Monitoring the Impact of Surface Water Flooding on Groundwater Quality around Nyabarongo River in Rwanda

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Abstract**—** *Rwanda exhibits a climate characterized by two rainy seasons in which erosions and inundations are likely to occur and cause the flooding of rivers which threaten the quality of waters. Most of rivers are connected hydrologically with groundwater aquifers which allow the recharge. This study aimed to monitor the impact of surface water flooding on groundwater quality around Nyabarongo River in Rwanda. Two parameters namely turbidity and color which are directly influenced by flooding of water bodies were monitored between January 2017 and June 2020. Laboratory analyses for turbidity on an hourly and color on a monthly basis were conducted at Nzove Water Treatment Plant Laboratory and the computed monthly average values were used. The laboratory results for surface water and groundwater were compared through graphical presentation which indicated that there is a relationship between the change in quality of both waters due to the fact that the trends in variation of the quality of both waters correlate in the same periods or groundwater quality changes similarly just a little bit after surface water quality has changed. This observation has led to the conclusion that the changes in water quality of Nyabarongo River which is mainly exacerbated by the flooding of March to May and October to December rainy seasons affect the quality changes of the groundwater recharged by this river. This finding indicates the need and urgency of implementation of Nyabarongo catchment rehabilitation and management plans.*

***Keywords* — Floods, groundwater recharge, impact, Nyabarongo River, water quality change.**

I. INTRODUCTION

Rwanda is located within the equatorial belt with a modified humid climate including rainy forest and Savannah types. The rainfall characteristics for Rwanda are known to exhibit large temporal and spatial variation due to varied topography and existence of large water bodies throughout the country as well as the influence of climate change [10]. However, two rainy seasons are generally distinguishable, one centered on March – May and the other around October – December [17]. The existing literature indicate that temporal variability of the rainfall in terms of intensity and frequency in some occasions has resulted in extreme events such as the floods and frequent droughts that have far reaching socio-economic impacts to the country and water resources in particular used to get increasingly polluted [17] and Meteo-Rwanda official website. Water resources in Rwanda occupy a total of 135,000 ha or 8% of the country's surface area. These include 101 lakes (1,495 km^2), 861 rivers totaling 6,462 km and a network of disconnected wetlands [17] while ground Water accounts for 4.554 billion m^3, Rainfall Water for 27.5 billion m^3 per annum, Ground water recharge being 4.5 billion m^3 per annum, Total renewable water is 6.8 billion m^3 per annum while Renewable water availability per capita is 670 m^3 and artificial water storage is 2.5 m^3 [10], [15], [17].

Studies indicated that groundwater aquifer around Nyabarongo river is generally shallow occurring between 3-5m and 12m, with a thickness of at most 8m and is recharged by the river [1]; Nyabarongo floodplain gets completely inundated during the rainy season where the floodwater rise can completely submerge the river, the boreholes and wetland in general, the Nyabarongo River channel is not permanent; thus it significantly changes meanders across its entire flood plain. This has resulted in some boreholes being washed away and lost due to erosion as a result of river encroachment due to river erosion [1], [12] and [14] . This study has monitored the changes in turbidity and color of both surface and groundwater between 2017 and 2020 with a target to examine whether there is a relationship in the changes of both categories of water quality. It is expected that the findings will provide decision makers in water resources management and water supply a baseline information for further mitigation actions.

II. MATERIAL AND METHODS

2.1 Description of the study area

Nyabarongo is the longest river in Rwanda as it touches all the provinces along its flow pathway where it serve water for different purposes such as irrigation, hydropower production, habitat for biodiversity, water treatment and supply, recharging the surrounding groundwater aquifer. The study area is the part of the river in the Nyabarongo wetland located in Kigali city, Nyarugenge district, Kigali sector, which is currently serving both surface and ground raw water for three Water Treatment Plants (WTP) constructed in the in the area and supplying water to Kigali city and its peri-urban areas. Surface water is conveyed for treatment by two intakes while groundwater intakes consist of 31 boreholes which are designed to abstract underground water and collect in a 600mm diameter pipeline towards another separate WTP as illustrated on Fig.1. As the area is a wetland which has its upstream area of hilly and sloppy prone to erosion and sediments loads together with its proximity to the densely populated Kigali city, it has been undergoing flooding during rainy seasons which used to last for many weeks as the recent flooding of the area in April 2020 lasted around two months [1], [12], [14].

