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# Urbanization and Water Quality; The Effect of Bujumbura Municipal Effluents on the Western Shores of L. Tanganyika in Burundi

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**Abstract:** ***Lake Tanganyika is, one of the African Great Lakes, and the world's second longest and deepest freshwater lake. It is shared among four countries: Tanzania, Democratic Republic of Congo, Burundi and Zambia. Lake Tanganyika is one of the resource-rich freshwater Lakes and is highly valued for its recreational, aesthetic and scenic qualities. Lake Tanganyika is an important hotspot of biodiversity, with 40 % of its 1, 500 plant and animal species being endemic. However, Lake Tanganyika basin is facing multiple challenges as a result of rapid expansion of human population in the riparian countries. The city of Bujumbura (Burundi) was identified as the greatest pollution threat on the lakeshore, because it hosts a variety of industries and pollution sources close to the lakeshore. This research assessed the effect of urbanization on water quality of Lake Tanganyika in two divisions Ngagara and Kanyosha of Bujumbura city an established and upcoming division respectively, in Burundi. The research used both qualitative and quantitative methods. Water samples were collected from the point sources of pollution, along the lake away from the point source. The water samples were collected at different times of the day and were taken to the laboratory for analysis of the physico-chemical and micro-biological parameters. The results showed high mean Electrical Conductivity (925.55 ± 275.147 µS/cm), TDS (453. ± 150.438mg/l), Turbidity (374.8 ± 273.4 NTU), Chloride (52.6 ± 35.1mg/l), and Escherichia coli (45.89±42.18 CFU/100ml) were recorded in Ngagara division, and were above WHO Maximum Permissible Limits for Effluent Discharge. Significantly higher (p<0.05) values of physico-chemical and microbiological parameters of water from the two divisions were recorded for most of the parameters; indicating thatRapid Urban Development (road construction, towns and cities, building houses, industrialization, sewage effluents discharge) contributed to the deterioration of the water quality of Lake Tanganyika. This trend suggests that the studied littoral zone of Lake Tanganyika (Ngagara) has undergone pollution. Therefore, this research recommends that waste waters should be properly treated before discharge into the Lake. Decision makers should effectively plan for urbanization without compromising the health of environmental resources such as water bodies in order to attain sustainability development.***

**Keywords:** Lake Tanganyika, physico-chemical parametrs, pollution, urbanization, water quality, effluent

## 1. Introduction

Freshwater constitutes only 3% of all water on Earth and only about 1% of this can easily be accessed for human use. In spite of this fact, Freshwater sources are heavily impacted by anthropogenic activities. Lake ecosystems have undergone rapid environmental changes, often leading to significant declines in their functions as ecosystems (Jorgensen, 2006). It is acknowledged that freshwater species are the world's most endangered group of plants and animals (Newbury, 2010).More than 20% of the world's 10, 000 freshwater species have become extinct, threatened or endangered in recent decades (Mekonnen and Hoekstra, 2016). The causes of the current extinction are attributed to destruction of habitat, and pollution which interferes with the metabolism of organisms and make them unable to cope (Fox, 1995).

Formal scientific interest in Lake Tanganyika dates back to the first sighting by Richard Burton and John Speke in 1858. The Lake is an important hotspot of biodiversity with 1500 plant and animal species, 40 % of which are endemic, meaning that they cannot be found anywhere else on the earth (Foxall *et al.*, 2000). The lake basin which scans four countries (Burundi, Tanzania, Zambia, and DRC), is facing multiple challenges as a result of rapid expansion of human population in the riparian countries (GNF, 2017). The rising human population has increased need for housing and food supply hence the natural habitats around the lake are destroyed by the expansion of land use for agriculture or construction of infrastructure. Every day, 2 million tons of sewage and industrial and agricultural waste are discharged into the world's water (WHO, 2008), the equivalent of the weight of the entire human population of 6.8 billion people. The UN estimates that the amount of wastewater produced annually is about 1, 500 km3, six times more. Freshwater scarcity is increasingly perceived as a global systemic risk. Previous global water scarcity assessments, measuring water scarcity annually, have underestimated experienced water scarcity by failing to capture the seasonal fluctuations in water consumption and availability (WHO, 2008). We assess blue water scarcity globally at a high spatial resolution on a monthly basis. We find that two-thirds of the global population (4.0 billion people) live under conditions of severe water scarcity at least 1 month of the yea (Mekonnen and Hoekstra, 2016). Half a billion people in the world face severe water scarcity all year round. Putting caps to water consumption by river basin, increasing water-use efficiencies, and better sharing of the limited freshwater resources will be key in reducing the threat posed by water scarcity on biodiversity and human welfare. The global demand for water has been increasing at a rate of about 1% per year over the past decades as a function of population growth, economic development and changing consumption patterns, among other factors, and it will continue to grow significantly over the foreseeable future.

