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Assessment of Water Pollution Levels in the Nyabugogo Catchment, Rwanda

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Abstract: This study aims to develop a comprehensive system of pollution monitoring and control in the Nyabugogo catchment of Rwanda, which also includes the capital city, Kigali, through locating and highlighting pollution and its sources. Pollution hotspots were identified, covering areas of both anthropogenic and natural pollution. The study focused on water quality assessment especially the identification of the critical points of pollution (hotspots), by measuring selected physico-chemical parameters in the Nyabugogo River system. An extensive monthly water quality monitoring study was conducted from October 2008 to May 2009 and covered nutrients, organic and heavy metal pollutants. The parameters covered are Ammonium-Nitrogen (NH_4^+-N), Nitric-Nitrogen (NO_2^-N), Nitrate-Nitrogen (NO_3^-N), Sulphates (SO_4), Phosphates (PO_4-P), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Chromium (Cr), Iron (Fe), Lead (Pb), Manganese (Mn), Zinc (Zn), Conductivity (EC), pH, and Turbidity. The samples were collected, preserved and analyzed in the laboratory using standard methods whilst TDS, conductivity, turbidity and pH were measured in the field using HACH field kits. The water quality study revealed that both urbanized and rural sub-catchments have serious but different types of pollution. For example, the water from rural areas is heavily contaminated with nutrients, suspended sediments (due to a lot of erosion upstream) and organic materials whilst from urban areas the predominant pollutants are heavy metals and some nutrients. It was therefore concluded that the Nyabugogo River system is very heavily polluted and urgent action to control both rural and urban pollution is required. Further studies are required to isolate and quantify the sources of this pollution.

Keywords: Land use activities, nyabugogo catchment, pollution hotspots, river water pollution assessment, rwanda.

1. INTRODUCTION

Nowadays catchments are becoming polluted by various human activities, including littering, pouring chemicals down drains and industrial discharges, all of which are washed into creeks and stormwater drains. There is a clear link between population growth, urbanization, industrial development and human activities that are likely to generate pollution. Rwanda is one of the most densely populated African countries and after the 1994 genocide the population of the country continue to grow. On the other hand City of Kigali (CoK), the capital of Rwanda, is rapidly expanding with increased population growth and industrial development. The population of the CoK is estimated to be over 1.2 million people [1]. This expansion has negatively affected water quality management in the city, especially wastewater management. Elevated levels of pollution have been reported in some of the major rivers passing through the City of Kigali, such as Nyabugogo River [2-5] and the Mpazi River [6]. The Nyabugogo Swamp feeds into the Nyabarongo River and is major outlet of the City of Kigali and it receives all the wastewater from City. A number of authors [4, 5] and [7] studied pollution in Lake Muhazi and attributed it to landuse activities in the catchment. Nkuranga [3] observed that the Nyabugogo wetland receives all kinds of untreated wastewaters, including industrial discharges. He showed that wastewater from industrial areas that are discharging into the Nyabugogo Swamp is polluted with heavy metals beyond acceptable environmental standards. Muhirwa *et al.* [6] characterised wastewater from the Nyabugogo Abattoir which discharges into the Mpazi River, a tributary of the Nyabugogo River. They concluded that the effluent from the Nyabugogo Abattoir is highly loaded with degradable organics and other pollutants that pose an environmental risk to the receiving Mpazi River. Further, Muhirwa *et al.* [6] iden-

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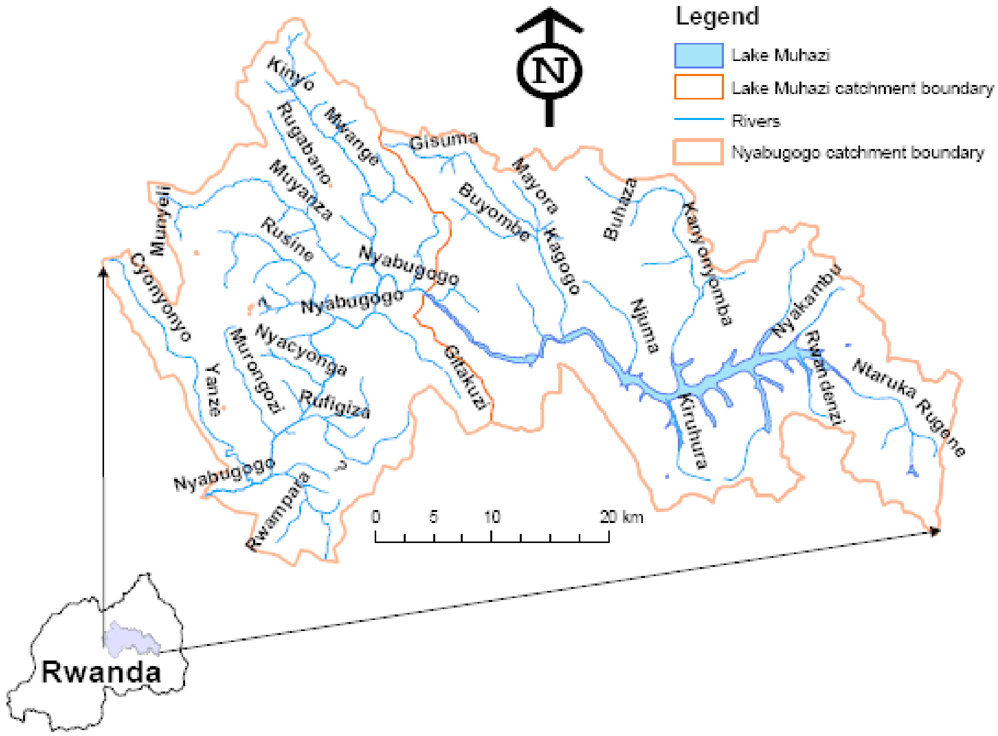

Fig. (1). Details of the Nyabugogo Catcthment including its location in Rwanda.

tified Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), nutrients, chloride, calcium, total coliforms and TSS as the major pollutants from that abattoir. Nshimiyimana [8] studied another tributary of the Nyabugogo River, the Yanze River and he reported high levels of flooding, erosion, sedimentation and high levels turbidity. The Nyabugogo River is a tributary of the Nyabarongo River which in turn is the tributary of Akagera Transboundary River which drains into Lake Victoria. Potentially this means that the Nyabugogo River contributes pollution to the Lake Victoria. Lake Victoria is one of the major lakes in Africa but is greatly affected by increasing loads of pollution from anthropogenic activities, rendering the massive water body eutrophic [9, 10].

Proper pollution management in the Nyabugogo Catchment requires good background knowledge of the types, levels and sources of pollution in the catchment [11]. The traditional approach to water quality management in developing countries is based on developing a monitoring network from which samples are collected periodically [12]. Related to this is the modern practice of environmental impact assessment, which occasionally includes water quality assessment [13]. What is missing from most of these approaches is the development of a comprehensive system of catchment pollution monitoring and control, something like a water pollution control master plan that would be used to control development and discharges by locating and highlighting the pollution and its sources. In this study, this idea was tested in the Nyabugogo catchment of Rwanda, which also includes the capital city, Kigali. The study mapped the area in terms of pollution hotspots, covering areas of both anthropogenic and natural pollution. The natural part is important since the hilly nature of the catchment in conjunction with high annual rainfall of around 2,000 mm/year means that a lot of erosion takes place even from virgin lands. The main objective of this study was to assess the types and levels of pollution, in the Nyabugogo catchment and to assess the impact of all this on the downstream Nyabarongo River.

2. MATERIAL AND METHODS

2.1. Description of the Study Area

The Nyabugogo Catchment is located in the central eastern part of Rwanda (Fig. **1**). The catchment drains a total area of about 1,647 km^2. The major landuse activity in the catchment is agriculture, which occupies about 897 km^2 (about 54%) of the catchment. The climate of the catchment is mostly of temperate and equatorial type with average temperature ranging between 16°C and 23°C, depending on the altitude of the area. The annual rainfall in Rwanda varies from about 800 mm to 1,600 mm. There are normally four seasons in Rwanda. The first is a long dry season that spans from June to September, followed by a short rainy season spanning from October to December. This season receives 30% to 40% of the annual rainfall with the highest rains falling in November. The third is a short dry season starting in December and ending in January. The fourth is a rainy season spanning from February to end of May. This season receives around 60% of annual rainfall.