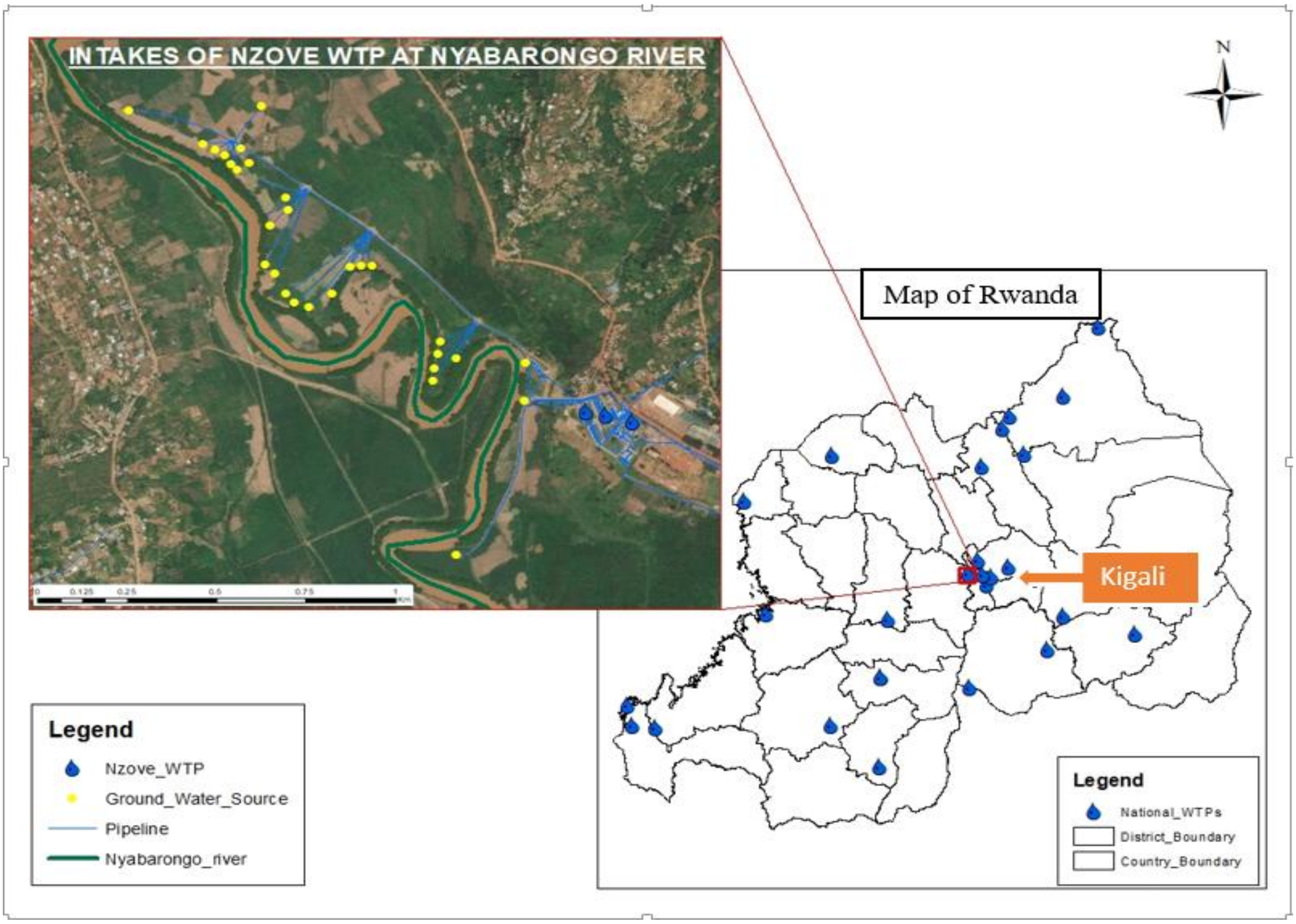

FIGURE 1: Map indicating the location of study area on Rwanda map, the river and groundwater in the study area