Bujumbura city is built on the shores of Lake Tanganyika in Burundi as shown in figure. The city has been growing since the colonial period; however, recently it has shown rapid growth and development to accommodate the increasing population. The growth of the city goes hand in hand with increased generation of waste and associated problems of waste evacuation. Given the fact that Burundi has the smallest portion of Lake Tanganyika and this portion is thought to be the most polluted (GNF, 2017), we hypothesized that the growth of Bujumbura city is responsible for the deterioration of the Lake waters. However, the extend of pollution of this Lake as a result of urban development has not been quantified. This study sough to establish the impact of Bujumbura city development on water quality and estimate the magnitude of water pollution on the western shores of Lake Tanganyika, as a result of urbanization activities along the Lake in Bujumbura city.

## 2. Main Objective

The main aim of this study was to establish the magnitude of water pollution in Lake Tanganyika as a result of urban development of Bujumbura city in Burundi.

Is there any significant difference in the levels of physico-chemical parameters (temperature, pH, electrical, conductivity, dissolved oxygen, turbidity, total dissolved solids, nitrates, phosphates, sulphates, total iron, manganese, biological oxygen demand and chemical oxygen demand) of Lake Tanganyika water between Ngagara and Kanyosha divisions? Do these parameters fall within the acceptable WHO range? What is the level of faecal coliforms (*Escherichia coli*) in the water of Lake Tanganyika in Ngagara and Kanyosha divisions? Is there a significant difference in the levels of contamination between the two divisions?

**Hypotheses**

Ho- There is no significant difference in the values of physico-chemical parameters of Lake Tanganyika water between Ngagara and Kanyosha divisions.

Lake Tanganyika, the largest of the African Rift lakes, is the principal source of water for consumption in Bujumbura. Some studies have shown that the part of Bujumbura city of the Lake is the most polluted compared to the other three riparian countries (D.R.C., Tanzania, and Zambia). The rate of urbanization in Burundi is relatively one of the highest in East Africa. The city of Bujumbura is still expanding. The planners, developers and planning agencies who t in allocate land seem not consider the impact on water quality because almost all developments that have happened and are continuing to happen are guided by economic benefits (Kharel, 2010). This study will therefore, provides information on the water quality of Lake Tanganyika in Ngagara and Kanyosha divisions in relation to the presence of human settlement and other urbanization activities such as industrialization along the Lake Tanganyika. This will contribute to the decision making process of management and control of planning for land use in urban areas. This will also contribute on the process of decision making on how to preserve the freshwater biodiversity. The study also will provide information which may be useful to the national water management (REGIDESO), urban water sanitation and waste management (SETEMU), National Environmental management (OBPE), and Ministry of Water, Environment, Spatial Planning and Town Planning (MEEATU) that may improve methods of water and sewage treatment before it finds its way into Lake Tanganyika.

## 3. Materials and Methods

The study was carried out between December and January in Ngagara and Kanyosha divisions, Bujumbura Municipality. The study was limited to evaluation of the effects of urbanization on the water quality of Lake Tanganyika in Ngagara and Kanyosha divisions, analyzing the physico-chemical and micro-biological parameters. The physico-chemical and micro-biological properties of the water samples collected from the industrial effluent and sewage discharge to Lake Tanganyika (for the riparian zone of these division), was taken to the laboratory for analysis to establish the water quality.

Bujumbura, the capital of Burundi, is located on the northeast shore of Lake Tanganyika in the western part of Burundi. It is located in a lowland area between two natural obstacles: to the east is a steep hilly area the foothills of the Mirwa and to the west is bordered by Lake Tanganyika. Its elongated form (Bujumbura) is justified by these natural obstacles which block the extension of the city to the east and west. The plain topography with respect to the escarpment relief to which it is attached often exposes it to floods following the rivers that cross it and which take the torrential character in times of heavy rainfall.

