The Use of Aquatic Macro-Invertebrate and Physico-Chemical Parameters for Water Quality Analysis in Wetlands of Kigali City.

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Abstract

The research provides information on the link of the physico-chemical and aquatic biodiversity water quality analysis in the wetlands around Kigali City, Rwanda. Rugunga and Nyabugogo wetlands were chosen as our case study. The analysed samples was from Rwampala River crossing in Rugunga wetland and Nyabugogo River crossing through Nyabugogo wetland. The biological water quality based on aquatic macro-invertebrates species were correlated with physico-chemical parameters in this study. Biological water quality monitoring was conducted as it has a capability of detecting the unexpected impact on aquatic environment and this technic is very cheap and environmental friendly than the use of chemicals during analysis. The link between biological quality and chemical quality analysis of water gives a full information stating that the chemical quality analysis of the water can be replaced by biological quality analysis. Different polluting substances are now emitted to the surface water body and requires chemical monitoring. Considering the rising in the number of pollutants, this chemical monitoring is now becoming a challenge especially in the developing countries due to the cost of chemicals, analytical equipment, trained personnel, materials, repairs and energy consumption. The biological monitoring however can not eliminate the need for chemical analysis of water but both methods should be combined to provide a system which is not too expensive and which provides maximum information with efficiency. The biological monitoring could for example reduce how often a chemical test is performed. The chemical parameters determined inlude; Electrical Conductivity(EC), turbidity, salinity, pH, temperature, Dissolved Oxgyen (DO), Total Suspended Solid (TSS), Total Dissolved Solid (TDS), Chemical Oxygen Demand(COD), phosphate, Total Alkalinity(TA), fluoride, chloride, nitrite and nitrate. The results of this study indicated that the turbidity, pH, DO, TSS, TDS and total alkalinity for the analysed water samples exceed the maximum permissible limit(MPL) set by Rwanda Standard Bureau for suface water. COD for Nyabugogo River exceeds the MPL, this implies that water quality in both Rwampala and Nyabugogo Rivers are polluted. The results for biological quality based on macroinvertebrates showed that the water is polluted. The Biotic Index (BI) indicates that the pollution increases from upstreams to downstream, from moderately polluted to heavily polluted, while the Multimetric Macroinvertebrate Index (MMI) showed that the water is polluted and is of poor to bad quality. The average basic prati index indicated that the water is slightly polluted upstream and highly polluted downstream. The predominant species in the Rivers across the wetlands of Rugunga and Nyabugogo wetlands are *diptera ceratopogonidae, diptera chironomidae, dipteral nonthummi-plumosus, diptera thummi-plumosus, hirudinea erpobdella, hirudinea glossiphonia, hirudinea helobdella, mollusca potamopyrgus, odonata anax* and *odonata aeshna*, those species are pollution tolerant.

Keywards: Macro-invertebrate, Physico-chemical, Multimetric Macroinvertebrate Index, Biotic Index, prati index, pollution, Rugunga wetland, Nyabugogo wetland, Kigali City.

1. Introduction

The three components that characterise water bodies are hydrology, physico-chemistry and biology. Those components are the basic to be analysed for an efficient water quality monitoring (UNESCO, 1996). Different study shows that the water quality is dynamic and depend on physical processes, chemical processes and biological phenomena (Sekomo et al., 2012; Abu, 2014), also is described in terms of the composition and state of the biological life present in the water body, the nature of the particulate matter present and the physical description of the water body (UNEP & WHO, 1996) and this is a global issues that is a result of a causal links starting with the driving forces through pressures to state change in physical, chemical and biological quality of water bodies. That force are needed in everyday life which lead to human activities exerting pressures on natural environment as a result of production or consumption processes. There is a clear link of the change in the water quality and ecosystems life as well as the living organisms consuming the water in different ways, the change in water quality has dramatic environmental and economical impacts on functionality ecosystems (Ndayisenga, 2020).

Aquatic ecosystems are valuable resources and a major source of protein for humans, this implies that the pollution of aquatic species lead to the human contamination through food chain. In most countries, commercial and sport which is fishing is economically important (Ahmad, 2012). Nowadays Rwandan

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Rivers are becoming polluted by various human activities, including littering, pouring chemicals down drains and industrial discharges, all of which are washed into creeks and storm water drains, and also the high levels of flooding, erosion and sedimentation contribute in surface water pollution (Nshimiyimana, 2008). There is also a link between water pollution and urbanization, population growth and industrial development (Nsengimana et al., 2011). This contribute to the deterioration of the quality of surface water like rivers, lakes, marshes and groundwater receiving different kind of pollutants from human activities and this have been known to be the one modifying biodiversity living in aquatic environment (Dufour et al., 2003).

Aquatic invertebrates, also known as benthic macro-invertebrates or benthos, include different species including insect, larvae, crayfish and other crustaceans, snails, clams, aquatic worms and leeches. They are found in all types of surface waters not only in Rwanda but also across whole globe mainly in large rivers, small streams, lakes and wetlands. A very diverse group, benthic macro-invertebrates, displays a wide range of sizes, habitat requirements, life histories, and are sensitive to water quality. Some are sensitive to changes in bottom composition while others are sensitive to changes in dissolved oxygen. Some require cold water temperatures, while others can tolerate a wide range. This makes benthic macro-invertebrates excellent indicators of human impact on aquatic systems.

Macro-invertebrates are bio-indicators that do not have back bones, they are small in size but they can be seen with the naked eyes. A healthy river will have a large amount and a variety of macro-invertebrates, and if it is not the case there is no healthy in river because there may be same factors that disturb the growth of macro-invertebrates in water such as sedimentation, habitat loss, and chemical pollution (Passuni and Fonkén, 2015).

This macro-invertebrates bio-indicator is organized into three categories which are pollution intolerant, pollution semi-tolerant and pollution tolerant. The presence of pollution intolerant organism indicates a healthy river with very little pollution, some of those organisms includes Mayfly Larva, Stonefly Larva, Dobsonfly Larva, Gilled Snails, Water Penny etc. And pollution semi-tolerant organisms includes Crayfish, Dragonfly Larva, Damselfly Larva, Whirligig beetle etc while pollution tolerant organisms includes aquatic worm, Backswimmers, Water boatman, etc. (Agouridis et al., 2015).

In this study we analyse the anthropogenic activities contribution to the wetlands selected which are Nyabugogo and Rugunga wetlands and the main target of this study is to establish the link between the level of pollution based on physico-chemical parameters and biological quality based on macro-invertebrates presents in the water body. We can reduce how often those parameters are monitored and use the sensitive species to monitor their increase. This can save money and the hazard impact of chemicals and give a clear literature added to the existing. Those wetlands under consideration receive pollution from Kigali City. In addition to this, those wetlands are used for agricultural activities which disturb the filtering capacity of the soil as well as the capacity of wetlands to prevent the pollutants from reaching the water bodies.

2. Sampling sites descriptions

Water samples were collected from 4 different locations in Rugunga wetland and 2 locations in Nyabugogo wetland, the collection of samples for invertebrate's identification was also performed at the same time with the water samples, hand net was used for collecting invertebrates. Sampling covered two rivers located in wetlands around Kigali City (Rugunga and Nyabugogo Wetlands), Rwampala River is one of the Rwandan small rivers located in Kigali city; it is situated in Rugunga wetland and receives much different kind of wastes from the neighboring anthropogenic activities and also erosion run-off up to this wetland. Near this river there are different human activities such as schools, hotels, automobiles cleaning stations, fuels stations, plantations, farming and small dumping site. Nyabugogo River on the other hand is located in Nyabugogo wetland and is characterized by moderately steep slopes, high rainfall intensity and intensive land use. The upstream part of the Nyabugogo River is regulated by the large Muhazi Lake with a catchment of 870 km^2. Apart from the waste water from human activities, the sampled rivers are affected by the impact of roofing of housing in Kigali city complexes and paving of roads and other access routes which reduce the surface area available for soil infiltration. The direct impact of reduced soil infiltration is increased run-off, soil erosion on bare soils and siltation of water ways in the lower slopes or marshlands, this problem is aggravated during the rainy season where much of the run-off flows to the valleys below with minimal infiltration which is one of the main ground water recharge pathways (Sekomo et al., 2012). Also associated with urbanization is watershed destruction and increasing incidences of dumping of untreated effluent in rivers and marshlands. There is no systematic way of disposing all waste water in Kigali City, Some waste water are treated by the producer before its discharge to the environment while the remaining waste water is discharged in small channel ending in the wetlands or rivers or discharged in underground holes. The six different sampling points in total were assessed for both physico-chemical and biological water quality in Rugunga and Nyabugogo wetlands. The figure 1 illustrate the locations of sampling points in this study.