2.2 Sampling Techniques

The three parameters that were used in this study namely turbidity, Color and Total Coliform have been chosen based on the fact that they are directly linked to processes such erosion, inundations and floods in water as a route of transportation of sediments, soils and other substances washed in different parts that cause turbidity and color of water to change immediately [10], [12] and [14]. Total Coliform may be caused by entry of soil or organic matter into the water or by conditions suitable for the growth of other types of coliform. In the laboratory total coliforms are grown in or on a medium containing lactose, at a temperature of 35 or 37 °C. They are provisionally identified by the production of acid and gas from the fermentation of lactose. Samples were taken on an hourly basis for turbidity and color and on a monthly basis for total coliform [6] and [7].

Turbidity was measured in situ while for other parameters sample collection was carried out in accordance with the Standard Methods procedures [7]. Samples were collected in sterile 500-ml polyethylene sampling bottles containing 10% sodium thiosulfate and brought to laboratory for analyzed. Working conditions were carefully selected and strict measures were adhered in avoiding contamination of samples during sampling; handling and storage and all samples were analyzed within 24hours after sampling [4].

2.3 Laboratory analyses

The measurement of turbidity was performed with Nephelometer in compliance with EPA standard for determining turbidity in drinking, ground, surface, waste, and seawater samples and the following steps shall be followed: Preparation of standard solution from formazine which appeared to be more reproducible than other types of standards, a synthetic polymer chosen for its consistency, calibrate the meter with standard cuvettes, fill a cuvette with your sample, clean the outside of the cuvette and if working with samples with very low turbidity, use silicone oil on the outside of the cuvette, place the cuvette inside the meter and take the reading [7].

This method is based upon a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension. The higher the intensity of scattered light, the higher the turbidity. A primary standard suspension is used to calibrate the instrument. A secondary standard suspension is used as a daily calibration check and is monitored periodically for deterioration using one of the primary standards. Formazine polymer is used as a primary turbidity suspension for water because it is previously used for turbidity analysis [4].

The Color was measured using Platinum-Cobalt Standard Method (HACH 8025). A 200ml of sample was placed into 400ml beaker and filtered using 0.45 micron membrane filter. The blank was prepared by pouring 10ml of filtered de-ionized water and placed into the cell holder. Next the 10ml sample was measured using HACH DR 6000 UV-VIS spectrophotometer and the results were taken in Pt/Co (HACH) [7].

In order to measure total coliform**,** MI broth and TSA were prepared. Plates are made ahead of time and stored in the refrigerator, remove them and allow them to warm to room temperature. Label the bottom of the MI broth plates with the sample number/identification and the volume of sample to be analyzed. Using a flamed forceps, place a membrane filter, grid-side up, on the porous plate of the filter base. Attach the funnel to the base of the filter unit so that the membrane filter is now located between the funnel and the base. Put approximately 30 mL of sterile dilution water in the bottom of the funnel and shake vigorously, add 100mL of the sample then. Invert the broth petri dish, and incubate the plate at 35°C for 24 hours. Expose each MI plate to long wave ultraviolet light (366 nm), and count all fluorescent colonies [blue/green fluorescent E. coli, blue/white fluorescent TC other than E. coli, and blue/green with fluorescent edges (also E. coli)] and then calculate the number of colonies using the formula below [4] and [7].

$$\mathrm{TC/100mL} = \frac{\text{Number of fluorescent colonies} + \text{Number of blue, non} - \text{fluorescent colonies (if any)}}{\text{Volume of sample filtered (mL)}} \times 100$$

III. RESULTS AND DISCUSSION

This section presents the results from laboratory analyses in Tables 1, 2 and 3 and the values for all parameters are high during the rainy seasons of March to April and from October to December for surface water of Nyabarongo River. The water from groundwater aquifer recharged by Nyabarongo river also indicate high values in the same period as surface water or a little bit later than the period of increase for surface water. In fact, the historical records and the available literature about the area indicate that Nyabarongo wetland in which the river flows and the groundwater aquifer is located, has been experiencing from the past fifty years heavy floods, inundations and river overflow as a result intensive rainfalls associated with factors like the vulnerability to landslides of the sloppy upstream of the study area and its proximity to Kigali city that exacerbate erosion and wash different sediments, soils and other substances to the river and causing the analyzed parameters to rise. The graphical presentations of the results helped to assess and compare the trend in variation of water quality of groundwater with respect to surface water and the graphs indicate a correlation in variation which has led the authors to detect a relationship between the changes in quality for the two types of waters [10], [12] and [13].