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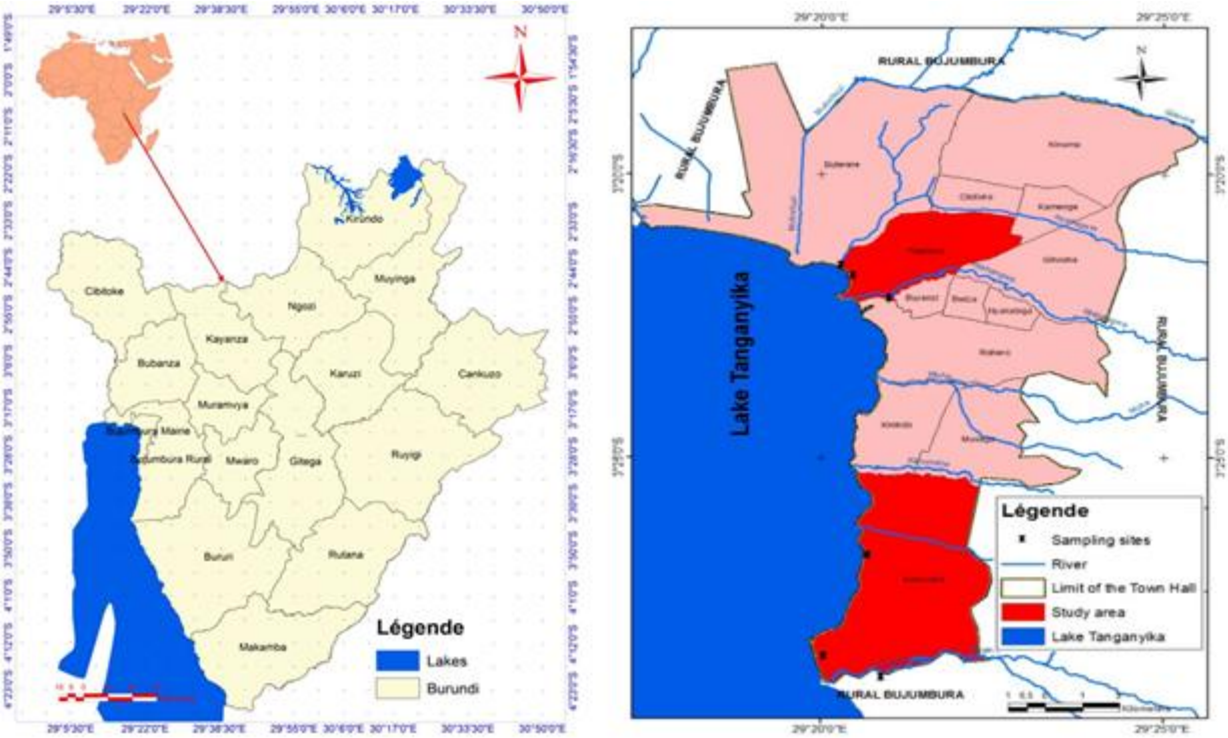


Figure 3.1 shows the location of Bujumbura, and the study site (Ngagara and Kanyosha)

This research used both quantitative and qualitative design for obtaining primary data on physico chemical and microbiological characteristics of water in Lake Tanganyika. In-depth interviews were employed using a guide of interview to study the effect of human settlement on water quality. Field observations have been used and photographs of pertinent issues relating to the topic under study was also documented. Sampling design was purposive. Six sampling sites were selected for the study; three sites were in Ngagara and three in Kanyosha. The site allocation was according to the human activities carried out in Ngagara and the activities done in Kanyosha respectively. These locations were mapped using a GPS. The human activities carried out in Ngagara were: industrialization, human settlement, hotel establishment, central market place and the outlet for the effluent of Ntahangwa River. The three sites in Ngagara were selected according to human activities which generate pollutants. One was at a point at the effluent of River Ntahangwa to determine the contribution of human settlement and flooding; the second site at the sewage effluent and the industrial wastewaters enters the lake; the third site was in recreational waters (bathing beaches) and here the sample were collected at location and times of heaviest activity. For Kanyosha division, one sampling point was at the effluent of Mugere River to determine the human activities like water plant Mugere and the pollutants from agriculture, the second site was near the wetland, were we expected some phytoremediation, finally another one was at Nyabugete beach to determine the contribution of human activities like hotels and restaurants. The water was collected at specific points marked out with a GPS. Plastic water samples bottles (for physico-chemical parameters) and glass water sample were cleaned at REGIDESO Laboratory. From each site, water samples were collected in 500ml for physical chemical parameters, and 500ml for bacteriology for measuring *E. coli* and total coliforms. Measurement of the physical parameters including temperature ($^0$C), and electrical conductivity, dissolved oxygen, turbidity and pH were done on site using the multi parameter. For the chemical parameters, they have been measured in the lab the same day at REGIDESO Laboratory.