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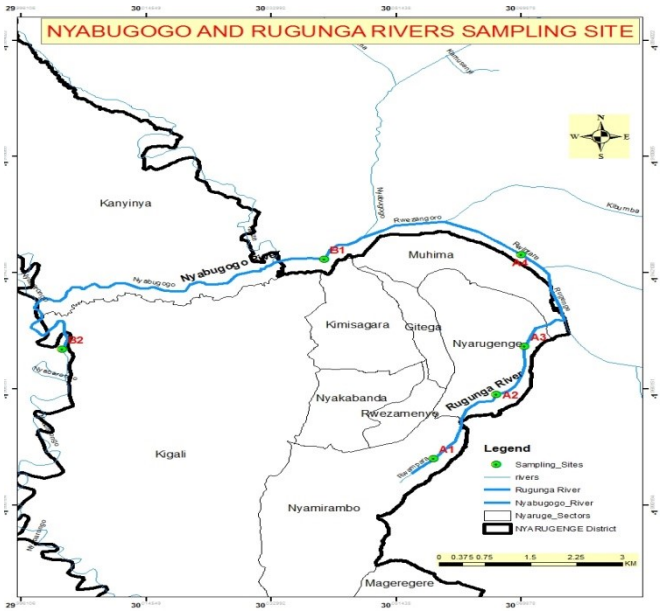

Figure 1: Sampling sites in Nyabugogo and Rugunga wetlands

3. Methodology

3.1. Collection of water samples and invertebrates

Different sampling points were chosen upstream, middle and downstream. Before sampling, sample containers were cleaned using deionized water followed by water sample to avoid any contamination of the sample. Two samples were taken in Nyabugogo River crossing through Nyabugogo wetland and four samples in Rwampala River passing through Rugunga wetland. Plastic containers were used in the collection of samples. On the field, samples were preserved in cooling box and after they were transported to laboratory for analysis but some parameters including dissolved oxygen (DO), pH, Salinity, total dissolved solid (TDS), electrical conductivity and temperature were measured on field.

The collection of invertebrates was performed by using a hand net and facing upstream into the current, handle held upright and the net placed on the bottom of the stream. The shuffler stands a foot upstream of the net and disturbs the stream bottom by slowly shuffling his feet, dislodging stones. Many invertebrates were jump off into the current and be carried down to the waiting net. After a couple of minutes of shuffling, the net was checked for sampled invertebrates. The net was raised and lowered into the water a few times to rinse and remove mud. Then after rinsing, the content of the net was transferred into a pan. The goal was to collect many macro-invertebrates. This procedure was repeated by moving a few feet from the original sampling site and repeating the shuffling-and-netting procedure. Samples were preserved in alcohol before sorting and identification of invertebrates.

3.2. Samples Analysis

Different equipments and/or analytical methods were used to determine the water quality parameters. Physico-chemical parameters measured on the field were obtained using a probes specific for each parameter. Nutrients were measured by using a UV-VIS-NIR spectrophotometer in the Laboratory where its measurement follows Beer-Lamberts law (Kulkarni et al., 2014 ; Austin, 1998).

3.2.1. Analysis of water samples

The summary of methods used in measuring water sample parameters are contained in this study. The details of the analytical procedure are outlined in appendix.

Description prati-index calculation

$$\text{Oxygen Prati Index} = \frac{0.08}{(100 - \text{Oxygen Saturation})}$$

$$\text{COD prati} = \frac{\text{COD}}{10}$$

$$\text{And Average Basic Prati Index} = \frac{\boldsymbol{Oxygen\ Prati + COD\ prati}}{2}$$

3.2.2. Analysis of invertebrate's samples

Sorting of invertebrate samples

Fresh water was put in smaller containers and sorting started by looking the appearance of the invertebrates. A plastic spoon was used to pick them up gently. At this point, it was only to estimate how many taxa and how many individuals in the sample. A taxon is a group of related individuals, note that many aquatic invertebrates belong to several similar-looking life stages that differ primarily in size. After picking them up, the collected macro-invertebrates were examined with a hand lens and look for differences in head and body shape, the appearance and placement of feathery external gills, coloration and the number of tails etc. Different types were placed in different containers.

3.3. Analytical Procedures

3.3.1. Calculation of MMI and BI

The MMI is calculated from 5 metrics: Taxa Richness (TAX), Number of Ephemeroptera, Plecoptera and Trichoptera Taxa (EPT), Number of other (i.e. non-EPT) Sensitive Taxa (NST), the Shannon–Wiener Diversity (SWD) Index and the Mean Tolerance Score (MTS). The description of those metrics is summarized in table 1.

The MMI is calculated as the sum of the 5 metric scores divided by 20, resulting in a final index ranging from 0 to 1.

Biotic Index was calculated according to (Gabriels et al., 2010). The BI method is a standardized method to assess biological quality of watercourses based on the macro-invertebrate community. This method is based on aquatic macro-invertebrates sampled with a standard hand net and the calculation of the biotic index is performed using a combination of the highest tolerance class encountered, the class frequency within the highest tolerance class and the total number of taxa. The tolerance scores, ranging from 10 for very pollution sensitive to 1 for very pollution tolerant taxa, are shown in table 2.

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Table 1. Metrics taken into account in the (Gabriels et al., 2010).

Abbreviation	Name	Calculation
TAX	Taxa richness	Total number of present taxa
EPT	Number of EPT taxa	Number of present *Ephemeroptera, Plecoptera* and/or *Trichoptera* taxa
NST	Number of sensitive taxa	Number of present taxa with tolerance score >5, not including *Ephemeroptera, Plecoptera* and *Trichoptera*
SWD	Shannon–Wiener diversity	- $\sum_{i=1}^{s} pilnpi$ (Shannon and Weaver 1949) with S = taxa richness, pi = relative abundance of taxon i
MTS	Mean tolerance score	Mean of the tolerance scores of all present taxa

Table 2: Table of tolerance score

Taxon	Tolerence score
Diptera:	
-Ceratopogonidae	3
Chironomidae	
-nonthummi-plumosus	3
-thummi-plumosus	2
Hirudinea:	
-Erpobdella	3
-Glossiphonia	4
-Helobdella	4
Mollusca:	
-Potamopyrgus	6
Odonata:	
-Anax	6
-Aeshna	6

Table 3. Scoring criteria for small Rivers (Gabriels et al., 2010).

Types	Score	TAX	EPT	NST	SWD	MTS
Small Rivers	0	≤ 5	0	0	≤ 0.2	≤ 2
	1	≤ 13.75	≤ 2.25	≤ 3	≤ 1.025	≤ 3.125
	2	≤ 22.5	≤ 4.5	≤ 6	≤ 1.85	≤ 4.25
	3	≤ 31.25	≤ 6.75	≤ 9	≤ 2.675	≤ 5.375
	4	> 31.25	> 6.75	> 9	> 2.675	> 5.375

3.3.2. Analysis procedure used for physico-chemical parameters

3.3.2.1. Analysis of turbidity and odor

The electrochemical method using turbidimeter was used to determine the intensity of turbidity and degree of turbidity by taking a sample and put into turbidimeter and record the results, in case the result was not detected we make dilution by any appropriate factor and rerecord . When the turbidity was less the water treatment is efficacious during purification. It was analyzed in laboratory using turbidimeter and expressing in NTU (Nephelometric turbidity Units). The odor indicates pollution or the presence of organic matters in water.