The Nyabugogo River traverses the City of Kigali and has many tributaries such as the Mwange River, Rusine River and Marenge River on its upstream portion. It is later fed by other rivers from the urbanised part of Kigali such as the Rwanzekuma River, the Ruganwa River, the Mpazi River and the Yanze River. The major possible pollution generating activities identified in the catchment include flower farming and the Kabuye sugar works which are both

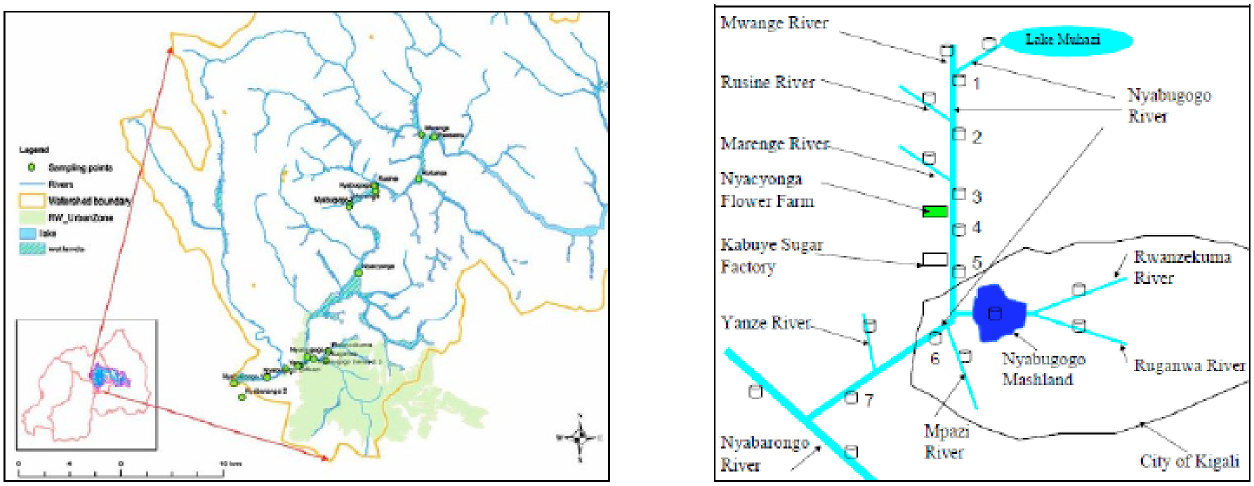

Fig. (2). Map of the Nyabugogo Catchment showing the location of sampling sites and a schematic chart of the monitoring network.

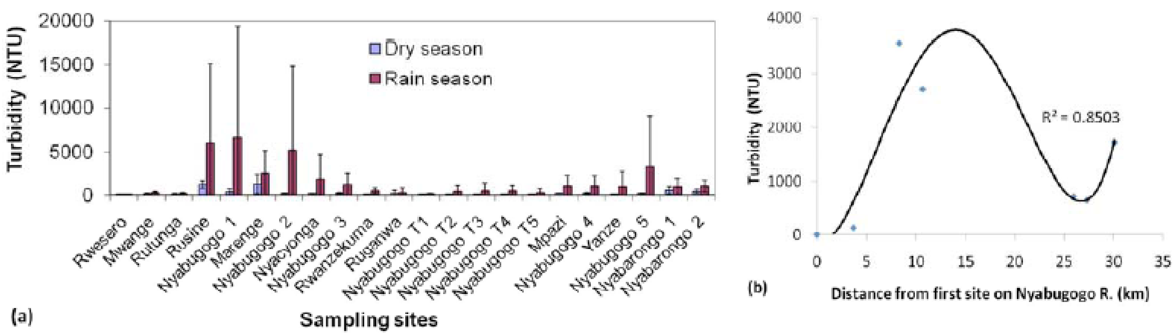

Fig. (3). Turbidity leveles for (**a**) all the sampling points and (**b**) sampling sites located on the Nyabugogo River for the monitored period.

located along the Nyabugogo River, sugar cane plantation upstream, legumes and rice cultivation, quarrying and mining activities. There are many other industries concentrated in the Kigali industrial area that discharge all their liquid wastes into the Ruganwa River. The UTEXRWA textile industry also discharges its effluent into the Rwanzekuma River.

2.2. Location of Sampling Points

A total of 22 sampling sites (Fig. **2**) were selected for the monitoring of pollution trends in the Nyabugogo Catchment. The rationale for choosing these sites was to ensure that all inflows could be isolated in order to be able to assess their contributions and impacts. Monitoring stations were established upstream and downstream of effluent discharges as well as major landuses. A transect was taken along the Nyabugogo Swamp, consisting of five sampling sites to give an idea about the water quality variation along the Swamp. The two last sampling points were located on the Nyabarongo River, before and after the point where Nyabugogo River joins the Nyaborango River.

2.3. Samples Collection and Analysis

The water samples were collected monthly for a period of 8 months from October 2008 to May 2009 using the grab sample method. Samples were collected and stored in 600 ml plastic bottles. The plastic bottles were rinsed overnight with 1M HCl and then with distilled water. The bottles were also rinsed thrice with sample water before final collection. The samples were placed in a coolerbox with ice for transportation to the laboratory. Where analyses were not done immediately upon arrival at the laboratories, samples had to be stored in a refrigerator at 4°C with preservation as appropriate. The samples were analysed according to standard procedures [14]. The parameters analyzed from October to December 2008 were dissolved oxygen (DO), pH, Turbidity, Conductivity, Total Dissolved Solids(TDS), NH_4^+-N, NO_3-N, $N0_2^-$N, PO_4^{2-}P, SO_4^{2-}, Fe, Mn, Zn, Pb, and Cr. From January 2009, BOD_5 and COD were added to the parameters analysed and these were analysed at another laboratory of the National University of Rwanda where appropriate equipment were available and functioning.

2.4. Analysis of Results

Data analysis involved the assessment of the variation of pollutants at each sampling point according to dry season and rainy season and the assessment of the variation of pollution with distance downstream of the Nyabbugogo River. The results are presented as mean values ± standard deviation. For all the tested parameters the results are presented in bar chart for all the monitored points and in line graph only for the points located on the Nyabugogo River stretch. The impact of the Nyabugogo River on the receiving Nyabarongo River was done using the Student T-Test for the arrays upstream and downstream of the discharge of the Nyabugogo River.

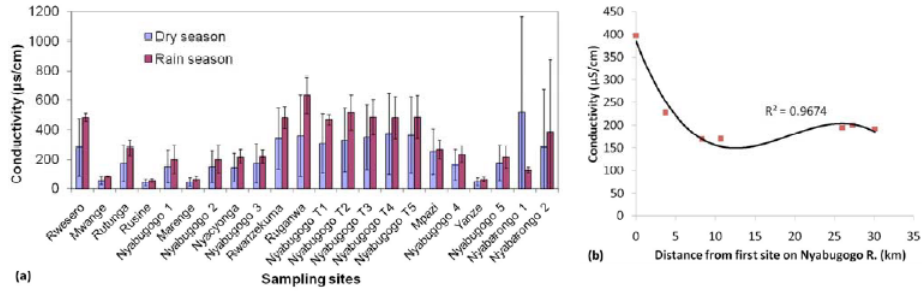

Fig. (4). Conductivity levels for (**a**) all the sampling sites and (**b**) sampling sites located on the Nyabugogo River for the monitored period.