Key pollution related physico-chemical parameters were determined. During the sampling period along Lake Tanganyika on the riparian zone of the two divisions, temperature, electrical conductivity, pH, turbidity, and dissolved oxygen were measured using the methods outlined below. The total phosphorous, Nitrogen ($NO_3^-$, $NO_2^-$, $NH_4^+$), sulphates, iron, chromium, manganese, calcium and magnesium were determined by taking water samples to the laboratory for analysis using the protocol outlined below.

Data collected from the study sites in each period was pooled and presented in form of tablets charts and graphs, analysis was done using descriptive statistics using Microsoft excel 2016 version. The complete dataset was exported from SPSS software into STATA software version 13.0 for analysis.

Student's t-test was used to compare each physical-chemical and microbiological parameter, between the two divisions, that is Ngagara and Kanyosha. This analysis was disaggregated by time of day sampling (that is morning and evening). Any difference in means was considered statistically significant when $p<0{\cdot}05$.Means of each physical and chemical parameter were generated and compared between sites in kanyosha alone and between sites in Ngagara, using simple linear regression. This analysis was repeated for both morning and evening sampling time independently. Any difference in means was considered statistically significant when $p<0{\cdot}05$

## 4. Results

Descriptive statistics of the physico-chemical and microbiological parameters of water analysed showed large ranges among most of the parameters except pH, Nitrite, Iron, sulfur, Cadmium. All the data was not normally distributed as Shapiro-Wilk test for normality was below 0, 005 for all parameters. Most of the parameters were Leptokurtic except BOD, pH., EC, TDS, Manganese, Iron which were Platycurtic.

The results for physical parameters, Student's t test showed significance difference between the two divisions Ngagara (the established one) and Kanyosha (the developing one) when $p<0.05$. Ngagara division had the highest mean in Conductivity, Dissolved Oxygen, TDS, and Turbidity as shown in Table below.

**Table 1:** Comparing physical parameters of water at Lake Tanganyika between divisions

| Division | Temp/ $^0$C | pH | EC/ µS/cm | Dissolved Oxygen/ mg/l | TDS/mg/l | Turbidity (NTU) |
|---|---|---|---|---|---|---|
| Kanyosha | 26.5±2.3 | 8.9±0.8 | 464.4±289.9 | 6.0±1.9 | 233.7±145.7 | 139.4±204.1 |
| Ngagara | 27.6±1.9 | 8.9±0.8 | 622.4±357.9 | 4.3±3.2 | 309.5±176.8 | 160 ±224.9 |
| Over all | 27±2.2 | 8.7±0.8 | 543.4±334.2 | 5.2±2.8 | 266.6±167.1 | 149.7±214.3 |
| P< 0.05 | 0.0006* | 0.000* | 0.0020* | 0.001* | 0.0008* | 0.5342 |
| OBPE MPL | 20-36 | 6.5-9.5 | N/S | N/S | N/S | N/S |
| WHO Standards | 20-35 | 6-8 | N/S | N/S | N/S | 5.5 |

Temperature mean for overall division was 27.6±2.2$^0$C with 26.5±2.3$^0$C at Kanyosha division, and 27.6±1.9$^0$C at Ngagara division. The lowest mean temperature recorded at Kanyosha (26.5±2.3$^0$C) while the highest mean temperature was recorded at Ngagara (27.6±1.9$^0$C). The table shows that there was significant difference in the mean temperature recorded in the two divisions (Ngagara and Kanyosha p=0.0006). Between the sampling sites, the table showed significant difference with p=0. 0000). pH mean for overall division was 8.7±0.8. With 8.9±0.8.at Kanyosha division, and 8.5±0.7.at Ngagara division. The table shows that there was significant difference in the mean pH recorded in the two divisions Ngagara and Kanyosha p=0. 0005.. The table showed significance difference in the mean pH recorded in morning p=0.0074. pH mean for the evening was 8.9±0.1 for overall division with 9.1±0.1 in Kanyosha division and 8.7±0.1 in Ngagara division.