3.1 General presentation of the laboratory analysis results

TABLE 1
RESULTS OF LABORATORY ANALYSIS OF TURBIDITY FOR SURFACE AND GROUND WATER FROM JAN. 2017 TO JUNE 2020

Period	Ground	Surface	Period	Ground	Surface	Period	Ground	Surface	Period	Ground	Surface
Jan-17	8.3	3450	Jan-18	20.1	4200	Jan-19	11.2	6520	Jan-20	18.5	1850
Feb-17	10.2	2440	Feb-18	54.6	5500	Feb-19	10.4	945	Feb-20	17.9	1560
Mar-17	7.2	10500	Mar-18	17.8	14200	Mar-19	17.6	4500	Mar-20	19.3	2415
Apr-17	13.5	14440	Apr-18	45.1	14140	Apr-19	35.4	5100	Apr-20	24.9	6370
May-17	15.4	3920	May-18	36.3	2540	May-19	24.4	3970	May-20	25.6	11250
Jun-17	14.7	1530	Jun-18	32.3	2250	Jun-19	17.9	1640	Jun-20	11.3	14840
Jul-17	6.5	260	Jul-18	14.8	1480	Jul-19	13.8	432			
Aug-17	5.62	451	Aug-18	13	929	Aug-19	9.34	230			
Sep-17	65.3	6530	Sep-18	14.7	1620	Sep-19	9.18	3240			
Oct-17	45.6	4560	Oct-18	14.2	4250	Oct-19	12.7	4560			
Nov-17	20.7	2250	Nov-18	7.2	13450	Nov-19	14.5	3380			
Dec-17	18.4	1820	Dec-18	6.26	18580	Dec-19	20.2	4200			
Unit: Nephelometric Turbidity Unit (NTU) ; Standard Limit for turbidity as per Rwandan standard RS EAC 12-2018: **5 NTU**											

TABLE 2
RESULTS OF LABORATORY ANALYSIS OF COLOR FOR SURFACE AND GROUND WATER FROM JAN. 2017 TO JUNE 2020.

Period	Ground	Surface	Period	Ground	Surface	Period	Ground	Surface	Period	Ground	Surface
Jan-17	105	7360	Jan-18	315	10350	Jan-19	52	3920	Jan-20	400	10510
Feb-17	173	9200	Feb-18	179	10798	Feb-19	39	3920	Feb-20	324	4192
Mar-17	349	8440	Mar-18	940	9550	Mar-19	65	12500	Mar-20	420	3752
Apr-17	480	12765	Apr-18	733	28150	Apr-19	120	12500	Apr-20	1240	13825
May-17	620	15340	May-18	490	10350	May-19	98	2987	May-20	663	13760
Jun-17	96	5284	Jun-18	403	10350	Jun-19	628	3850	Jun-20	540	10570
Jul-17	81	3166	Jul-18	271	1070	Jul-19	76	2013			
Aug-17	76	2570	Aug-18	163	1023	Aug-19	213	23150			
Sep-17	83	1080	Sep-18	102	9850	Sep-19	181	23150			
Oct-17	123	5390	Oct-18	89	14390	Oct-19	102	13300			
Nov-17	157	7990	Nov-18	41	2844	Nov-19	663	3380			
Dec-17	238	8700	Dec-18	41	2844	Dec-19	470	7340			
Unit: Platinum/Cobalt (Pt/Co) ; Standard Limit for turbidity as per Rwandan standard RS EAC 12-2018: **15 Pt/Co**											