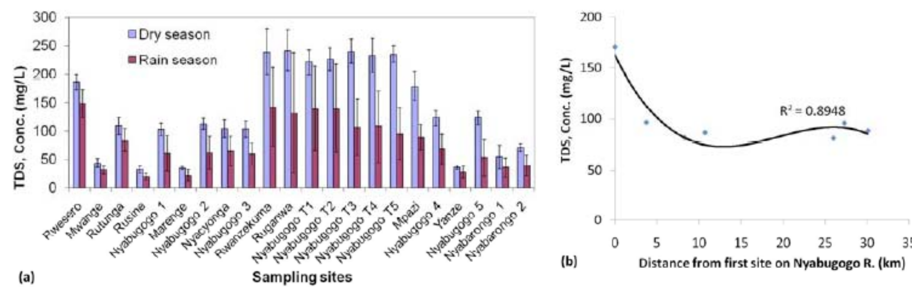

Fig. (5). TDS levels for (**a**) all the sampling sites and (**b**) sampling sites located on the Nyabugogo river for the monitored period.

3. RESULTS AND DISCUSSIONS

3.1. Physical Water Quality

3.1.1. Turbidity

The seasonal turbidity levels in Nephelometric Turbidity Units (NTU) for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Fig (**3**).

Turbidity was highest in the upstream part of the Nyabugogo catchment, especially on the Rusine River (1,215 ± 433) in the dry season and rising to 6,134 ± 893 in the rainy season. Turbidity levels in the Marenge River was 1,274 ± 1,582) NTU in dry season and 2,557 ± 2,604 in the rainy season. These high figures indicate serious sediment pollution of the Nyabugogo River. The Turbidity in Kigali is very low compared to the rural areas and the Nyabugogo Swamp is contributing to the reduction of Turbidity and other pollution through sedimentation. Muhirwa [6] reported Turbidity values of 707 ± 37 NTU on the Mpazi River and attributed this to high concentrations of TSS in wastewater discharged from the Nyabugogo Abattoir. In the current study Turbidity on the Mpazi River was 649 ± 845 NTU, and this value is not only coming from the Nyabugogo Abattoir, but also from all the activities located around the Mpazi River. Nshimiyimana (8) reported levels of Turbidity of water in the Yanze River for the period June 2005 to October 2007 of maximum 637 NTU recorded in November 2006. Turbidity values of 5 to 500 NTU have been reported in literature [15] impliying that in the current study landuse activities and the soil/topography of the area could be greatly influencing the Turbidity levels in the streams.

3.1.2. Conductivity and TDS

The seasonal conductivity and TDS levels for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Figs (**4** and **5**) respectively.

The conductivity and TDS results show a similar trend, as expected. High values were observed on all points located on the Nyabugogo River, Rwanzekuma River, Ruganwa River and in the Nyabugogo Marshland, which is due to the outflows from Lake Muhazi where high levels have been recorded in the past [4]. On the Rwanzekuma and Ruganwa Rivers different dissolved salts are coming from different industries located in Kigali. Nkuranga [3] attributed the large values of conductivity found in the Nyabugogo Swamp to the wasterwater inflows especially from the Rwanzekuma River and Ruganwa River. Muhirwa *et al.* [6] found that the effluent from the Nyabugogo Abattoir increased conductivity levels in the Mpazi river from 632 ± 33 µS/cm before discharge, to 726 ± 77 µS/cm after discharge. In comparison, a conductivity value of 262 ± 130 µS/cm was found downstream in this study. The conductivity values reported in this study are generally on the high side compared with values of 165 – 538 µS/cm reported by [15] for rivers passing through urban areas, and 45 – 183 µS/cm for rural rivers [16]. It was also expected that the conductivity values would increase downstream as the river passes from rural into urban areas. This did not happen and is suspected to be due to dilution from spring water and the cleansing of water by the vast wetlands system in Kigali [3].

3.1.3. Dissolved Oxygen (DO)

The DO levels for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Fig (**6**).

The Dissolved Oxygen variation shows low values of DO in cultivated areas. Nkuranga [3] attributed the low concentration of DO to the decaying *papyrus* in the Nyabugogo Swamp. Generally DO is not varying much along the Nyabugogo River. The DO values observed are within the normal range for streams and is safe for aquatic life [17].

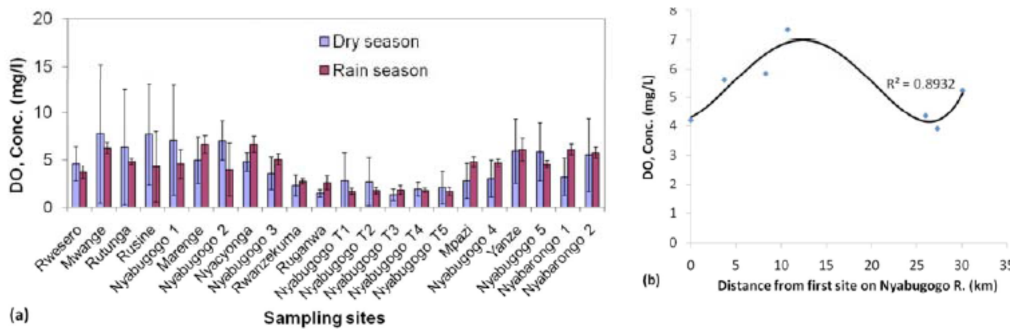

Fig. (6). Dissolved Oxygen levels for (**a**) all the sampling points and (**b**) sampling sites located on the Nyabugogo River for the monitored period.

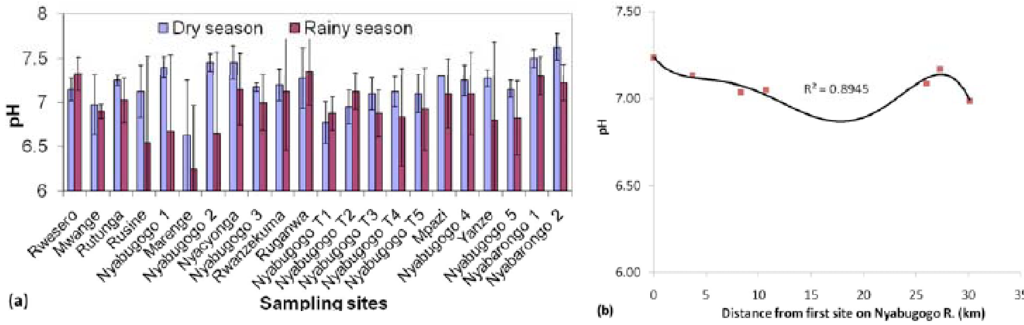

Fig. (7). pH levels for (**a**) all the sampling sites and (**b**) sampling sites located on the Nyabugogo River for the monitored period.

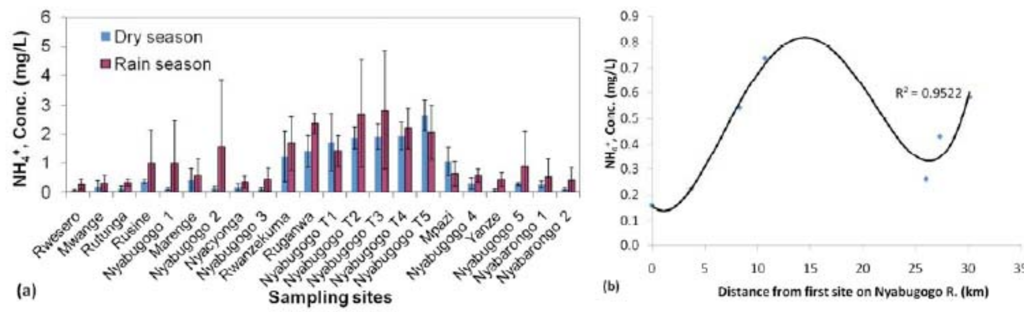

Fig. (8). NH_4-N levels for (**a**) all the sampling sites and (**b**) sampling sites located on the Nyabugogo River for the monitored period.

3.1.4. pH

The pH levels for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Fig (**7**).

The pH did not vary much in the Nyabugogo River system. Usanzineza *et al*. [4] described the water in Lake Muhazi as slightly alkaline, with a mean pH in the Lake of 7.8, which is very closer to the value observed at the Rwesero sampling point of 7.24 ± 0.18. Rwesero is the first point after the Nyabugogo River flows out of Lake Muhazi. Nkuranga [3] found a more or less constant pH in the Nyabugogo Swamp (around 7) and attributed the high value of pH in the Rwanzekuma and Ruganwa Rivers to alkaline reagents from UTEXRWA textile factory and other factories in Kigali. Muhirwa *et al.* [6] concluded that the increase of pH on the Mpazi River was due to effluent from the Nyabugogo Abattoir which has an average pH value of 8.9 ± 0.2. In the current study the pH on the Mpazi River is lower than the value observed by Muhirwa *et al*. [6] as it is located 3 km downstream.

