Table 4. Bacteriological analyze of water in Lake Eduard and around the watershed (col/mL).

Sites	Citrobacter (col/mL)	Enterobacter (col/mL)	Klebsiella (col/mL)	Hafnia (col/mL)	E. coli (col/mL)	Cholerae (col/mL)	Salmonella & Shigella (col/mL)
Semiliki River	0	0	0	0	0	0	0
Kagezi River	0	0	3200	0	0	0	0
Ikanga 1 River	2000	0	0	0	0	0	0
Ikanga Torrent River	0	0	0	0	1400	0	0
Sans nom River	0	2200	0	0	0	0	0
Ntungwe River	0	0	0	0	0	0	0
Kisaka River	0	3300	0	0	10,000	0	0
Rutshuru River	0	4800	0	0	0	0	0
Katundu River	0	0	0	0	0	0	0
Murhamba 2 River	0	0	3000	0	0	0	0
Rwindi River	0	5000	0	0	0	0	0
Butuku fountain	0	0	5800	0	0	0	0
Muwe River	0	3500	0	0	0	0	0
Kyavinyonge Spring	0	800	0	0	0	0	0
CEBK fountain	0	0	0	0	5500	0	0
Kinawa River	3300	0	0	0	0	0	0
Katiri fountain	0	0	0	0	5500	0	0
Biondi ground water	0	0	2000	0	5000	0	0
Gite 1 fountain	0	0	0	0	0	0	0
Kavasembe fountain	0	6000	0	0	0	0	0
Ikanga 2 River	0	0	3000	0	0	0	0
Karukumbwa River	0	0	0	0	5000	0	0
Kyalibwa River	0	0	0	0	4400	0	0
Gite fountain	0	0	0	0	0	0	0
Katana fountain	0	0	0	0	0	0	0
Apres Muko	0	0	0	0	0	0	0
Mulera spring	0	0	0	1050	0	0	0
Kavutika fountain	0	0	0	0	0	0	0
Lunyasenge River	0	4500	0	0	0	0	0
Musenda River	0	0	0	0	1700	0	0
Kisaka Spring	6500	0	0	0	0	0	0
Kisaka 1 River	0	6000	0	0	5000	0	0
Muko River	0	0	0	0	0	0	0
Lubiriya River	2000	0	0	0	0	0	0
Kyavinyonge 0 m large	0	2800	0	0	3000	0	0
Kyavinyonge 200 m large	0	0	0	0	0	0	0
Kyavinyonge 800 m large	0	0	0	0	0	0	0
Murhamba River	0	0	0	0	0	0	0
Muko Chute 2	4800	0	0	0	0	0	0
Ancien Murhamba River	0	0	0	0	0	0	0
Kalibuta river	0	2200	0	0	0	0	0
Rwessa River	0	0	0	0	2500	0	0
Muharabu spring	0	0	6500	0	0	0	0

poor hygiene practices. This is also observed in sites where water was contaminated with Enterobacteria. This contamination of water with pathogens is reported at the source but may also occur during handling in households or other working places as reported in other studies [47]. Inadequate protection of water collection and storage containers and unhygienic conditions contribute to contamination at home.

The results also revealed that population living in Lake Eduard watershed who consumes water from shallow wells, Lake, rivers and some fountains without treatment stands the risk of bacteria diseases as the concentration of bacteria exceeds the WHO recommended limit. However, education and awareness on health risk associated with the consumption of untreated water is necessary.

Macroinvertebrate fauna different rivers in the watershed are presented in **Table 5** below during the sampling period.

Macroinvertebrate varied from river to river in Lake Eduard watershed. The highest specific richness was found in Semuliki, Musenda and Lubiriyarivers. The orders of Ephemeroptera and Diptera are largely represented in the collection. Some species are rarely found in the rivers. The Order of Tricoptera is represented with only 2 families. The presence of *Bellamya contracta* was reported in astudy by Brown [48]. Snails, the intermediate host of schistosomiasis, were also found in the rivers and can contribute to the expansion of schistosomiasis in the watershed. These snails are *Biomphalaria pfeifferi*, *Biomphalaria sudanica*, *Bulinus truncatus* and *Ferrissia burnipi* [49].

The comparison of specific richness for dry and wet season in the Lake Eduard watershed is presented in **Figure 2**.

Figure 2 shows that specific richness varied in rivers from 0 to 7. The high value was recorded in the river Lubiriya in dry season while the lowest (0 taxa) was found in wet season in Karukumba and Kisaka after rivers and also in dry season in Kalibuta River. In wet season the high runoff in rivers are pointed as the source of disappearance of many taxa while in dry season Kalibuta river forms a delta distroying the habitat of macroinvertebrate. The number of individual taxa varied also from river to river during the two sampling seasons (**Figure 3**).

The highest number of taxa was recorded in Karukumba River with 44 individuals in wet season. In general in wet season the number of indivudual taxa was high than in dry season. But comparatively to other tropical region, this number is low [17].

4. Conclusion

Variation in all the physicochemical parameters, bacteriological parasites and the macroinvertebrate assemblage were recorded around Lake Eduard watershed. Although some of the parameters of rivers conform to the WHO standard for drinking water, it still needs to be treated since parameters have values that are above the WHO standard for drinking water. Some species of macroinvertebrates

Table 5. Macroinvertebrate composition and abundance in rivers in Lake Eduard watershed.