TABLE 3
RESULTS OF LABORATORY ANALYSIS OF TOTAL COLIFORM FOR SURFACE AND GROUND WATER FROM JAN. 2017 TO JUNE 2020

Period	Ground	Surface	Period	Ground	Surface	Period	Ground	Surface	Period	Ground	Surface
Jan-17	4.4	93670	Jan-18	6	258600	Jan-19	482	127380	Jan-20	11	22615
Feb-17	16	14540	Feb-18	6	48840	Feb-19	103	241960	Feb-20	244	14230
Mar-17	28	72150	Mar-18	305	14366	Mar-19	6.3	173290	Mar-20	298	24965
Apr-17	44	77010	Apr-18	554	39500	Apr-19	5.2	48810	Apr-20	344	377660
May-17	35	52290	May-18	605	43000	May-19	5.2	40010	May-20	6.3	102400
Jun-17	5	47890	Jun-18	12	43000	Jun-19	7.4	35790	Jun-20	7.7	64300
Jul-17	3	29090	Jul-18	8	43000	Jul-19	6.9	312420			
Aug-17	5	30760	Aug-18	7.5	10900	Aug-19	9	24190			
Sep-17	11	20000	Sep-18	23	84400	Sep-19	6.3	48390			
Oct-17	130	73300	Oct-18	958	193650	Oct-19	6.3	87240			
Nov-17	80	135700	Nov-18	345	32678	Nov-19	9	164780			
Dec-17	55	276000	Dec-18	618	111990	Dec-19	12.4	164780			
Unit: Most probable number (MPN) ; Standard Limit for turbidity as per Rwandan standard RS EAC 12-2018: **Absent**											

3.2 The similarity of trends in change in groundwater quality with respect to surface water

The graphs presented under this subsection serve for a comparison in the trend of variation in the analyzed parameters with respect to water from Nyabarongo River. In all cases similarity in trends indicate a relationship between both water qualities.

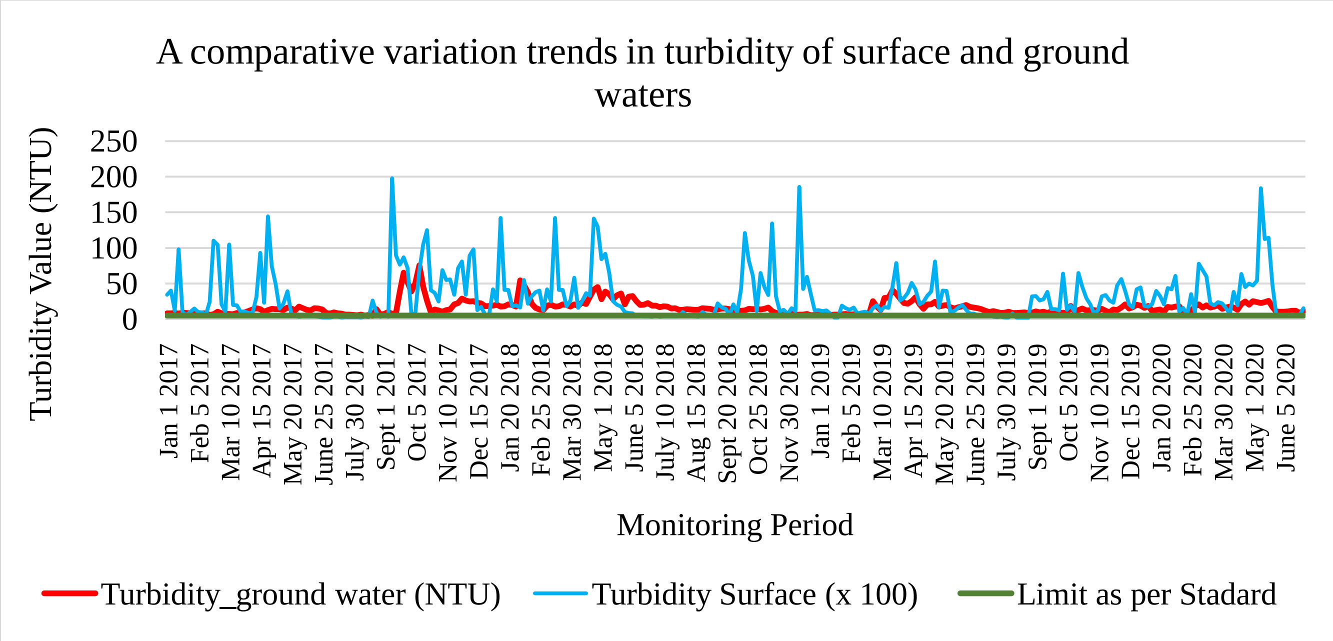

FIGURE 2: Plotted Turidity variations of surface and groundwater for Nyabarongo river and its groundwater aquifer respectively

The trend illustrated in Fig.2 for variation indicated that there is a relationship between surface water quality variation and groundwater. The maximum turbidity values were recorded for both cases in rain seasons or the values for ground water tend to rise a bit after the period of rise in surface water turbidity[18].