Electrical Conductivity mean for overall division was 543.4±334.2µS/cm. Ngagara had the highest mean EC with 622.4±357.9µS/cm, while Kanyosha had the lowest mean EC with 464.4±289.9µS/cm. The table shows that there was significant difference in the mean Electrical Conductivity recorded in the two divisions Ngagara and Kanyosha with p=0.0020. Between the sampling sites, the table showed significant difference with p=0.0020. The mean Electrical Conductivity recorded in Ngagara division during the study was all above the OBPE recommended Maximum Permissible Limits range 400 µS/cm. Turbidity mean for overall division was 149.7±2.3 NTU with 139.4±204.1 NTU at Kanyosha division, and 160.1±0.5342 at Ngagara division. The lowest mean turbidity recorded at Kanyosha while the highest mean turbidity was recorded at Ngagara. The table shows that there was significant difference in the mean turbidity recorded in the two divisions Ngagara and Kanyosha p=0.5342. Between the sampling sites, the table showed significant difference. Mean turbidity for the Morning was 124.0±167.6 NTU for overall division with 113.5±133.5 NTU.in Kanyosha division and 134.4±197.1 NTU in Ngagara division.

DO mean for overall division was 5.2±2.8mg/l with 6.2±2.4mg/l.at Kanyosha division which was the highest, and 6.0±1.9mg/lat Ngagara division which was the lowest. Between the sampling sites, the table showed significant difference with p=0.000. Mean DO for the Morning was 4.9±1.9mg/l for overall division 5.8±1.0mg/l .in Kanyosha division and4.0±2.0mg/l in Ngagara division. the mean DO record in Evening p=0.0454. The mean DO record during the study was all below the OBPE recommended Maximum Permissible Limits.

TDS mean for overall division was 266.6±167.1mg/l with 233.7±145.7mg/l.at Kanyosha division which was the lowest, and 309.5±176.8 mg/l at Ngagara division which was the highest. The lowest mean TDS recorded at Kanyosha while the highest mean TDS was recorded at Ngagara. The table shows that there was significant difference in the mean TDS recorded in the two divisions Ngagara and Kanyosha p=0.0008. Between the sampling sites, the table showed significant difference. The mean TDS recorded during the study was all below the OBPE recommended Maximum Permissible.

**Table 2:** Comparing chemical parameters of water at Lake Tanganyika between sites

| Sites | $Cl_2$ (mg/l) | $NO_2$-N (mg/l) | $NO_3$-N (mg/l) | PO4-P (mg/l) | Mn (mg/l) | Total Fe (mg/l) | NH4-P (mg/l) | $SO4_2$ (mg/l) | Cad (mg/l) | $BOD_5$ (mg/l) | E. coli CFU/100ml | TC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kany 1 | 17.5 ± 16.1 | 0.1 ± 0.2 | 0.8 ± 0.4 | 0.6 ± 1.1 | 0.5 ± 0.4 | 0.4 ± 0.3 | 0.0 ± 0.1 | 0.1± 0.1 | 0.2 ± 0.3 | 2.5 ±1.7 | 10.85± 28.60 | 11.32±28.48 |
| Kany2 | 38 ± 10.2 | 0.0 ± 0.1 | 0.5±0.8 | 0.3 ±0.7 | 1.2 ± 5.4 | 0.2±0.2 | 0.1± 0.01 | 0.1 ± 0.2 | 0.1 ± 0.2 | 1.9 ±1.7 | 0.575 ± 2.47 | 0.50±2.45 |
| Kany3 | 42.7 ± 8.2 | 0.5 ± 2.1 | 0.3±0.4 | 0.4 ± 0.7 | 0.3 ± 0.4 | 0.3±0.3 | 0.01 ±0.2 | 0.0 ± 0.1 | 0.1 ± 0.1 | 6.3 ±6.3 | 0.28 ± 0.654 | 47.14±53.96 |
| P | 0.0000* | 0.2332 | 0.0027* | 0.2522 | 0.9299 | 0.1693 | 0.3633 | 0.5400 | 0.0157 | 0.0114 | 0.0291* | 0.0000 |
| Nga1 | 28.7 ± 26.1 | 0.2 ± 0.2 | 0.9±0.4 | 0.3 ± 0.6 | 3.1± 14.7 | 0.3 ± 0.2 | 0.6 ± 0.3 | 0.8 ± 4.0 | 0.1 ± 0.1 | 8.3 ±5.6 | 45.89± 52.18 | 4.4±19.26 |
| Nga2 | 81.5 ± 37.6 | 0.1 ± 0.1 | 0.8±0.4 | 0.4 ± 1.0 | 0.4 ± 0.3 | 0.5 ± 0.3 | 1.3 ± 1.1 | 0.1 ± 0.3 | 0.1 ± 0.3 | 13.8 ±5.2 | 0.75 ± 3.59 | 6.36±13.05 |
| Nga3 | 47.7 ± 14.5 | 0.0 ± 0.1 | 0.7 ± 0.5 | 0.0 ± 0.0 | 0.0 ± 0.1 | 0.1 ± 0.2 | 0.5 ± 0.5 | 0.0 ± 0.1 | 0.2 ± 0.3 | 6.0 ± 3.4 | 6.28 ± 13.06 | 11.7±30.93 |
| P | 0.0415* | 0.0004* | 0.1104 | 0.1459 | 0.1842 | 0.1350 | 0.4841 | 0.2161 | 0.0262 | 0.2596 | 0.0000* | 0.0000 |
| WHO Standards | 20 | 2 | 20 | 5 | 1 | 10 | 10 | 400 | 1 | 50 | 0 | 0 |