3.2. Chemical Water Quality

3.2.1. Ammonium-Nitrogen (NH_4-N)

The term ammonia includes the non-ionized (NH_3) and ionized (NH_4^+) species. The NH_4-N levels for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Fig (**8**).

The NH_4-N increased downstream towards Kigali City; 1.4 ± 0.54 mg/L for the Ruganwa River in dry season and 2.37 ± 0.35 mg/L in rainy season, 1.23 ± 0.86 mg/L for the Rwanzakuma River in the dry season and 1.68 ± 0.94 mg/L in rainy season. For all other sampling sites, the NH_4-N is below 1 mg/L, except in the Nyabugogo Swamp (Fig **8**); this high value of NH_4-N could be attributed to the domestic wastewater from Kigali urban areas. The NH_4-N values found in this study are in line with findings by Mvungi *et al*. [15] for a contaminated urban river in Zimbabwe. Ammonia in the environment originates from metabolic, agricultural and industrial processes and from disinfection with chloramine [17]. Natural levels in groundwater and surface water are usually below 0.2 mg/litre.

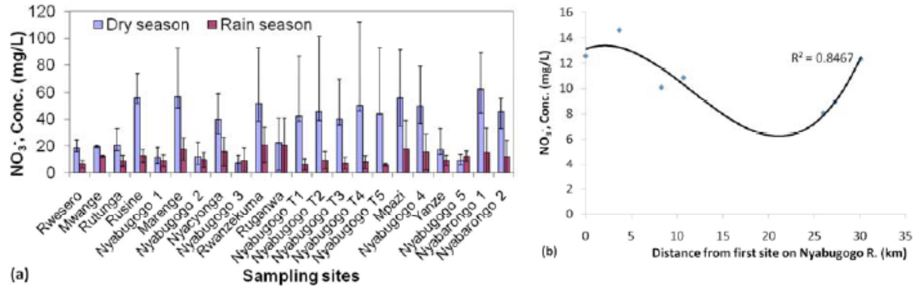

Fig. (9). NO_3-N levels for (**a**) all the sampling sites and (**b**) sampling sites located on the Nyabugogo River for the monitored period.

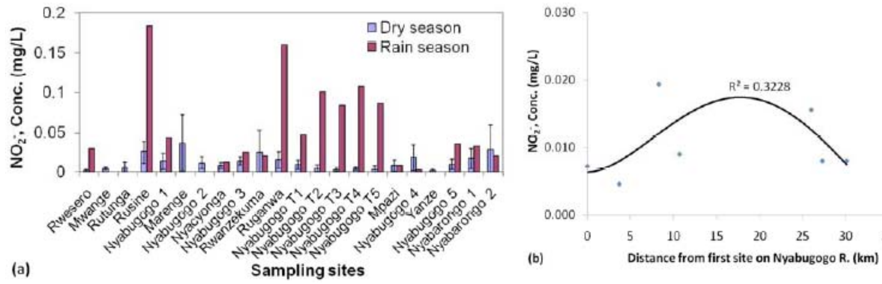

Fig. (10). NO_2-N levels for (**a**) all the the sampling sites and (**b**) sampling sites located on the NyabugogoRiver fpr the monitored period.

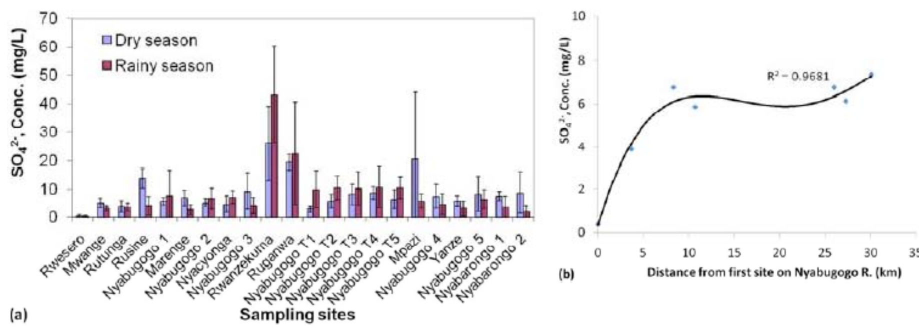

Fig. (11). Sulphate levels for (**a**) all the sampling sites and (**b**) sampling sites located on the Nyabugogo River for the monitored period.

3.2.2. Nitrate-Nitrogen (NO_3-N)

The NO_3-N levels for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Fig (**9**).

The NO_3-N results show a high value on the Rusine River, Marenge River, Nyacyonga, Rwanzekuma River, Ruganwa River and in the Nyabugogo Swamp, especially in the dry season (Fig. **9**). The NO_3-N profile on the Nyabugogo River show that the NO_3-N along the Nyabugogo River is generally decreasing downstream and rising again in the Kigali area. The NO_3-N values from this study are on the higher side, indicating possible contamination from direct and indirect sewage discharges. The NO_3-N values found by Mvungi *et al*. [15] and other researchers are generally below 10 mg/L.

3.2.3. Nitrite-Nitrogen (NO_2-N)

The NO_2-N levels for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Fig (**10**).

The NO_2-N results show that the NO_2-N were not varying much in the Nyabugogo catchment, except on the Rusine River and Ruganwa River and in the Nyabugogo Swamp where there were highest values especially in the rainy season (Fig. **10**). There were no Nitrites measurements for March to April 2009 because of resource limitations, hence the absence of error bars for the rainy season in Fig (**10**). The NO_2-N along the Nyabugogo River shows two peaks on the Nyabugogo 1 and the Nyabugogo 3 sampling sites. These two peaks are due to the discharges from Rusine River for Nyabugogo 1 and for Nyabugogo 3 sampling site this might be due to the Nyacyonga flower farming or rice plantation practiced in that area. The nitrite levels on the Nyabugo River stretch did not show a noticeable pattern, as shown in the second graph in Fig (**10**). This is as expected as presence of Nitrite shows that there is oxidation whose occurence depends on many environmental factors (natural re-aeration, photosynthesis, presence of Ammonium, etc) which will not be favourable all the time.

3.2.4. Sulphates

The sulphate levels for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Fig (**11**).

The sulphate results show high values on the Mpazi River 20.50 ± 23.72 mg/L in the dry season and 5.75 ± 2.63 mg/L in the rainy season, and on the Rwanzekuma River

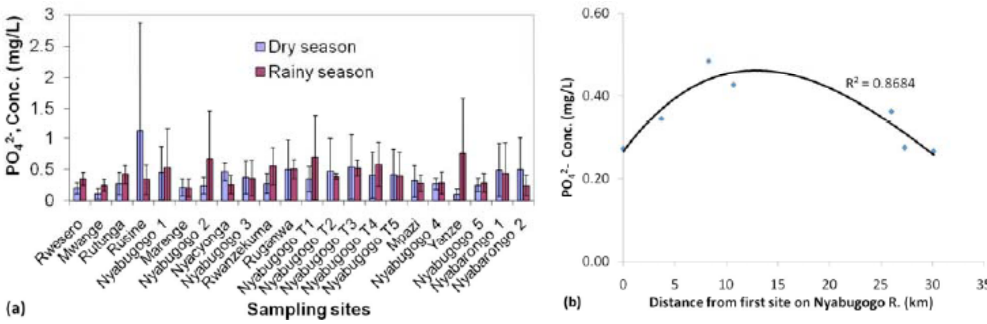

Fig. (12). Phosphate levels for (**a**) all the sampling sites and (**b**) sampling sites located on the Nyabugogo River for the monitored period.