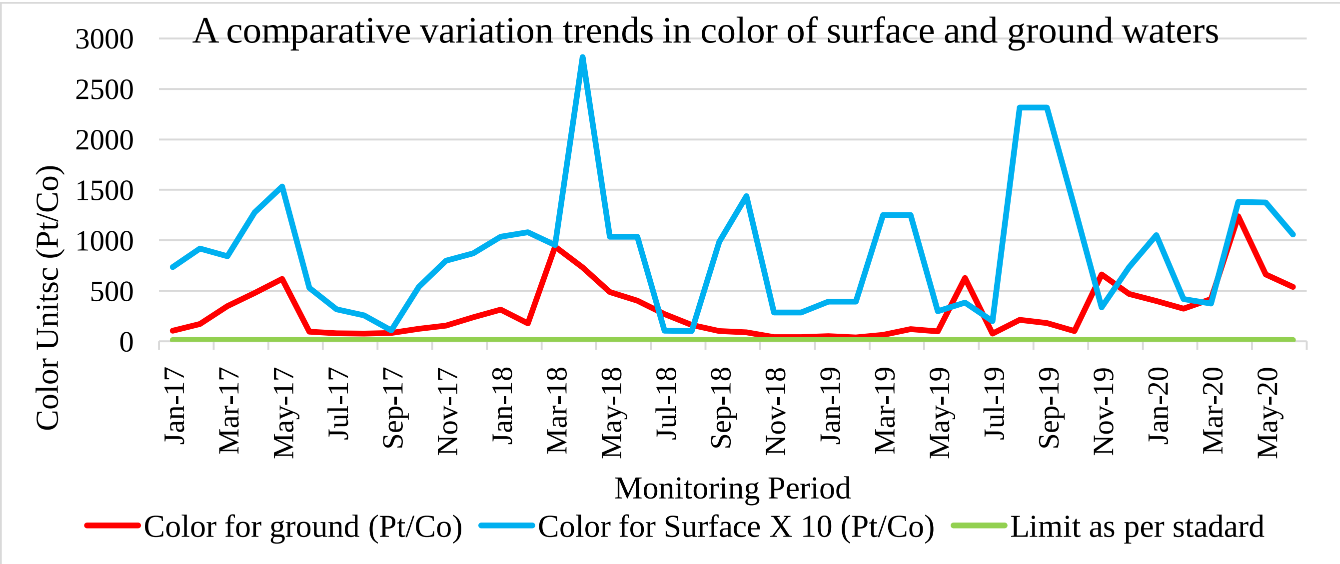

FIGURE 3: Plotted Color variations of surface and groundwater for Nyabarongo river and its groundwater aquifer respectively

As illustrated by Fig.3 the maximum values for color recorded during the whole monitoring period are in the rain seasons and a similar variation appear for groundwater because in all period of rise in color for Nyabarongo water groundwater turbidity has also risen. It is worth noting here that the color of groundwater can be caused by other parameters in water related to the geological nature of the area such as Manganese and Iron. However the variation in of color in groundwater proportionally to the variation of river water is a proof that the quality of the river is surface water in the river has impact on groundwater quality [11].