$PO_4^-P$ mean for overall division was 0.3±0.3 mg/l with 0.3±0.3 mg/l. at Kanyosha division, and 0.3±0.3 mg/l at Ngagara division. The lowest mean $PO_4^-P$ was recorded at Ngagara, while the highest mean $PO_4^-P$ was recorded at Kanyosha. The table shows that there was no significant difference in the mean $PO_4^-P$ recorded in the two divisions Ngagara and Kanyosha p=0.0697. Between the sampling sites, the table showed significant difference. The mean $PO4^-P$ recorded during the study was all below the OBPE recommended Maximum Permissible Limits.

$NO_{3-}N$ mean for overall division was 0.7±0.6 Mg/l with 0.6±0.6mg/l. at Kanyosha division, and 0.8±0.5 mg/l at Ngagara division. The lowest mean $NO_{3-}N$ recorded at Kanyosha, while the highest mean $NO_{3-}N$ was recorded at Ngagara. The table shows that there was significant difference in the mean $NO_{3-}N$ recorded in the two divisions Ngagara and Kanyosha p=0.0041. Between the sampling sites, the table showed significant difference p=0.027.The mean $NO_{3-}N$ recorded during the study was all below the OBPE recommended Maximum Permissible Limits.

$NO_{2-}N$ mean for overall division was 0.1±0.6 mg/l with 0.2±1.2 mg/l. at Kanyosha division, and 0.2±0.1mg/l at Ngagara division. The lowest mean $NO_{2-}N$ recorded at Kanyosha, while the highest mean $NO_{2-}N$ was recorded at Ngagara The table shows that there was significant difference in the mean $NO_{2-}N$ recorded in the two divisions Ngagara and Kanyosha p=. Between the sampling sites, the table showed significant difference with p=0.4093. The mean $NO_{2-}N$ recorded during the study was all below the OBPE recommended Maximum Permissible Limits.

$NH_{4-}N$ mean for overall division was 0.4±0.7 mg/l with 0.1±0.1 mg/l. at Kanyosha division, and 0.8±0.8mg/l at Ngagara division. The lowest mean $NH_{4-}N$ recorded at Kanyosha, while the highest mean $NH_{4-}N$ was recorded at Ngagara. The table shows that there was significant difference in the mean $NH_{4-}N$ recorded in the two divisions Ngagara and Kanyosha p=0.000. Between the sampling sites, the table showed no significant difference with p=0.3633. The mean $NH_{4-}N$ recorded during the study was all below the BBN recommended Maximum Permissible Limits (0.2mg/l).

$SO_4^{2-}$mean for overall division was 0.2±2.3 mg/l with mg/l at Kanyosha division, and 0.0±0.1 mg/l at Ngagara division. The lowest mean $SO_4^{2-}$ recorded at Ngagara, while the highest mean $SO_4^{2-}$ was recorded at Kanyosha. The table shows that there was no significant difference in the mean $SO_4^{2-}$ recorded in the two divisions Ngagara and Kanyosha p=0.2681. Between the sampling sites, the table showed no significant difference with p=0.5400 in Kanyosha and p=0.2161 in Ngagara. The table showed significance difference in the mean $SO_4^{2-}$ recorded in Evening p=0.0000. The mean $SO_4^{2-}$ recorded during the study was all below the OBPE recommended Maximum Permissible Limits 2mg/l.