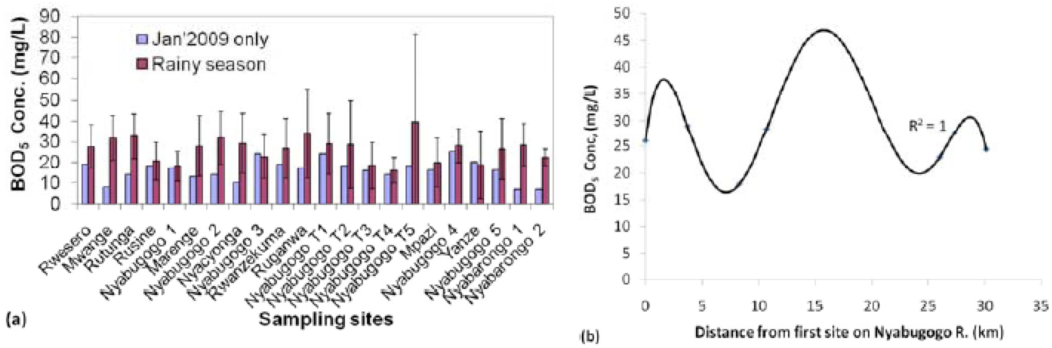

Fig. (13). BOD_5 levels for (**a**) all the sampling sites and (**b**) sampling sites located on the Nyabugogo River for the monitored period.

where the value in the dry season was 26.00 ± 12.96 mg/L and 43.25 ± 17.15 mg/L in wet season. Sulphate levels in rivers passing through urban areas have been generally reported below 1,000 mg/L [15], [18]. We therefore recommend further studies around the UTEXRWA textile industry as this may be a potential source of pollution. The sulphates profile shows that the sulphates are increasing downstream the Nyabugogo River, starting with the Nyabugogo 1 site which is about of 8.7 km from the first sampling point, suggesting that the Rusine River is contributing to polluting the Nyabugogo River with sulphates.

3.2.5. Phosphates

The phosphate levels for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Fig. (**12**).

The highest concentration of phosphates was found on the Rusine River in the dry season (1.11 ± 1.76 mg/L). This was attributed to a slaughterhouse located near the Rusine River, which discharges wastes directly into the river. The phosphates profile on the Nyabugogo River shows an increase near the upstream part with a peak at Nyabugogo 1 sampling site which is about 10.7 km from the first sampling point. This is due to discharges from the Rusine River, after which the phosphates concentration starts decreasing again. The presence of high phosphate levels in a river indicates pollution from from domestic sewage discharges.

3.2.6. Biochemical Oxygen Demand

The BOD_5 levels for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Fig (**13**).

BOD_5 and COD were only monitored from January to May 2009, hence the absence of error bara for the figures for the dry season as these only represent figures for January 2009 only. The BOD_5 High BOD_5 values for the wet season are attributed partly to the absence of proper sanitation systems in the area, whilst the presence of decaying plants in the wetlands would also play a role. Muhirwa *et al.* [6] also reported on high BOD_5 values in the Mpazi River.

3.2.7. Chemical Oxygen Demand

The COD levels for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Fig (**14**).

The COD analysis shows high values on the Rusine River especially in the rainy season (355.73 ± 599.57 mg/L). The COD load is coming from different chemicals like Iron, Manganese, Sulphates, Phosphates and Nitrogen which all use Oxygen for oxidation. Muhirwa *et al.* [6] concluded that the main source of the high organic load in the Mpazi River is the wastewater from the abattoir slaughtering area especially blood.

3.2.8. Iron

The iron levels for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Fig. (**15**).

The Iron analysis shows a high value of Iron on the Rusine River and on the Marenge River especially for the dry season; 8.76 ±8.88 mg/L for Rusine and 6.85 ±5.92 mg/L for Marenge. It was suspected that this pollution is due to the geological composition of the red soils in the area. Usanzineza *et al.* [5] reported a mean value for

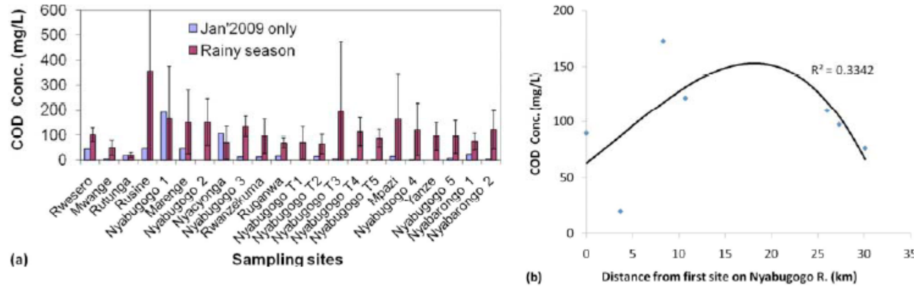

Fig. (14). COD levels for (**a**) all the sampling sites and (**b**) sampling sites located on the Nyabugogo River for the monitored period.

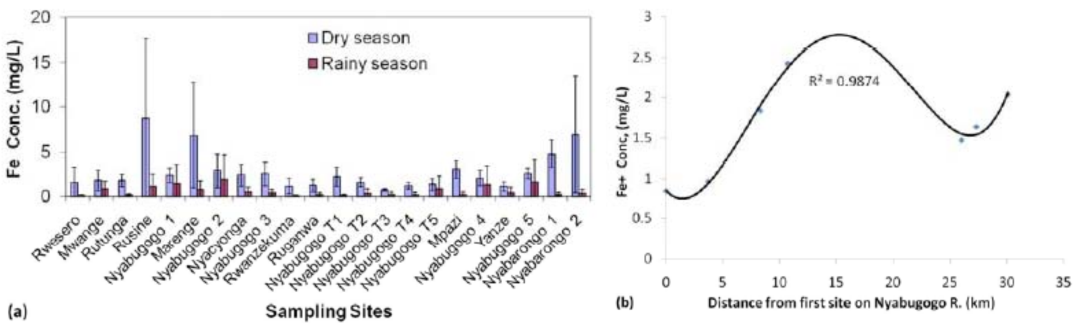

Fig. (15). Iron levels for (**a**) all the sampling sites and (**b**) sampling sites located on the Nyabugogo River for the monitored period.

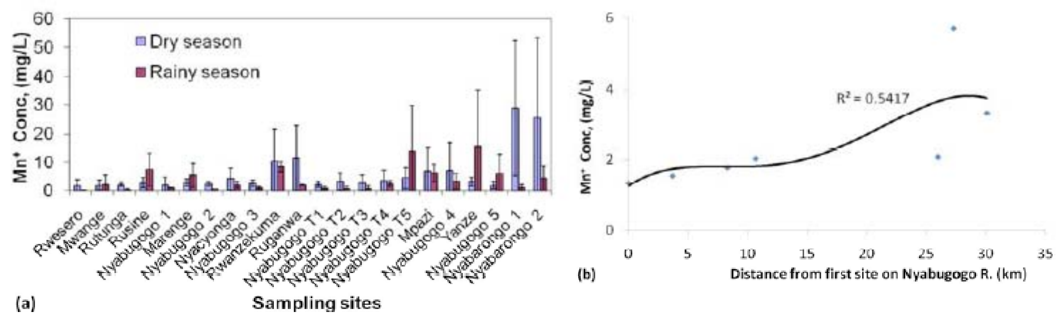

Fig. (16). Manganese levels for (**a**) all the sampling sites and (**b**) sampling sites located on the Nyabugogo River for the monitored period.

Fe of 0.756 ±0.734 mg/L at the Lake Muhazi outlet. The Iron levels profile of the Nyabugogo River shows that the Rusine River and Marenge River are contributing to increased Iron concentration levels in the Nyabugogo River in both the dry and the wet season. It was also observed that the inflows from the Kigali City are adding to this increased Iron levels in the Nyabugogo River. Iron is found in natural fresh waters at levels ranging from 0.5 to 50 mg/L [17].

3.2.9. Manganese

The manganese levels for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Fig (**16**).