3.3.2.2. Total Alkalinity (HCO_3^-/CO_3^{2-})

Alkalinity was determined using titrimetric analysis using titration apparatus. In this method 50 ml of sample was used and we add 5 drops of phenolphthalein as indicator in titrant solution 0.02 N HCl until red color disappears and the volume used was recorded. And we add to the same solution 5 drops of methyl orange as the mixed indicator and titrate until red color appears, and then record the volume used. In case no color was appear (pH ≤ 8.3) we adds 5 drops of methyl orange indicator and

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titrates until a red color appears, the volume used was recorded (Sekomo et al., 2012).

Calculations

Alkalinity as mg/l $CaCO_3 = \frac{V*N*1000}{ml\ sample*2} * 100$

In case initial pH ≤ 8.3 mg/l $HCO_3^- = \frac{V*N*1000}{ml\ sample} * 61$

Where V= Titration volume in ml
N= Normality of the acid solution
100= Molecular mass of $CaCO_3$
61= Molecular mass of HCO_3^-

3.3.2.3. Fluorides (F^-)

Fluoride was determined with SPADNS method. We pipet 10 ml of sample into a dry round sample cell and another same quantity of deionized water into sample cell and add for both 2 ml of SPADNS Then mix and wait one minute for reaction then read the sample with spectrophotometer where deionized sample content is a blank solution. The dosage of fluorides is based on a reaction of complexation of fluorine in the zirconium solution according to the reaction:

$Zr^{4+} + 6\ F^- \rightarrow ZrF_6^{2-}$

The complex ZrF_6^{2-} has a red color proportional to the concentration of a spectrophotometer at a wavelength of 580 nm (Sekomo et al., 2012).

3.3.2.4. Chloride (Cl^-)

While for analyzing chloride we were use argentometric titrimetry method using titration apparatus. Samples was titrated with $AgNO_3$ as titrant solution and with K_2CrO_4 as indicator reagent using titration apparatus, at the equivalent point there is appearance of pinkish yellow color. The volume was recorded and then after the chloride concentration is calculated as follow: (Sekomo et al., 2012)

Calculations

mg Cl^-/Cl= $(A-B)*M*35.45*\frac{1000}{ml\ sample}$

Where A= ml titration for sample
B= ml titration for blank
M= $\frac{0.141}{ml\ titrant}$ (molarity of $AgNO_3$)

3.3.2.5. Determination of COD

During the COD determination, the sample of water was oxidized in reflux by solution of potassium bichromate ($K_2Cr_2O_7$) which is strong oxidant, in strong acid medium and in presence of silver sulphate (Ag_2SO_4) as a catalyst (Sekomo et al., 2012). During the digestion of Cr (VI) orange was reduced in Cr (III) with green color by the following reaction:

$Cr_2O_7^{2-} + 14\ H^+ + 5e^- \rightarrow 2\ Cr^{3+} + 7\ H_2O$

After the digestion, the orange color will persist because of $K_2Cr_2O_7$ not reduced and its determination by colorimetric method was permits to evaluate the quantity of $K_2Cr_2O_7$ consumed by oxidable matters of sample and this was expressed in terms of equivalent oxygen. The intensity of color is proportional to organic matters available in our sample (Sekomo et al., 2012). Therefore, 1.5ml of digestion solution was added to 2.5ml of sample followed by 3.5ml of indicator sown above and shake well using agitator and the remaining was to place on HACH COD reactor for heating about 150°C in two hours and wait for ambient temperature before measurement using UV Spectrophotometer.

3.3.2.6. Total suspended solids (TSS).

Measurement of TSS is now widely employed in both rivers monitoring. Ideally, individual samples should be taken from three to five depths along three to eight vertical profiles at the river station. These samples are then united proportionally to the measured velocity at each depth. When velocities are not measured, special depth integrating samplers can be used: they provide a velocity-averaged water sample for each vertical profile. Once the composite water sample is obtained, we measured TSS using spectrophotometer. Sampling TSS for chemical analysis requires more precautions in order to avoid contamination. These samples are generally taken at mid-depth in the middle of rivers assumed to be representative of the average quality of river particulates, or with depth integrating samplers. For eventual chemical analysis the TSS samples must be taken in the same manner for the same categories of pollutants. During field operations, we take great care to avoid any contact with rusted devices, greasy wires, etc which affect automatically the results to be obtained (UNESCO, 1996).

3.3.2.7. Phosphates (PO_4^{3-})

To measure the Phosphates content in the sample, we filled a sample cell with 10 ml of sample and the content of one Phos Ver 3 Phosphate powder pillow to the cell was added, and we immediately cap and invert to mix and wait two minutes of reaction, then this sample was measured using spectrophotometer where the blank solution is the sample. Orthophosphate reacts with molybdate in an acidic medium to produce a mixed phosphate / molybdate complex, ascorbic acid then reduces the complex giving an intense molybdenum blue color. Test result was measured at 880nm.

3.3.2.8. Nitrate ($N0_3^-$)

Nitrate was determined using cadmium reduction method. Where we filled a round sample cell with 10 ml of sample and the content of one Nitra Ver 5 Nitrate reagent powder pillow cap was added, then shake about one minute for reaction and after wait five minutes for reaction period to begin where an amber color was developed because nitrate is present. After this period we pour carefully 10 ml of the sample into a clean, round sample where it was taken as the blank solution. And then we measure the nitrates contents in our sample using UV Spectrophotometer.

3.3.2.9. Sulphate (SO_4^{2-})

Sulphate was determined using SulfaVer 4 Method. A clean sample cell with 10 ml of sample was filled and the contents of one SulfaVer 4 reagent powder pillow to the sample cell was

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added then mix and wait for five minutes for reaction period to begin and we never disturb the cell during this time, then the remaining is the measurement using spectrophotometer where the blank solution was our sample. Sulfate ions in the sample react with barium in the SulfaVer 4 and form a precipitate of barium sulfate. The amount of turbidity formed is proportional to the sulfate concentration. The SulfaVer 4 also contains a stabilizing agent to hold the precipitate in suspension. Test results are measured at 450 nm.

4. Results and discussion

4.1. Biological water quality based on macro-invertebrates

4.1.1. Biotic Index

In this section the color code are mostly useful for clear understanding to the information contained within the figures. The blue, green, yellow, blown and red color indicate lightly polluted or unpolluted, slightly polluted, moderately polluted, heavily polluted and very heavily polluted water respectively.

A large number of macro-invertebrates species can share the same habitat, some of which may have very large populations with different duration of life circle but most species have annual life cycles and depend on suitable breeding conditions being present every year at the appropriate time. For species with more than one generation a year these requirements are repeated through the year. Fewer species have generations longer than one year.

Generally invertebrates have short life circle and have a complex life cycles and each part of the life cycle has specific habitat condition of living within the limits of mobility for the life stage of the species. Most invertebrates have very limited means of dispersal and are therefore very slow at decolonization of sites from where they have been lost, and are cold blooded and therefore dependent on external heat for normal activity. Therefore, warm surfaces are important for their survival (Patrick, 1994).

To ensure the integrity of surface water, we need to know the relationship between activities and their effects on specific aquatic life. Pollution in surface water comes from different many sources. Testing water quality by chemical analysis only can fail to detect these wider impacts. Aquatic organisms spend all or a vast majority of their life cycles in the water and this becomes a key fact for its ability to analyse aquatic biological quality. Therefore, biological monitoring is often able to detect water quality impairments that other methods may miss or underestimate, by analyzing BI, MMI and other index as done in this study.