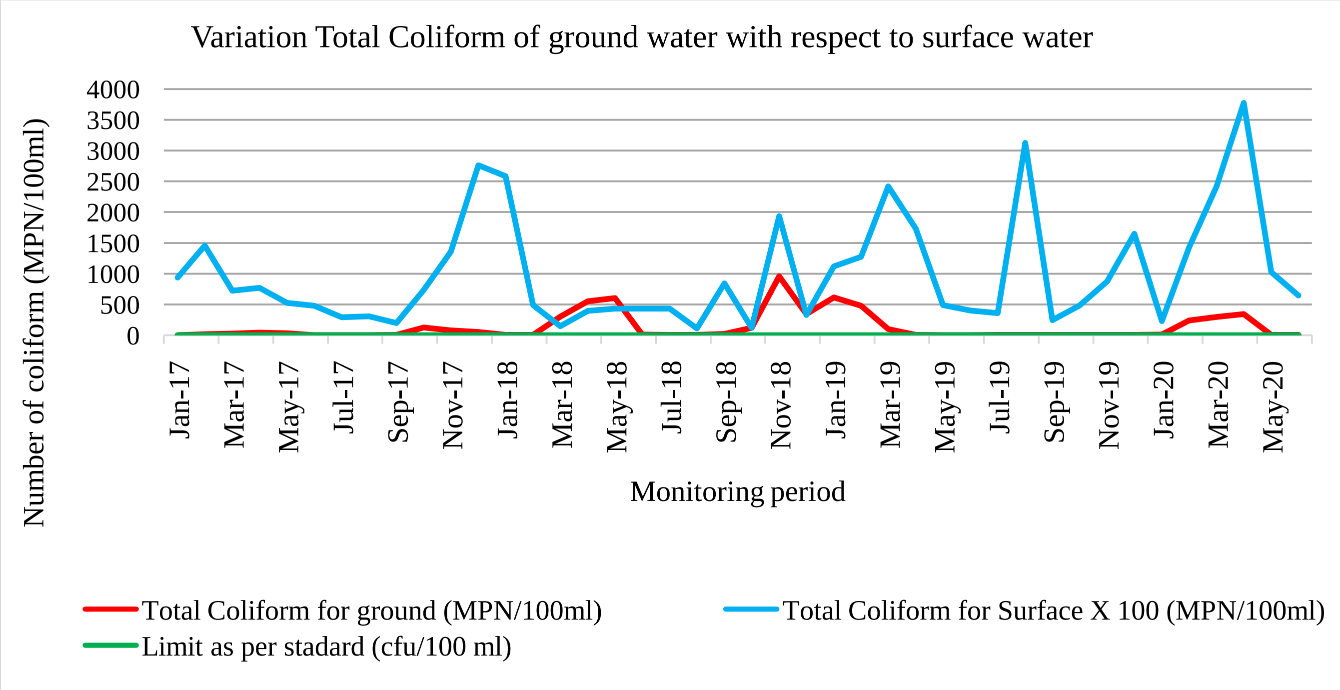

FIGURE 4: Plotted Total coliform variations of surface and groundwater for Nyabarongo river and its groundwater aquifer respectively

The literature indicates that the coliform bacteria in water are attached ot organic matter and other sediments loaded in water. In Nyabarongo river, the high values of total coliform during the rain season are related to the sediments and other contaminants loaded in the river during erosion and inundations[14]. The increase in value for the total coliform in ground water in the same periods a the variation for surface water indicate that the surface water quality has impact on groundwater.

IV. CONCLUSION

This study has used the results of laboratory analysis of turbidity, color and Total coliform parameters recorded in the period between January 2017 and June 2020 to assess the impact of the changes in Nyabarongo river quality as a result of flooding to the quality of groundwater. The findings indicated that turbidity and color highly rise most of the times in the rain seasons of March to May and October to December as a result of the sediments and other substances loaded in the river and its area during overflow and flooding [3]. The similar trend in water quality changes for both parameters on groundwater was observed which indicate that the pollution of surface water is impacting on groundwater provided the fact that the two water sources are hydrologically connected by the recharge [4]. The laboratory analyses were recorded on an hourly and daily basis which indicates the reliability of the results. However, the analysis did not cover the whole river length and the whole ground aquifer but the results of this study may represent the whole length based on the similarity in terms of physical and hydrological characteristics [1]. Another limitation is that the study did not analyze all parameters can be transferred through communication between surface and groundwater [9]. The findings of this study can serve as a reference for taking appropriate mitigation measure for protecting rivers in Rwanda from erosion and related pollution as well as for protection groundwater such as strategies for enhancing the natural treatment process of groundwater. This study can inform the institutions exploiting the river and its aquifer to incorporate technical measures to lessen the impacts on water quality such as to raise the wellhead at each borehole to a given height upward so that it is not submerged during flooding and installation of a groundwater telemetry system with for real time data capture and real time decision making.

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