Taxa	Semiliki River	Kagezi River	Ntungwe River	Katundu River	Murhamba 2 River	Muwe River	Kinawa River	Karukumba	Kyalibwa River	Apres Muko	Musenda River	Muko River	Lubiriya River	Ancien Murhamba River	Kalibuta river	Rwessa River	Kisaka after river	Ikanga River
Classe Insecte																		
O. Odonata																		
F. Libellulidae																		
Tachopteryx thoreyi		3			2	2	3				3	1				2		
Helocordulia sp		1									1							
F. Coenagrionidae																		
Coenagrion sp					3					5	1		3					
F. Gomphidae																		
Progomphus obscuris			2	2									2					
Gomphus sp																1		
O. Hemiptera																		
F. Nepidae																		
Ranatra sp		2														1		
F. Naucoridae																		
Ambrysus mormon										3								
O. Ephemeroptera																		
F. Baetidae																		
Baetis sp						10	4	8	3									
F. Heptagenidae																		
Isogenus modesta														2				
O. Coleoptera																	1	1
F. Dyticidae																		
Dytiscus marginalis			2				5		5				3	5				
F. Elmidae																		
Phococerrus clavicornis										1								
O. Diptera																		
F. Chironomidae																		
Chironomus tantans						32		4	8									
F. Simulidae																		
Simulis sp							6	12	17									
F. Tatanoceridae																		
Dictya pictipes								1										
F. Ceratopogonidae																		
Palpania sp								1		1								

Continued

F. Psychodidae																		
Pyschoda sp								3	3									
Classe Nematoda																		
O. Gordiidae																		
F. Gordiidae																		
Gordius sp										1								
O. Rhycobdellidae																		
F. Glossiphonidae																		
Glossiphonia complanata																1		
Classe Cristacea																		
O. Decapoda																		
F. Potamonidae																		
Potamogeton sp														2				
Classe Arachnidea																		
O. Arachnidae																		
F. Agyronectidae																		
Agyronecta aquatica																	3	3
Classe Mollusk																		
O. Basommatophora																		
F. Lymaedae																		
Lymnae natalensis													2					
F. Planorbidae																		
Biomphalaria pfeifferi													1					
Biomphalaria smithi	2																	
F. Piliidae																		
Pila ovata													5					
F. Melanoidae																		
Melanoides wagenia	4																	
F. Viviparidae																		
Bellamya constricta	1																	
O. Bivalve																		
F. Matelidae																		
Mutella dubia	2																	
F. Mactridae																		
Rangia cuneata	1																	
Specific Richness	5	3	2	1	2	3	4	6	5	5	3	2	7	3	0	4	2	2
Shannon_H	1.471	1.011	0.6931	0	0.673	0.7088	1.355	1.461	1.377	1.367	0.9503	0	1.684	0.995	0	1.332	0	0

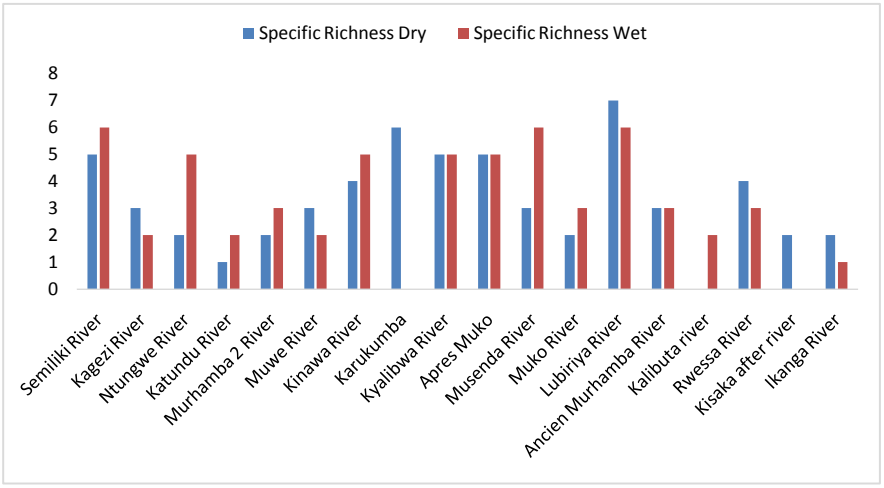

Figure 2. Seasonal variation of specific richness in Lake Eduard watershed.

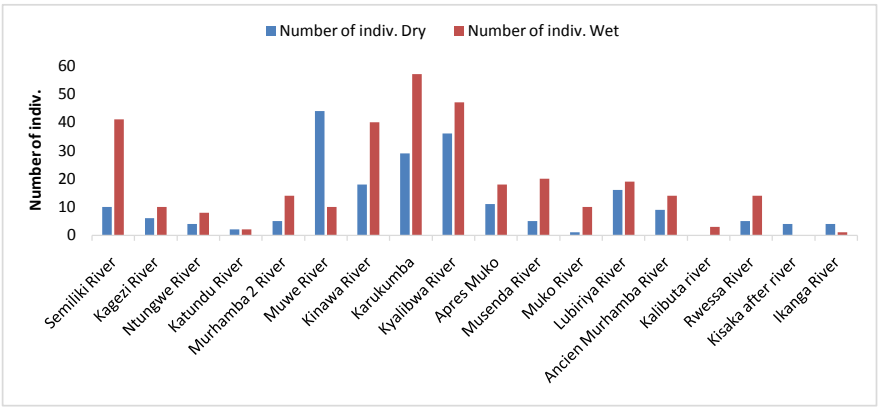

Figure 3. Seasonal variation of number of indivual taxa in Lake Eduard watershed.

are the intermediate host of many diseases including schistosomiasis and fasciolosis. Regular monitoring of water bodies with required number of parameters in relation to water quality to prevent the outbreak of diseases and occurrence of hazards should be considered. Bacteriological water quality should be carried out for a longer period of time to get a more clear idea about the water quality in the watershed. To understand variations of water quality in the Lake Eduard watershed, more sampling time in the watershed is needed.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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