Biological monitoring tracks the health of plants, fish, insects, and small organisms including invertebrates in lakes, streams and rivers which are under consideration in our study. Researchers use several measures of a biological community to create an Index of Biological Integrity (BI). These help distinguish between natural processes and artificial processes impact to the species. For example, species considered tolerant of some form of pollution, such as sedimentation, could form a "tolerant" measure. Polluted water would tend to have more of these tolerant species. A high BI score indicates biological species similar to least-impacted (reference) sites of comparable size and type in the same geographic region

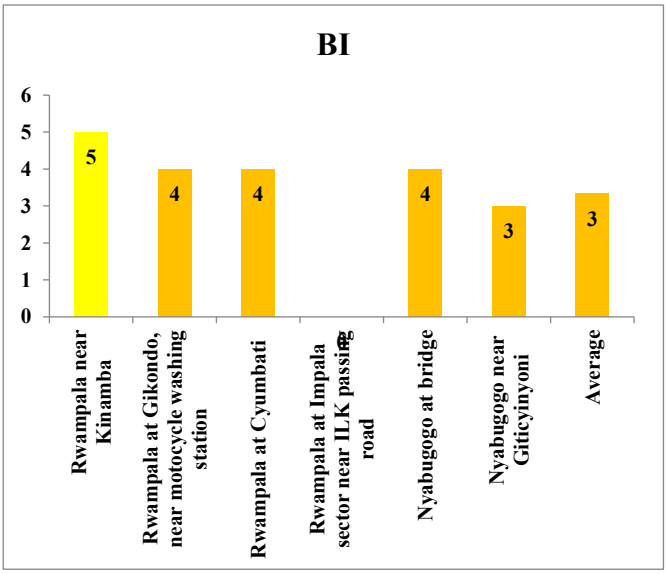

Figure 2: Variation of BI in both Rwampala and Nyabugogo rivers sampling sites

A low BI score indicates the species are significantly different or degraded compared with regional reference sites. Narrative descriptions can be used to rate the integrity of a site as excellent, good, fair, poor, or very poor (Lafayette and Paul, 2008).

4.1.2. Multimetric Macro-invertebrates Index

Multimetric Macro-invertebrates Index (MMI) allow multiple biological measurements, or metrics, to be combined into a single, unitless index value. Metrics are attributes of the biological assemblage, which can be quantified as a response to human and natural alteration or stress of the environment. MMI are calibrated using reference conditions and are created to exhibit a site's correlation to these conditions based on multiple categories. By incorporating metrics including richness, composition, functional feeding group, and pollutant tolerance for benthic macro-invertebrate communities, MMI can accurately indicate macro-invertebrate community health and help in stream condition determination statewide (TetraTech, 2005).

Water quality indices are necessary for resolving lengthy, multi-parameter, water analysis reports into single digit scores. This is essential for comparing the water quality of different sources and in monitoring the changes in the water quality of a given source as a function of time and other influencing factors. Time of the sampling also significantly influences water quality parameters and hence the index value. However, it is extremely difficult to develop a universally acceptable general water quality index. Most of the developed water quality indices are surface water

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specific and there is scope to develop groundwater quality index (Tirkey et al., 2015).

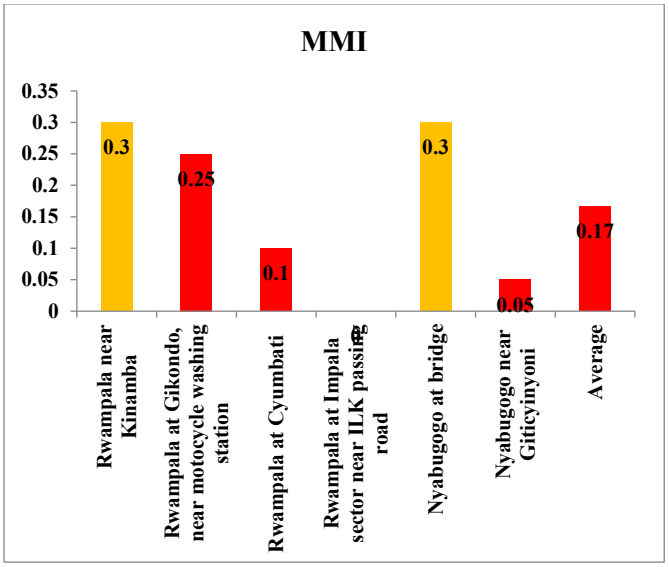

Figure 3: Variation of MMI in both Rwampala and Nyabugogo rivers sampling sites.

4.2. Physico-chemical parameters

4.2.1. Electrical conductivity

Electrical conductivity, or specific conductance, refers to the ability of water to conduct an electric current. This is mainly based on variations in dissolved solids, especially mineral salts. The highest minerals water containing, the more electric conductance. The ability for which these minerals dissociate into ions, the ability of electric transport, the temperature and also ion mobility of the sample solution all have a large influence on electrical conductivity. The unit of measurement for electrical conductivity is either micro Siemens per centimeter (µS/cm) or Millisiemens per centimeter (mS/cm). (Nkuranga, 2007).

In both Rwampala and Nyabugogo rivers all sampling sites had electrical conductivity values ranged to Rwanda Standard Board guideline. The conductivity of most freshwaters ranges from 277 to 678 µS/cm, in this range the aquatic biodiversity are possible and there is no threats on species living in this medium, but electrical conductivity may exceed 1000 µS/cm, especially in polluted waters, or those receiving large quantities of land run-off. In addition to being an indicator of mineral content when other methods cannot easily be used, conductivity can be measured to establish a pollution zone, for example around an effluent discharge, or the extent of influence of run-off waters.

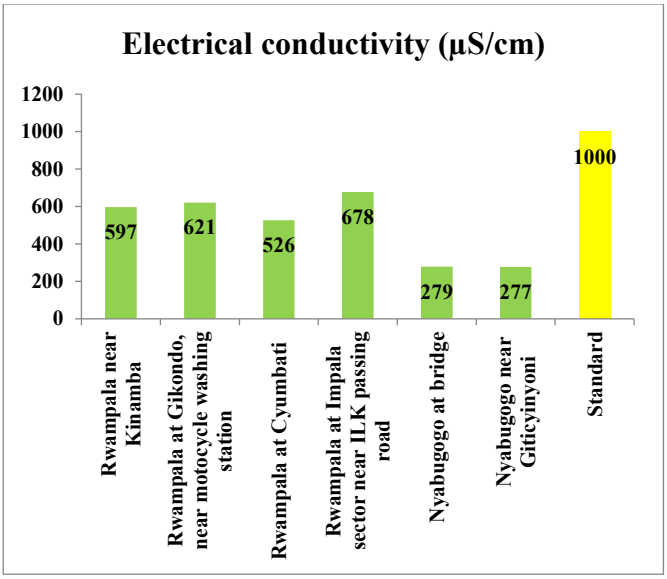

Figure 3: Variation of conductivity in both Rwampala and Nyabugogo rivers sampling sites.

4.2.2. Turbidity

Turbidity of water is the basic measure of clarity of water. Simply it is the results obtained from the absorption and scattering of incident radiation by the contained particles in water body, and the transparency of water is the limit of its visibility. Both can vary periodically or seasonally according to biological activity in the water column and also surface run-off carrying soil particles into the River. Heavy rainfall may also result in immediately variation in turbidity like in each hour due to inlet surface runoff or erosion and also higher temperature may increase turbidity because the amount of dissolved oxygen start to decrease. The higher turbidity can provide shelter and food for pathogen. (Abu, 2014).

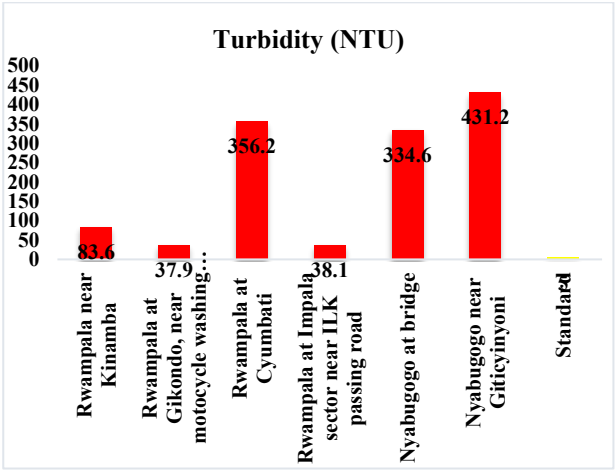

Figure 4: Variation of turbidity in both Rwampala and Nyabugogo rivers sampling sites

The turbidity for all sampling site are higher than the standard which is 5NTU, in all sampling sites for both Rwampala and Nyabugogo rivers as shown on Figure 5. Generally there is a pollution problem of surface water caused by high turbidity. This means that both Rwampala and Nyabugogo rivers is more murky

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and dirty because it accumulates too much suspended matters from its surroundings. At Rwampala river on sampling site near Kinamba there was border of river construction and on sampling site located at Cyumbati there was removal of gravels, and those activities increases turbidity and disturb aquatic biodiversity and most of them can be dead or rehabitate. Simply, appropriate measurements are needed in order to increase infiltration of rain water on hill side and avoid surface run-off as prevention against erosion furthermore, river banks needs also to be protected.