The Manganese concentration levels were high especially in the dry sesason, with values of 10.28 ± 11.44 mg/L on the Rwanzekuma River and 11.58 ± 11.46 mg/L on the Ruganwa River. These high levels are also attributed to the surrounding geological formation and disturbance of soils, leading to the discharge of Manganes-rich runoff. Other high values were at the Nyabarongo River especially also in the dry season; 28.85 ± 23.53 mg/L for Nyabarongo upstream and 25.56 ± 27.91 mg/L on the Nyabarongo downstream point. In the rainy season the values are reduced due to dilution. It is noted from studies sucha as Valere [19] that the groundwater in Rwanda generally contains high levels of Manganese.

3.2.10. Lead

The lead levels for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Fig (**17**).

The Lead analysis results show a high value on the Mpazi River especially in the dry season (0.113 ± 0.054 mg/L). The source of this could be the Nyabugogo tannery which uses a lot of chemicals and a lot of car parks in the area. Other points such as the Nyabugogo 1 and 2, and the Nyacyonga site, had high values in the wet season only, suggesting that the metal is being swept off from somewhere – possibly a geological source. Okonkwo and Mothiba [16] reported Lead levels of 0.010 – 0.012 mg/L from three urban rivers in South Africa, whilst Mvungi *et al.* [15] reported 0.213 – 0.544 mg/L in Zimbabwe. However, as shown by Usanzineza *et al.* [5], the prevalence of Lead in the Nyabugogo Catchment is an issue which needs further investigations.

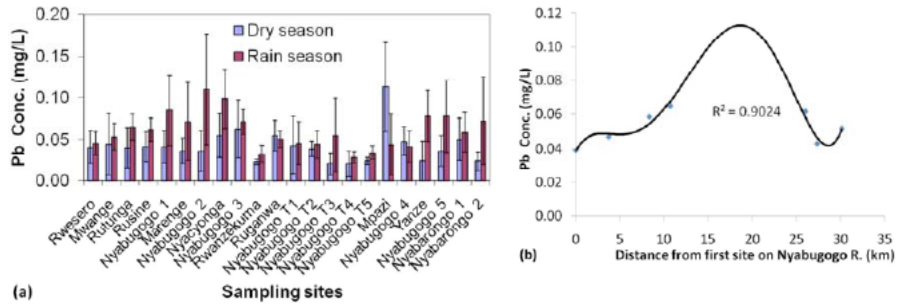

Fig. (17). Lead levels for (**a**) all the sampling sites and (**b**) sampling sites located on the Nyabugogo River for the monitored period.

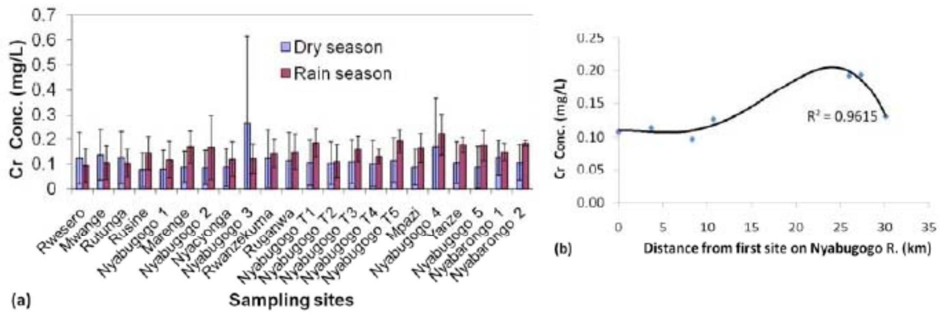

Fig. (18). Chromium levels for (**a**) all the sampling sites and (**b**) sampling located on the Nyabugogo River for the monitored period.

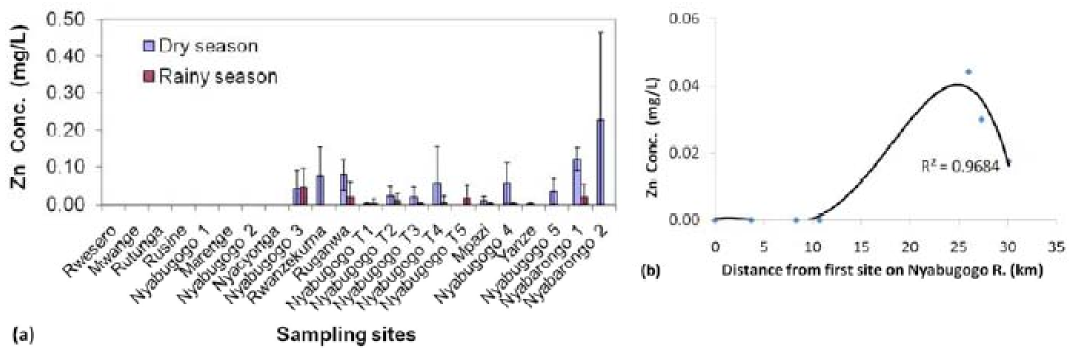

Fig. (19). Zinc levels for (**a**) all the sampling sites and (**b**) sampling sites located on the Nyabugogo River for the monitored period.

3.2.11. Chromium

The chromium levels for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Fig (**18**).

Chromium values are very high in the rainy season except for Rwesero, Mwange, Rutunga and Nyabugogo 3 sampling points. The highest value was on the 9^{th} site (Nyabugogo 3), and this point is located on the Nyabugogo River after the Kabuye sugar refinery factory has discharged its wastewater. Usanzineza *et al.* [5] did not detect Cr in Lake Muhazi. However, this study found an average value of 0.11 ± 0.09 mg/L at the Rwesero sampling point, which is closer to Lake Muhazi. Total Chromium concentrations in drinking-water are usually less than 2 µg/litre, although concentrations as high as 120 µg/litre have been reported [17]. The presence of Chromium is attributed to both natural and industrial discharges although the contribution of each needs further investigation. Most of the chromium in soils is present in the form of highly insoluble chromites. Weathering, oxidation, and bacterial action convert these chromites into soluble forms, and in this way chromium mineral deposits contribute slightly to the chromium content of natural waters. Chromium can also be present in natural waters as a contaminant from the discharge of industrial wastes or water from cooling systems in which chromates are used as corrosion inhibitors.Chromium is widely used in industry. The hexavalent chromium compounds are used in the metallurgical industry for chrome alloy and chromium metal production and chrome plating, and in the chemical industry as oxidizing agents and in the production of other chromium compounds. Trivalentchromium salts are used less widely, being employed in textile dyeing, in the ceramic and glass industry, and in photography.

3.2.12. Zinc

The zinc levels for all the monitored points and for the points on the Nyabugogo River stretch only are shown in Fig (**19**).

The level of zinc is undetectable upstream of the Nyabugogo River and starts to increase especially after the Kabuye sugar refinery factory where the highest peak of zinc level all along the Nyabugogo River is located The zinc pollution is mainly coming from industries Kigali City especially in the dry season. Usanzineza *et al*. [5] reported a mean value of Zn of 0.041 ± 0.045 mg/L in Lake Muhazi, whilst this study did not detect any Zn at the Rwesero sampling site; the first sampling site after the Nyabugogo River has left Lake Muhazi. Nkuranga [3] attributed the high levels of heavy metals in the Nyabugogo Swamp to the overflowing of wastewater from surrounding urban activities. Okonkwo and Mothiba [16] reported Zinc levels of 0.002 – 0.003 mg/L from three urban rivers in South Africa, whilst Mvungi *et al*. [15] reported 0.184 – 0.418 mg/L in Zimbabwe.

3.3. Identification of Pollution Hotspots

A summary of the mean values (± standard deviation) for the whole monitoring period is shown in Table **1**. The values are compared with three selected guidelines which are in line with the possible uses of water in the study area. The highest value for each parameter is shown in bold print in Table **1**. These areas which exceed standards are the hotspots which will be further studied in order to identify and isolate the actual sources of pollution in this on-going study. The results from Table **1** are further analsysed in Table **2**. After the above analyses, it can be concluded that the major sources of the pollution for the Nyabugogo River are:

1. Rusine River (mining activities); highest in Turbidity, PO_4-P, and COD.
2. Ruganwa River; highest EC and TDS values. The Ruganwa River collects a lot of water from the City of Kigali, especially the Kicukiro, Remera, Kiyovu, Kimihurura, Muhima areas, and also receives waste from the industrial area of Kigali.
3. Nyabugogo T3; lowest DO and highest NH_4-N values. The Nyacyonga Flower Farm could be having an influence though this warrants further investigation.
4. Nyabarongo 2; highest in Fe, Mn and Zn values. A water treatment plant is discharging sludge from iron/manganese removal processes.