Total Iron mean for overall division was 0.3±0.3mg/l with 0.3±0.3 mg/l. at Kanyosha division, and 0.3±0.3mg/l at Ngagara division. The table shows that there was no significant difference in the mean Total Iron recorded in the two divisions Ngagara and Kanyosha p=0.7431. Between the sampling sites, the table showed no significant difference with p=0.1350. The mean recorded during the study was all below the OBPE recommended Maximum Permissible Limits.

$Cl_2$ mean for overall division was 42.8±29.0mg/l with 32.9±16.2 mg/l. at Kanyosha division, and 52.6±35.1mg/l at Ngagara division. The lowest mean $Cl_2$recorded at Kanyosha, while the highest mean $Cl_2$ was recorded at Ngagara. The table shows that there was significant difference in the mean $Cl_2$ recorded in the two divisions Ngagara and Kanyosha p=0.0000. Between the sampling sites, the table showed significant difference.

## 5. Discussion

The moderately temperature recorded could be due to the fact that sampling was done in dry and hot month (December and January). The slight variation in mean temperature noted during the study, were possibly due to variation in exposure of the Lake and river waters.

Ntakimazi (2015) found mean temperature 28ºC. The values of temperature recorded in this study are consistent in comparison to studies so far carried in Bujumbura by Lwikitca (Du and Et, 2012). The high temperature was observed at KANY3 and NGA 2. This could be due to the time of sampling but also, Lakes temperatures are higher than rivers waters.

The highest mean Electrical conductivity was observed in Ngagara division especially at NGA2. This was due to the to the leather tannery which is which was observed to be realizing effluents containing chemicals in tanning into the Lake. We could observe decomposition of amount of nitrogenous compounds into nitrites and nitrates also increase the concentration of dissolved solids and influence the Electrical Conductivity. The low Electrical conductivity at KANY1 could be due to the waters characteristics of rivers which has low Electrical Conductivity than Lakes. But comparing KANY1 and NGA1, Ntahangwa has the highest mean EC than Mugere though they are all rivers. This could be due to the run off of waters from urban settlement, from waste water industries and sewage from upper lands.

The high pH at Ngagara may be attributed to the effluents from sewage discharge leaching from the industries (9.4) Mean pH values did not vary much along the Lake. Similar results were also recorded by Ntakimazi (Allison, Paley and Ntakimazi, 2000). Low pH values were recorded at Nga1 (Ntahangwa river), this could be due to decomposition of high levels of organic matter from high pressure of human population and, mining activities. Previous study showed the same results (Buhungu *et al.*, 2018)

Ngagara division has the highest mean Turbidity especially at Nga 1. Among all the sampling sites, Nga 1 has the highest mean Turbidity. This could be due to finely dissolved organic and inorganic material from the urban settlement and also microorganism such as bacteria or viruses. The soil erosion from the hills around Bujumbura city comes in rivers. Nga1 and Kany1 Turbidity value were below OBPE maximum Permissible Limit but showed that waters were quite cloudy and enough to cause negative effects to aquatic organisms remarkably change. Turbidity has remarkably increased whereas dissolved oxygen has sensibly decreased during that period. This trend suggests that the studied littoral zone of Lake Tanganyika has undergone pollution (Buhungu *et al.*, 2018).

The high mean DO was observed at Kanyosha division, it was below the Maximum permissible limit according to OBPE. The lowest mean DO was observed at NGA2 and this could be due to the results from excessive algae growth caused by phosphorus. Nitrogen is another nutrient that can contribute to algae growth. As the algae die and decompose, the process consumes dissolved oxygen.

The mean TDS results recorded at Ngagara division was the highest but below the OBPE Maximum Limits Permissible (≤1g/l), Nga3 has the highest mean TDS, it might due to the effluents from the industry SAVONOR (production of soaps and refined oils).

The highest mean chloride at Ngagara division though the site which had a high mean of Chloride was Nga2 with 81.5±37.6mg/l. This mean Chloride is below the Burundi National Standards according to BBN. Tis high mean of Chloride could be due to leather tannery, which was near the sampling site.