4.2.3. Salinity

Salinity is the total concentration of salts dissolved in the water body. Salinity is directly proportional to the electric conductivity of water body. The salts dissolved in water are mainly NaCl, $CaCO_3$, K_2CO_3, $MgCO_3$, etc. The salinity obtained in the analyzed sample for both Rwampala and Nyabugogo Rivers are shown on Figure 5. The salinity measured was much lower compared to the RSB standards, Thus salinity of this rivers does not exceed 0.32 mg/l and are in range of the RSB standards it means that the salts content in water is not higher.

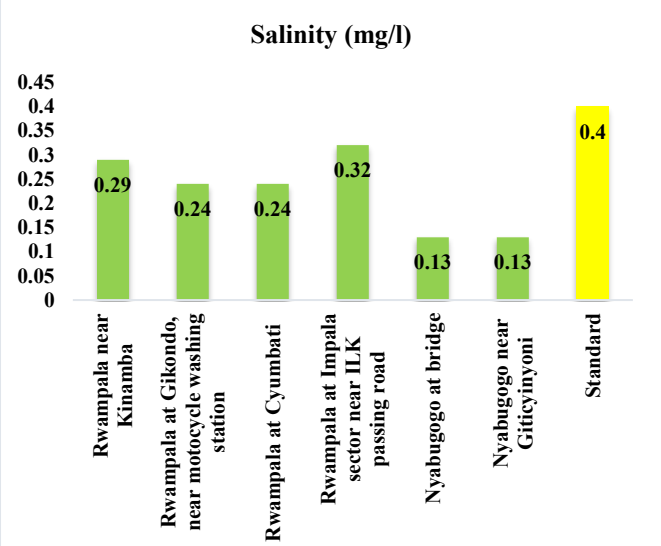

Figure 5: Variation of Salinity in both Rwampala and Nyabugogo rivers sampling sites.

4.2.4 Temperature

The temperature of surface water is influenced by latitude, altitude, seasons, time of the day, air circulation, cloud cover and the flow and depth of the water body. Thus, temperature can affects physical, chemical and biological processes in water bodies and also the concentration of many variables (Abu, 2014).

The temperature values for Rwampala river at sampling site located near Kinamba, and other sampling site located at Impala sector near ULK passing road, and also sampling site located at Nyabugogo river at bridge are normal compared to the RSB temperature standards of surface water, while the temperature values for sampling site located at Rwampala

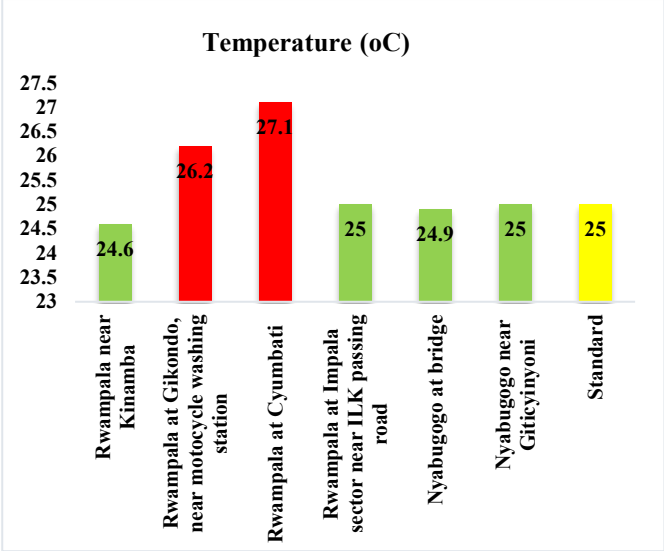

Figure 6: Variation of temperature in Rwampala and Nyabugogo rivers sampling sites.

river at Gikondo near automobile washing station, and other located at Rwampala river at Cyumbati exceed ambient temperature which is the RSB standard. In all sites, the values recorded were equals or close to the ambient temperature as shown on Figure 6. This is within the acceptable range for the aquatic life maintenance even if same species may live in very cold or very hot medium.

As water temperature increases, the rate of chemical reactions generally increases together with the evaporation and volatilization processes of substances from the water and also may decreases the solubility of gases dissolved in water, including oxygen, carbon dioxide, nitrogen, methane gases and other gases. The rate of metabolic for aquatic organisms is also related to temperature, and in warm waters, respiration rates increase leading to increased oxygen consumption and increased decomposition of organic matter. Growth rates also increase (this is most noticeable for bacteria and phytoplankton which double their populations in very short time periods) leading to increased water turbidity, macrophyte growth and algal blooms, when nutrient conditions are suitable.

4.2.5. pH

The pH is an important variable in water quality assessment as it influences many biological and chemical processes within a water body. The pH values meet the standard for surface water (6.5 - 8.5) for all sampling sites on Rwampala River. In general, the values of pH observed in this region are favorable to aquatic life protection, drinking water production and irrigation purposes. The pH did not dramatically vary in the Nyabugogo River system as mentioned on Figure 7.

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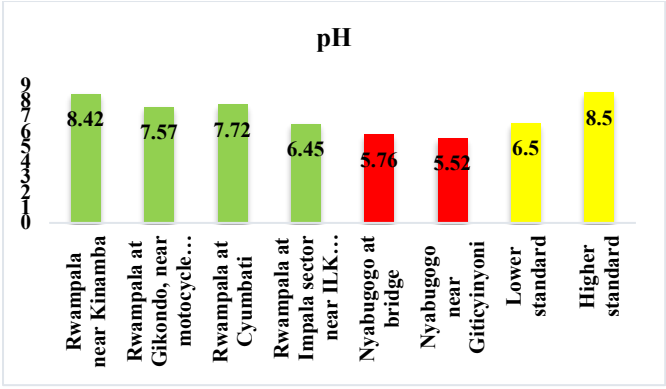

Figure 7: Variation of the pH recorded in both Rwampala and Nyabugogo rivers sampling sites

High pH and warmer temperatures increase the toxicity of a given ammonia concentration. High ammonia concentrations can stimulate excessive aquatic production and indicate pollution. This can also be used as a measure of the health of water in natural bodies such as rivers or lakes, or in artificial water reservoir (Abu, 2014)

4.2.6 Chemical Oxygen Demand (COD)

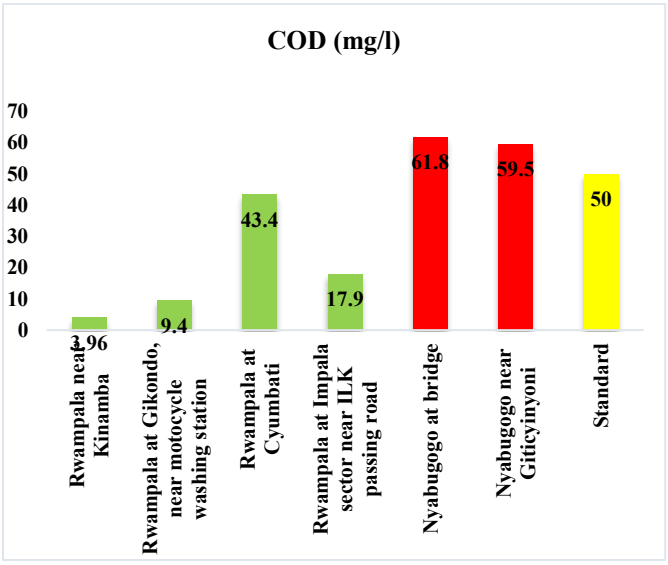

Figure 8: Variation of COD in both Rwampala and Nyabugogo rivers sampling sites.

The COD is the measure of the susceptibility to oxidation of the organic and inorganic matter present in the body of water and in the effluents from sewage and industrial plants. The COD was high when compared to the standard for surface water at both sampling sites at Nyabugogo River due to the industrial discharge, these high values of COD are an indication of the water pollution especially due to the surrounding human activity occurring near the sites. This may be due to flower farming and the Kabuye sugar works which are both located along the Nyabugogo River, sugar cane plantation upstream, legumes and rice cultivation, and industrial discharge (Nsengimana et al., 2011). While for Rwampala river is acceptable to the standard as shown in Figure 8.