Further studies are recommended in order to assess the origin of the pollution present in these rivers.

3.4. Assessment of Impact on the Downstream Nyabarongo River

Whislt the Nyabugogo river is heavily polluted, its impact on the Nyabarongo River is minimal since Nyabarongo River is more polluted before receiving the Nyabugogo River. For example, Nyabarongo upstream had higher values than Nyabarongo downstream except for COD, Fe, Mn, Zn, NO_2. Statistical analysis (T-Test) of samples from the Nyabarongo 1 and 2 sampling sites showed P $(T<=t) > 0.05$ for all parameters except sulphates (Table **3**), hence the impact of pollution before and after the discharge of water from Nyabugogo River was statistically not significant. This observation needs to be considered in its right perspective. What this means is that only the impact on the level of pollution in the Nyabarongo is not that significant but it does not mean that the water from Nyabugogo River is considered clean. The Nyabarongo River is already heavily polluted even before the discharge of water from the Nyabugogo catchment, which includes the City of Kigali. To further explain this, the flows of the two rivers can be compared and this shows that in term of volumes of flow, the Nyabugogo River is only about 10%% of the Nyabarongo River. It would be most interesting to carry out further water quality monitoring upstream of the Nyabarongo River to establish the exact sources of this pollution, considering that there are no large size towns in this catchment. Also considering the visible impact of sediments in the Nyabarongo River, there is a need to address erosion problems in the catchment. Further studies should also cover more parameters such as total suspended solids, to ensure the impacts of erosion are taken into account.

4. CONCLUSIONS

From the objectives and results of this study, the following conclusions were made:

1. The water in the Nyabugogo River system is polluted as far as physical parameters are concerned.
2. The chemical parameters monitored showed consistently high levels of pollution, warranting urgent attention to arrest further deterioration of water quality in the Nyabugogo River.
3. Although the Nyabugogo River is heavily polluted, its impact on the pollution levels in the Nyabarongo River is currently insignificant because the Nyabarongo River is much larger and already heavily polluted upstream of the confluence of the two rivers.

5. ACKNOWLEDGEMENTS

Acknowledgements are made to *(i)* SIDA/SAREC through the Inter University Council for Eastern Africa that co-funded this work under the Lake Victoria Research (VicRes) programme and *(ii)* Nuffic through the WREM Project, a collaborative capacity building project between the National University of Rwanda and the UNESCO-IHE Institute for Water Education.

NOMENCLATURE

%	=	Percentage
BOD_5	=	Biological Oxygen Demand
Cd	=	Cadmium
COD	=	Chemical Oxygen Demand
Cr	=	Chromium
EC	=	Electro-Conductivity
Fe	=	Iron
mg/l	=	Miligram per litre
Mn	=	Manganese
NH_4^+-N	=	Ammonium-Nitrogen
NO_2^-N	=	Nitric-Nitrogen
NO_3^-N	=	Nitrate-Nitrogen

Table 1. Summary of Monthly Results for the Period Oct'08 to May'09 Showing Mean Values ± Standard Deviation

	Turbidity	**EC**	**TDS**	**DO**	**pH**	**NH_4_N**	**NO_3-N**	**NO_2-N**	**SO_4-**	**PO_4-P**	**BOD_5**	**COD**	**Fe**	**Mn**	**Pb**	**Cr**	***Zn***
Sampling site	NTU	µS/cm	mg/L	mg/L		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Rwesero	8.25±5.97	397.33±167.94	170.29±27.18	4.19±1.29	7.24±0.18	0.16±0.16	12.58±7.82	0.01±0.01	0.38±0.52	0.27±0.12	25.96±9.80	89.92±34.76	0.85±1.36	1.33±1.72	0.04±0.02	0.11±0.08	0.00±0.00
Mwange	244.38±154.23	72.92±25.26	37.71±9.89	7.05±4.73	6.94±0.23	0.24±0.23	15.83±3.95	0.00±0.00	4.25±1.67	0.18±0.11	26.97±14.19	41.68±33.05	1.29±1.03	2.08±1.88	0.05±0.03	0.12±0.08	0.00±0.00
Rutunga	136.00±106.63	227.40±105.54	96.28±20.76	5.60±3.92	7.14±0.21	0.22±0.15	14.6±10.73	0.00±0.01	3.88±1.73	0.35±0.17	28.98±12.51	19.90±8.20	0.96±0.94	1.55±1.09	0.05±0.02	0.11±0.08	0.00±0.00
Rusine	**3675.25±6419.60**	50.52±20.22	25.13±8.20	6.02±4.51	6.84±0.73	0.67±0.81	34.44±26.31	0.06±0.07	9.00±5.93	**0.73±1.23**	20.13±8.01	**293.98±537.28**	4.94±7.16	4.40±3.77	0.05±0.02	0.11±0.07	0.00±0.00
Nyabugogo 1	3539.50±8978.07	169.22±100.46	81.50±31.55	5.85±4.03	7.04±0.69	0.54±1.09	10.10±5.69	0.02±0.02	6.75±5.97	0.49±0.49	17.91±6.18	172.86±179.93	1.83±1.66	1.78±2.07	0.06±0.04	0.10±0.07	0.00±0.00
Marenge	1915.56±1988.23	56.35±26.16	27.25±9.44	5.82±1.89	**6.44±0.65**	0.48±0.48	37.33±31.71	0.03±0.03	4.88±3.14	0.21±0.13	24.96±14.29	131.16±120.40	3.83±5.08	3.72±2.44	0.05±0.04	0.13±0.07	0.00±0.00
Nyabugogo 2	2702.38±6859.62	169.83±99.23	86.50±34.25	5.53±2.75	7.05±0.74	0.74±1.52	10.86±8.41	0.01±0.01	5.86±2.54	0.43±0.52	28.38±13.64	122.00±105.70	2.43±2.23	2.04±1.04	0.07±0.06	0.13±0.11	0.00±0.00
Nyacyonga	1024.50±2080.03	180.75±82.43	84.00±29.04	5.76±1.29	7.3±0.33	0.26±0.18	27.70±19.44	0.01±0.00	6.00±2.78	0.36±0.17	24.41±15.24	79.75±58.01	1.44±1.34	3.42±3.12	**0.08±0.04**	0.10±0.07	0.00±0.00
Nyabugogo 3	716.50±1023.60	194.77±95.33	81.13±28.38	4.34±1.39	7.09±0.23	0.26±0.32	8.08±7.21	0.02±0.01	6.75±5.31	0.36±0.25	22.94±9.18	110.40±65.02	1.47±1.45	2.08±1.14	0.07±0.03	**0.19±0.25**	0.04±0.05
Rwanzekuma	285.63±340.63	403.17±154.14	190.75±73.29	2.59±0.78	7.16±0.45	1.46±0.87	70.55±32.53	0.00±0.03	**34.63±16.83**	0.41±0.27	25.16±13.12	79.16±70.68	0.61±0.77	9.63±8.95	0.03±0.01	0.13±0.08	0.04±0.06
Ruganwa	263.94±399.66	**484.17±237.16**	**186.63±94.26**	2.09±0.82	7.31±0.34	1.88±0.68	72.55±18.26	0.04±0.07	21.00±12.04	0.50±0.33	30.39±19.91	58.94±28.84	0.71±0.67	8.43±10.13	0.05±0.01	0.13±0.09	0.05±0.05
Nyabugogo T1	69.00±62.50	384.48±151.93	180.00±66.96	2.30±1.96	6.83±0.21	1.57±0.75	24.29±34.89	0.02±0.02	6.50±5.71	0.52±0.50	27.98±13.01	56.38±63.51	1.16±1.28	1.87±1.08	0.04±0.03	0.14±0.08	0.00±0.01
Nyabugogo T2	217.38±499.07	400.33±165.20	183.13±70.09	2.29±1.70	7.04±0.21	2.28±1.30	27.35±41.59	0.02±0.04	8.13±4.02	0.42±0.35	26.57±18.87	54.46±41.27	0.97±0.75	2.47±2.66	0.04±0.01	0.11±0.07	0.02±0.02
Nyabugogo T3	250.63±639.20	408.33±174.07	173.25±80.03	**1.62±0.55**	6.99±0.24	**2.37±1.44**	23.54±26.56	0.02±0.04	9.25±4.59	0.53±0.35	17.91±9.73	158.64±255.86	0.48±0.32	2.13±2.35	0.04±0.04	0.13±0.07	0.01±0.02
Nyabugogo T4	243.13±483.82	394.83±178.91	170.63±81.18	1.90±0.50	7.00±0.37	2.07±0.57	29.21±46.30	**0.03±0.05**	9.75±5.04	0.49±0.34	15.7±5.37	93.06±69.21	0.69±0.60	3.13±2.83	0.02±0.01	0.12±0.06	0.03±0.07
Nyabugogo T5	169.88±365.47	392.50±170.61	165.13±81.43	1.94±1.14	7.01±0.35	2.35±0.78	25.10±37.72	0.02±0.04	8.50±3.96	0.40±0.37	**35.21±37.60**	70.64±50.06	1.08±0.99	7.67±9.07	0.03±0.01	0.15±0.08	0.01±0.02
Mpazi	646.88±903.74	261.70±108.40	133.75±53.16	3.80±1.62	7.20±0.28	0.85±0.48	**69.10±33.81**	0.02±0.01	13.13±17.50	0.30±0.19	19.12±10.45	127.23±164.52	1.64±1.65	6.6±6.82	0.08±0.06	0.13±0.07	0.01±0.01
Nyabugogo 4	642.75±875.49	200.27±87.14	95.63±35.34	3.90±1.54	7.18±0.34	0.43±0.24	8.95±27.93	0.01±0.02	6.13±4.05	0.28±0.13	27.57±7.22	97.38±104.34	1.64±1.54	5.70±8.11	0.04±0.02	0.19±0.14	0.03±0.05
Yanze	506.13±1231.26	57.77±23.88	30.88±8.64	6.03±2.25	7.04±0.63	0.24±0.25	28.90±11.47	0.00±0.00	4.63±2.62	0.43±0.68	18.92±13.94	76.80±64.47	0.76±0.60	7.33±10.89	0.05±0.04	0.14±0.07	0.00±0.00
Nyabugogo 5	1725.75±4124.37	191.68±93.74	88.13±44.11	5.23±2.07	6.99±0.33	0.58±0.85	12.35±3.96	0.01±0.01	7.38±4.72	0.27±0.12	24.35±13.64	76.17±69.42	2.03±1.85	3.33±3.80	0.06±0.04	0.13±0.08	0.02±0.03
Nyabarongo 1	805.93±737.44	285.88±386.82	43.14±20.31	4.98±1.89	**7.39±0.20**	0.41±0.47	35.54±32.24	0.02±0.01	5.43±3.55	0.46±0.42	24.15±13.11	65.12±336.91	2.22±2.59	17.79±22.51	0.05±0.02	0.14±0.05	0.06±0.06