The mean $NO_2$-N concentration was highest at Kany3but not harmful according to national standards0.5mg/l). Nitrites alone don't mention a pollution problem but their presence in combination with ammonia and nitrate may indicate environmental contamination. This could be due to the artificial fertilizers in Kanyosha, there were animals feeding near the lakes.

The mean $NO_3$-N results were high at Nga1 indicating possible pollution from direct effluent discharge from urban areas (urban settlement). In many locations, river water degrades mainly through human activities thus exacerbating the problem of $NO_3$-N loading into lakes.

The mean $NO_4$-N for all sampled sites was below the National standards for waste water discharge. Nga1 was the highest. This could be to the domestic waste water from the urban settlement. Ammonia is usually originating from metabolic, agriculture, and industrial wastes.

$PO_4$-P mean was high at Kany1 but was above the national standards water quality, 0.5mg/l. It could be due to waters from agricultural cultivation common along the river are contributive to increase $PO_4$-P loading the Lake Tanganyika waters, according to Fadiran (Society, 2008). It also could be to the water plant which is upstream the river Mugere which is the likely factor accountable for the observed high $PO_4$-P mg/l for that site.

The Mn mean result show low values except Nga1 which has the highest concentration of Mn, this is indicative of high pollution level caused by urban wastes from human settlement in Ngagara and Buyenzi the division which is near.

The sulfate results show low values in most of the sites, and the values were below1g/l. The highest mean sulfate concentration recorded at Nga1 is indicative of high pollution level caused by the effluents from the sewage from Ngagara and Buyenzi the division which is near.

The Cadmium results showed low values in most of the sites. The values were below 0.3mg/l. Nga 3 has the highest value comparing to others sampling sites. This could be due to the soap industry (SAVONOR) which is near the site.

The high mean $BOD_5$ recorded at Nga1 is due to the organic matter as fat, solid wastes, waste waters from urban settlement, released into the water within the effluents from the channels from Buyenzi and Ngagara divisions. The continued disposal of wastes into the river through effluents from septic system or sewage discharges and infiltration of domestics' waste lead to increased consumption of dissolved oxygen, and this affect the aquatic life. But BOD5's lowest values recorded at Kany 1 and Kany 2are associated with little organic matter present at these sites.

Mean T.C and E. coli values were the highest at Nga1; comparing the two divisions Ngagara has the highest mean E. coli than Kanyosha. Vyumvuhore et al. (Vandelannoote *et al.*, 1996) found Ntahangwa River most polluted than others rivers, but also, the E. coli mean values of Mugere showed a high contamination, this could be to fecal contamination from unsanitary settlement conditions at Ngagara and Buyenzi (Vandelannoote *et al.*, 1996).

## 6. Conclusion

Water pollution is a serious problem in Bujumbura and has an adverse impact on the sustainability of water resources. Not only that, but it also affects living plants and organisms, the health of the population and the economy. Water pollution is a serious problem in Lake Tanganyika and has an adverse impact on the sustainability of water resources. The results of this study found that the developing division has better water quality as reflected by better mean values of physico chemical and microbiological parameters. Not only that, but it also affects living plants and organisms, the health of the population. The results of this study revealed that both point source and non-point sources are greater contributors to water pollution. The study revealed that Ngagara is the most polluted in many parameters. High densities of population, high density of industries and schools have adverse effects on water resources in Lake Tanganyika

Sewage effluent discharge, industries effluent discharge, and runoff have contributed to increasing nutrient and pollutant loads into Lake Tanganyika. Poor sanitation conditions in Ngagara exacerbate the water pollution in Lake Tanganyika through contaminated surface runoff and untreated wastewater discharge.Sewage water purification is not done in a very efficient way.

## 7. Recommendations

Before doing such projects like building cities, the government should make sure that all steps of Reviewing an

Environmental Impact Assessment have been followed. Industrial water must be treated, before throwing in to the channels carrying domestic effluents, especially waste water from AFRITAN (African Tannery) which is in Ngagara because it is a major source of water pollution in the area under study.

The authorities must impose strict measures to manage household waste. Waste collected in the city should be stored in the dumping ground and not in open air.

The authorities should impose measures like planting trees to reduce sediment runoff, promoting water filtration. The high human density at Ngagara and Kanyosha, have effects on water quality along Lake Tanganyika. The government must regularly monitor the sewage treatment plant, because they break down and they take a good time to repair them.

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