4.2.7 Dissolved oxygen (DO)

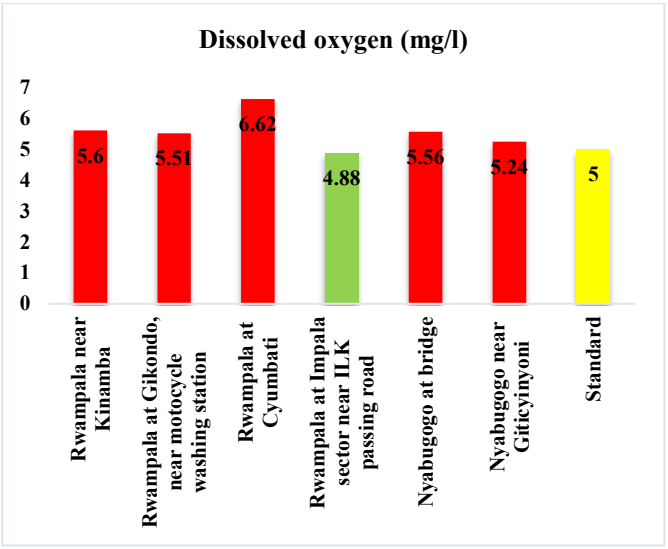

Figure 9: Variation of D.O in both Rwampala and Nyabugogo rivers sampling sites.

Oxygen is necessary to all forms of aerobic aquatic life, including invertebrate and other organisms able to act as self-purification processes in natural water. Oxygen can enter in the water in three ways, through diffusion at the surface of the water, through aeration (due to movement of water), as a waste product of photosynthesis. The oxygen content varies due to different parameters including temperature, salinity, turbulence, the photosynthetic activity of algae and plants, and atmospheric pressure (Manahan, 2000a). Oxygen is essential because it is required for aerobic metabolism of organisms, influences inorganic chemical reactions and different other processes.

DO measured from the analyzed samples for both Nyabugogo and Rwampala rivers are moderately high compared to their standard concentration of 5 mg/l given by RBS except sampling site at Rwampala river at Impala sector near ULK passing road which DO value is lower but approximately to the DO standard value for natural water as shown on figure 9, these results DO indicate that both Nyabugogo and Rwampala rivers are favorable for macroinvertebrates, fish survival and some others aquatic animals.

Frequent death of fishes and others aerobic species including invertebrates in surface water doesn't come from its toxicity only, but also from some time is from deficit of consumed oxygen from biological decomposition of pollutants. The amount of dissolved oxygen in water is inversely proportional to the temperature of the water; as temperature increases, the amount of dissolved oxygen (gas) decreases.

The following Figure 10 indicates oxygen prati indices and Figure 11 Indicates, Basic prati index combining Oxygen and COD calculated to specify the quality of water body of Nyabugogo and Rwampala Rivers.

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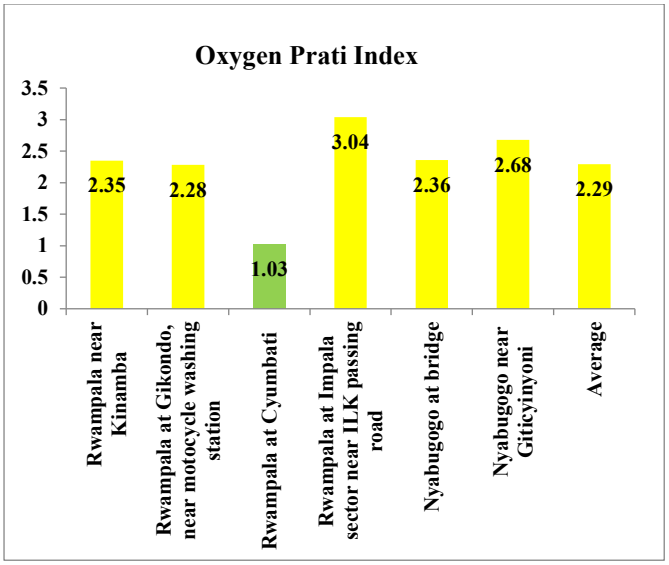

Figure 4: Variation of Oxygen Prati Index in Rwampala and Nyabugogo rivers sampling sites.

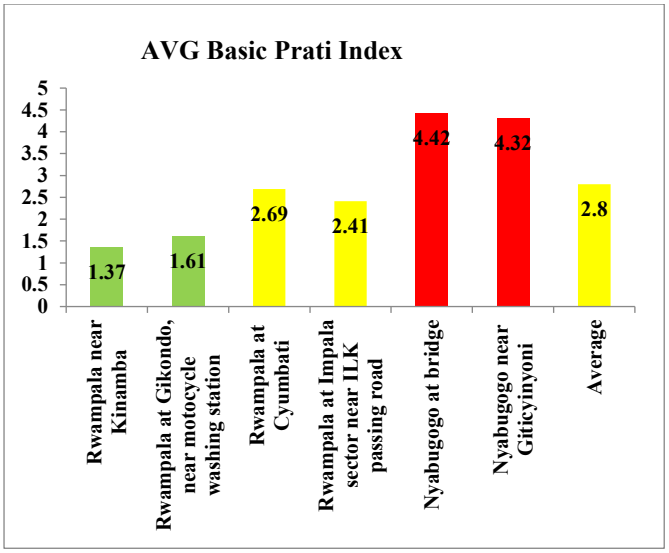

Figure5: Variation of Average Basic Prati Index in Rwampala and Nyabugogo rivers sampling sites.

4.2.8. Total Dissolved Solid (TDS)

The TDS is a measure the degree of dissolved matter contained in the water body, this parameter is directly proportional to the turbidity and on other side is also proportional to the total suspended matter. At Rwampala River TDS was higher than TDS at Nyabugogo River as mentioned on Figure 12, because in upstream of Rwampala River there was an extraction of gravels which increase TDS and turbidity and also turbulence increase downstream which affect aquatic biodiversity because it disturb the medium.

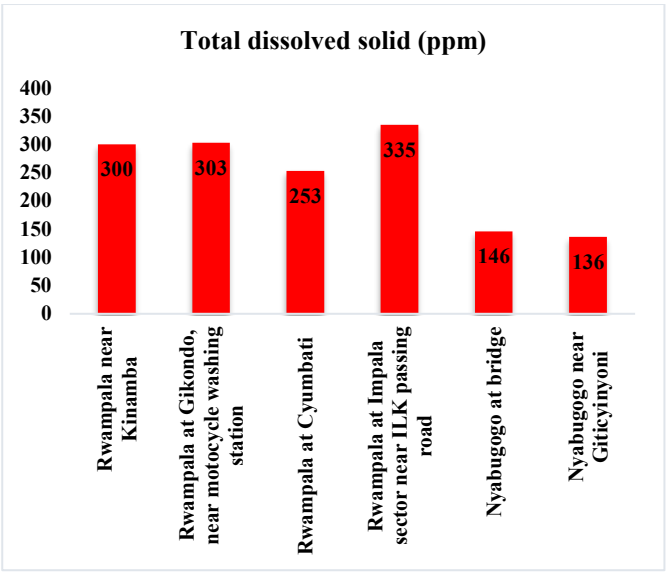

Figure 6: Variation of TDS in both Rwampala and Nyabugogo rivers sampling sites.

4.2.9 Total Suspended Solid (TSS)

The turbidity and transparency of a water body is affected by the type and concentration of suspended matter including silt, clay, fine particles of organic and inorganic matter, soluble organic compounds, plankton and others microscopic organisms (Abu, 2014). Total suspended solids are high in all sampling sites as mentioned on Figure 13. In other ways total suspended solids are often the result of sediments carried by the water, same of the originality of these sediments are naturally or anthropogenic (human) activities in the watershed, including natural or excessive soil erosion from agriculture, forestry or construction. Particularly during sampling period there was gravels extraction in upstream of Rwampala River and this river flow into Nyabugogo River. Suspended solids can also raise water temperature which reduces the dissolved oxygen.