Table 1. cont….

	Turbidity	EC	TDS	DO	pH	NH_4-N	NO_3-N	NO_2-N	SO_4-	PO_4-P	BOD_5	COD	Fe	Mn	Pb	Cr	*Zn*
Nyabarongo 2	737.28±571.03	376.08±447.85	55.00±21.39	5.65±2.47	7.43±0.27	0.26±0.33	28.79±20.94	0.03±0.03	5.38±6.19	0.37±0.37	19.32±7.74	99.20±85.45	**3.67±5.56**	**18.46±24.34**	0.05±0.04	0.14±0.06	**0.11±0.20**
Aquatic Life limit [20]				5.5-9.5	6.5-9.0			0.02					0.30	Not defined	0.001-0.007	0.010	0.03
WHO Drinking Water Guide-line [17]	1	-	<500	-	6.5 – 8.5	-	11	0.06	<500	-	-	-	2.00	0.4	0.01	0.05	3.00
Irrigation use limit [21]		<700	<450		6.5-8.0		<5						5.00	0.02	0.2	Not defined	5 (pH> 6.5)

Table 2. Assessment of Results for Major Parameters Against Selected Water Quality Standards

Parameter	Assessment Against Selected Standards	Probable Source and/or Recommendation
Turbidity	Turbidity was generally higher than standard limits for points upstream which were receiving runoff from disturbed catchments and was reduced by wetland polishing	Activities around Rusine, Marenge and Mpazi need to be controlled to reduce erosion and sedimentation.
EC, TDS, DO and pH	On average EC and TDS were not a problem compared to guideline values. Do and pH values were generally within guideline values.	
NH_4-N	The results were generally low compared to [15], though no guideline value is given. The maximum value of 2.37 mg/L was recoreded at Nyabugogo T3.	High levels are probably due to fertiliser washoffs from the Nyacyonga Flower Farm and organic waste from the Kabuye Sugar Factory.
NO_3-N	NO_3-N values were generally higher than the guidelines values for drinking and irrigation use. Particularly high values were recorded at Rwanzekwuma, Ruganwa and Mpazi River.	Points with high values drain residential and industrial areas of Kigali, indicating domestic pollution.
PO_4-P	No guideline value is given for PO_4-P, but the observed average values are all below 1 mg/L which is considered very low compare to values reported in literature [15, 16].	Lowlevels of phosphorus could be attributed to natral pollution although it is suspected that domestic sewage is still playing a role but the impact would be buffered by the extensive Nyabugogo Swamp.
COD and BOD_5	COD and BOD_5 are not specified in the guideline values used. The highest COD value of about 293 mg/L was recorded at Rusine upstream, whilst the highest BOD_5 value of about 35 mg/L was downstream at Nyabugogo T5.	The source of high COD values at Rusine, where BOD5 is much lower, needs further investigation as it seems there are some chemical discharges upstream. The high BOD5 value at Nyabugogo T5 is most likely due to organic matter discharges from the Kabuye Sugar Factory.
Fe and Mn	The standard for aquatic life limit was on average, exceeded at all the points but values were all below the irrigation limit. High values were observed at Marenge, Rusine and Nyabarongo 2.	These are related to the geological nature of the soils and their subsequent disturbance in mining activities. High values at Nyabarongo 2 are due to the discharge of iron and manganese removal processes at the Nzove Waterworks.
Pb	Lead levels exceeded limits for aquatic life and drinking water but were all below limit for irrigation.	Source of lead unknown as Usanzineza et al. [5] also reported high levels in Lake Muhazi. Could be relared to geology of the area.
Cr	The chromium levels exceeded drinking water limit for all points.	Geological formation.
Zn	Zinc levels were very low for upstream points and incresed to above limit of aquatic life in the urbanised part of Kigali. However, levels were all belo limits for drinking and irrigation purposes.	Zinc is originating from urban areas and its source needs to be pinpointed. There is also a possibility that Zinc is also being removed in groundwater treatment processes at Nzove Waterworks.

Table 3. Summary of Monthly Results for the Period Oct'08 to May'09 Showing Mean Values ± Standard Deviation

Parameter	T-Test, P (T<=t)
Turbidity	0.64
EC	0.49
TDS	0.18
DO	0.75
pH	0.59
NH_4_N	0.13
NO_3-N	0.24
NO_2-N	0.23
TN	0.14
SO_4-	0.03
PO_4-P	0.16
TP	0.12
BOD_5	0.19
COD	0.37
Fe	0.37
Mn	0.34
Pb	0.99
Cr	0.13
Zn	0.58

NTU = Nephelometric Turbidity Units

Pb = Lead

Pb = Lead

pH = potential of Hydrogen

PO_4-P = Phosphates

SIDA/SAREC = Swedish International Development Cooperation Agency/Swedish International Development Cooperation Agency

SO_4 = Sulphates

TDS = Total Dissolved Solids

TN = Total Nitrogen

TP = Total Phosphorus

VICRES = Lake Victoria Research Initiative

Zn = Zinc

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