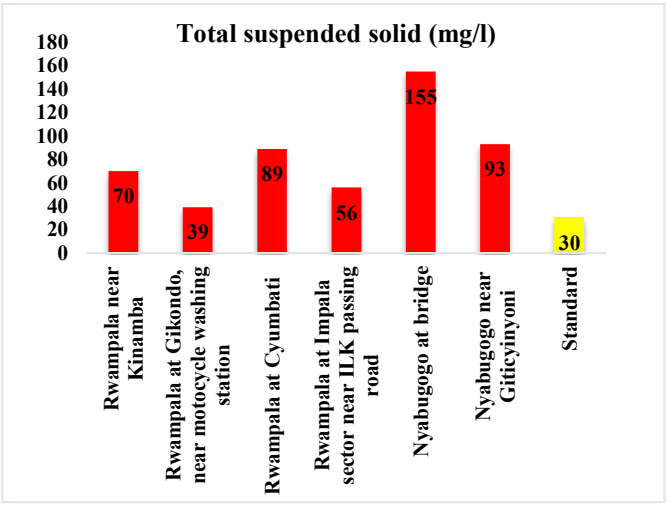

Figure 7: Variation of TSS in Rwampala and Nyabugogo rivers sampling sites.

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4.2.10 Nitrate (NO_3^-)

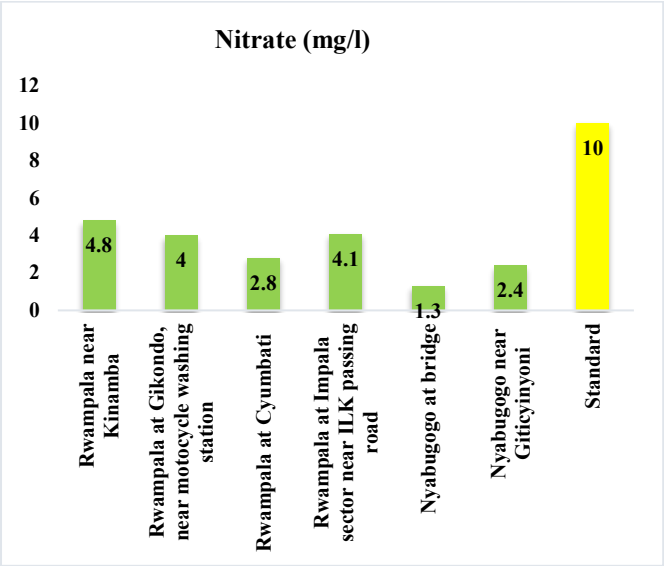

Figure 8: Variation of Nitrate in both Rwampala and Nyabugogo rivers sampling sites.

The nitrate ion (NO_3^-) is the common form of combined nitrogen found in natural waters. Nitrate are essential for plant growth but too many nitrates is a bad, too many nitrates in water can cause too much plant growth which can reduce the amount of DO available in water. It may be biochemically reduced to nitrite (NO_2^-) by the processes known as de-nitrification, just under anaerobic medium. The nitrite ion is rapidly oxidized to form nitrate. Natural sources of nitrate to surface waters include igneous rocks, land drainage and plant and animal debris. Nitrate is an essential nutrient for aquatic plants and seasonal fluctuations can be caused by plant growth and decay, Nitrate can increase temperature, decrease DO and indicate pollution. In rural and suburban areas, the use of inorganic nitrate fertilizers can also be a significant source. When influenced by human activities, surface waters can have nitrate concentrations up to 5 mg/L NO_3^-, While Concentrations in excess of 5 mg/L usually indicate pollution by human or animal waste, or fertilizers run-off (Nsengimana et al., 2011). In all sampling sites, nitrate concentrations are below the acceptable standard limit for surface water as mentioned on Figures 14.

4.2.11 Sulphate (SO_4^{2-})

Sulphate is present naturally in surface waters as SO_4^{2-} ion. It comes from the atmospheric deposition of oceanic aerosols and the leaching of sulphur compounds, like sulphate minerals such as gypsum or sulphide minerals such as pyrite, from sedimentary rocks. For which is the stable, oxidized form of sulphur and also is readily soluble in water except lead, barium and strontium sulphate which precipitate. Industrial discharges and atmospheric precipitation can also add significant amounts of sulphate to surface waters. Sulphate can be used as an oxygen source by bacteria which

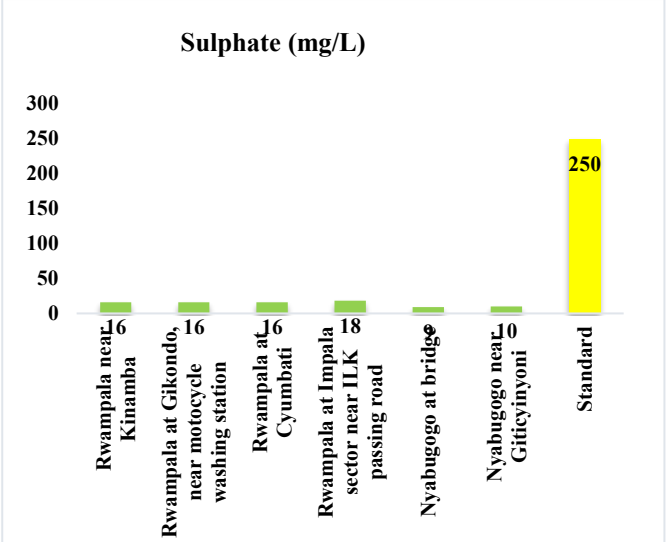

Figure 9: Variation of sulphate in Rwampala and Nyabugogo rivers sampling sites.

convert it to hydrogen sulphide (H_2S, HS^-) under anaerobic conditions. Sulphate concentrations in natural waters are usually between 2 and 80 mg/L, although they may exceed 1000 mg/L near industrial discharges or in arid regions where sulphate minerals, such as gypsum, are present (Sekomo et al., 2012). As mentioned on Figures 15, Sulphate concentrations for all sampling sites belong to the range of surface water standard this implies that aquatic life is possible.

4.2.12 Phosphate (PO_4^{3-})

Phosphorous is an essential nutrient for living organisms and exists in water bodies as both dissolved and particulate species. It is generally the limiting nutrient for algal growth and, therefore, controls the primary productivity of a water body. Artificial increases in concentrations due to human activities are the principal cause of eutrophication. In natural waters and in wastewaters, phosphorus occurs mostly as dissolved orthophosphates and polyphosphates, and also organically bound phosphates. Changes between these forms occur continuously due to decomposition and synthesis of organically bound forms and oxidized inorganic forms. Natural sources of phosphorus are mainly the weathering of phosphorous-bearing rocks and the decomposition of organic matter. Domestic waste-waters such as those containing detergents, industrial effluents and fertilizer run-off contribute to elevated levels in surface waters. Phosphorus associated with organic and mineral constituents of sediments in water bodies can also be mobilized by bacteria and released to the water column. Phosphorus is rarely found in high concentrations in freshwaters as it is actively taken up by plants. As a result there can be considerable seasonal fluctuations in concentrations in surface waters (Abu, 2014).

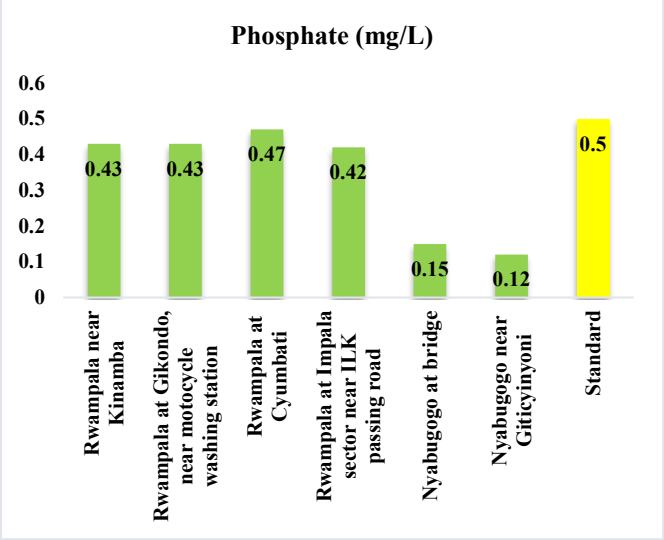

Figure 10: Variation of Phosphate in both Rwampala and Nyabugogo rivers sampling sites.

Results from this study are showing low phosphate values for both sampling sites on Nyabugogo river compared to the standard while on Rwampala river for all four sampling sites phosphate values are lower but very closer to the standard values for natural water as shown on Figure 16.

4.2.13 Fluoride (F^-)

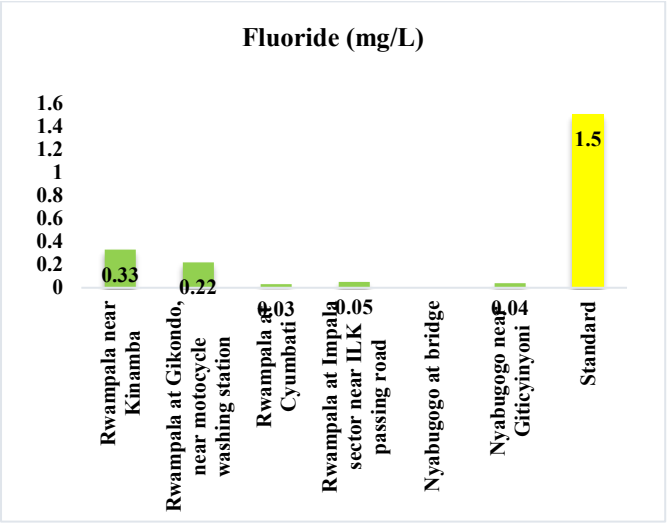

Figure 11: Variation of Fluoride in both Rwampala and Nyabugogo rivers sampling sites.

Fluoride comes from the weathering of fluoride-containing minerals and enters surface waters with run-off and groundwater through direct contact. Liquid and gas emissions from certain industrial processes (such as metal-and chemical-based manufacturing) can also contribute fluoride ions (F^-) to water bodies. Fluoride mobility in water depends, to a large extent, on the Ca^{2+} ion content, since fluoride forms low solubility compounds with divalent cations. Others ions that determine water hardness can also increase Fluoride solubility (Sekomo et al., 2012). Fluoride concentrations in natural waters vary from 0.05 to 100 mg/L, although in most situations they are less than 0.1 mg/ L as like our research except for sampling site at Nyabugogo River at bridge which was not detected as shown in Figure 17.

4.2.14 Chloride (Cl^-)

Potential source for chloride contamination in these waterways include septic effluent (private and municipal), animal waste, and agrichemicals. Most chlorine occurs as chloride (Cl^-) in solution. It enters surface waters with the atmospheric deposition, with the weathering of some sedimentary rocks (mostly rock salt deposits) and from industrial and sewage effluents, and agricultural and road run-off. High concentrations of chloride can make waters unpalatable and, therefore, unfit for drinking or livestock watering. As chloride is frequently associated with sewage, it is often incorporated into assessments as an indication of possible faecal contamination or as a measure of the extent of the dispersion of sewage

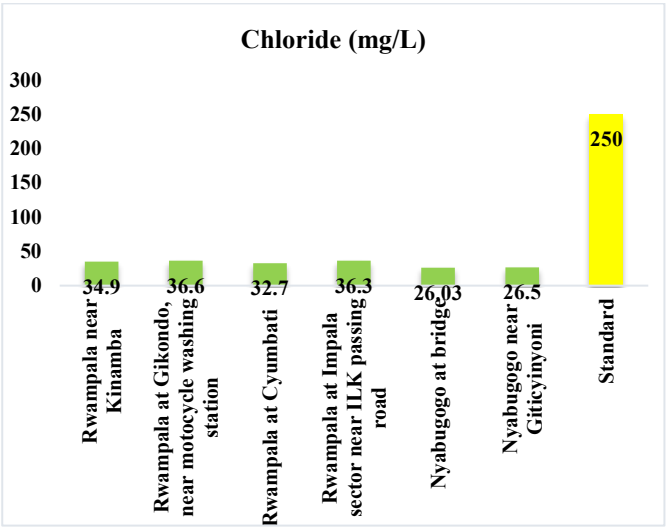

Figure 12: Variation of Chloride in both Rwampala and Nyabugogo rivers sampling sites.

discharges in water bodies (Nsengimana et al., 2011). The concentration of Chloride recorded in this research in all sampling sites in both Nyabugogo and Rwampala rivers was below the standard limit for surface water as shown below on Figures 18.

4.2.15 Total Alkalinity

Alkalinity of water is the capacity of that water to accept proton ion (H^+), this is important in water treatment and in the chemistry and biology of natural waters. Alkalinity of water must be known to calculate the quantities of chemicals to be added in treating the water. Thus highly alkalinity of water also high pH and generally contains elevated levels of dissolved solids. These characteristics may be detrimental for water to be used in boiler, food processing, and municipal water systems. Alkalinity serves as a pH buffer and reservoir for inorganic carbon, and used to determine the ability of water for algal growth support and other aquatic life, simply it can be used to measure water fertility. Generally, the basic species responsible for alkalinity in water are bicarbonate ion, carbonate ion, and hydroxide ion, and other

minor contributors include ammonia, conjugated bases of phosphoric, silicic, boric, and organic acids (Manahan, 2000a).

$HCO_3^- + H^+ \rightarrow CO_2 + H_2O$

$CO_3^{2-} + H+ \rightarrow HCO_3^-$

$OH^- + H^+ \rightarrow H_2O$

Theoretically alkalinity is calculated as follow

$[Alk] = [HCO_3^-] + 2\,[CO_3^{2-}] + [OH^-] - [H^+]$

For all sampling sites total alkalinity measured exceed the standard value as mentioned on the following Figures 20.

4.3. Correlation of physico-chemical parameters with Biological Index

Simply Nyabugogo river is Heavily polluted, and we found that the predominant species in this river is *Diptera Chironomidae* this implies that it tolerate the excess values of total alkalinity, Turbidity and COD and lower pH under standard while for Rwampala river the pollution increase downstream and same physico-chemical parameters was bad like alkalinity, Turbidity, TDS, and TSS. All the species obtained in Nyabugogo and Rwampala Rivers tolerate higher water pollution. Those species include *Diptera* of order *Chironomidae, Diptera* of order *Ceratopogonidae, Hirudinea* of order *Erpobdella, Hirudinea* of order *Glossiphonia, Hirudinea* of order *Helobdella, Mollusca* of order *Potamopyrgus, Adonata* of order *Anax, Adonata* of order *Aeshna*.

5. Conclusion

Rwampala and Nyabugogo Rivers' water quality are affected by human activities around these Rivers such as old dumpsite and farmer region located upstream of Rwampala, inlet discharge of domestic waste waters, inlet water runoff from the roof of the surrounding houses or the big roads, the nearby manufacturing plant or industries, the surrounding vegetations that require fertilizers and others different sources of pollutions which affect physico-chemical parameters, and as indices calculated above, shows that both Nyabugogo and Rwampala Rivers are polluted, whenever Nyabugogo River is heavily polluted while Rwampala River is slightly polluted. Changes in agriculture have deeply modified landscape structure with several negative consequences on aquatic communities. As results shows, the increase in field size river flow and the destruction of surrounding vegetation also induce an increase in fine sediment inputs into streams or rivers, changes in the chemical characteristics of interstitial water, and in the composition of interstitial assemblages, The destruction of nearby woody buffer generates a decrease in leaf litter inputs, that modifies community composition (decrease of shredders), but increases light availability for aquatic vegetation and phytophilous invertebrates. Thus based on macroinvertebrate species observed and biological indices calculated we clearly notice that Nyabugogo and Rwampala rivers are polluted as the macro-invertebrates species present in that rivers are pollution tollerants and indices mention it and even chemical analysis results shows. Both biological and chemical analysis done in this study shows a full information and a clear literature to the existing, and then biological water quality analysis are cheap and the most environmental friendly technique.

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