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List of Abbreviations

%	Percentage
µS	Micro Siemens
BOD	Biochemical Oxygen Demand
CFU	Colony Formed Unit
Cl^-	Chloride
cm	centimetre
DEMI	Digital Elevation Model
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorus
DO	Dissolve Oxygen
E. Coli	Escherichia coli
EC	Electro conductivity
F.C	Faecal coliform
FDEAS	Final Draft East African Standards
FDRS	Final Draft Rwanda Standards
GIS	Geographical Information System
GPS	Global Positioning System
l	liter
mg	milligram
MINIRENA	Ministry of Natural Resources
ND	not detectable
NO_3^-	Nitrate
NTU	Nephelometric Turbidity Unit
pH	Potential of Hydrogen
REMA	Rwandan Environmental Management Authority
RNRA	Rwanda Natural Resources Authority
RWFA	Rwanda Water and Forestry Authority
SO_4^{2-}	Sulphate
SOPs	Standard Operating Procedures
TDS	Total Dissolved Solids
TIN	Triangulated Irregular Network
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
UNEP	United Nations Environment Program
WASAC	Water and Sanitation Corporation Ltd

1. Executive Summary

Within the framework of meeting one of its mandates related to water quality monitoring, the Rwanda Water and Forestry Authority (RWFA) has commissioned a study aiming at establishing water quality baseline of some selected 36 water bodies in Rwanda. The study was conducted at the nine level one catchments. A set of sixteen (16) parameters were selected for this monitoring activity for each sampling site. These are: Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), Potential in Hydrogen (pH), Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Turbidity, Chloride (Cl^-), Sulfate (SO_4^{2-}), Nitrate (NO_3^-), Total nitrogen (TN), Total Phosphorus (TP), Total Dissolved Inorganic Nitrogen (DIN), Total Dissolved Inorganic Phosphorous (DIP), Faecal coliform (F.C) and *Escherishia coli* (E.coli).

The findings from the study revealed that some water quality parameters are generally within the acceptable range countrywide like the Total Dissolved Solids (TDS), dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), Electro conductivity (EC), Hydrogen potential (pH), Nitrate (NO_3^-), Total phosphorus (TP), Total nitrogen (TN), Chloride (Cl^-), Sulphate (SO_4^{2-}). However, other parameters like Dissolved oxygen (DO), Faecal coliform (F.C), *Escherichia coli* (E. coli), Total Suspended Solids (TSS) and Turbidity are almost always out of the acceptable range for natural potable water.

These results clearly illustrate that the main concerns in terms of surface water quality in Rwanda are mostly related to the sedimentation /siltation of water bodies mainly due to soil erosion as well as the microbiological contamination that can be linked to poor sanitation systems and practices. The most critical water bodies in terms of turbidity and microbiological contamination were found to be Akanyaru River border to Burundi, Secoko River before discharging into Nyabarongo, Sebeya River at Musabike, Sebeya River at Nyundo Station, Akagera at Kanzenze bridge and the Nyabarongo River before receiving Mukungwa River.

Considering that this study aimed at providing baseline data for future monitoring, it is strongly recommended to carry out a number of other similar regular water monitoring campaigns and covering both the rainy and dry seasons over many consecutive years to be able to draw reliable conclusions on the water quality status. From this study, it appears that lack of adequate sanitation is a very big issue in most parts of the catchments and this being the case for both urban and rural areas. Therefore, the best approach to deal with this issue in urban areas could be through improved wastewater treatment technology and management, whereas for rural areas the most appropriate approach could be through on-site sanitation systems coupled with education, sensitization and behaviour change campaigns on improved sanitation practices

The presence of high values of TSS in Akanyaru River border to Burundi, Sebeya and Secoko Rivers are attributed to the fact that in these river catchments there are agricultural activities on hill side combined with intensive unsustainable mining activities mainly for Sebeya being done from its source in Muhanda Sector of Ngororero District and Nyabirasi Sector of Rutsiro District, but also downstream in Kanama and Nyundo Sector of Rubavu District. Even if agricultural activities are also contributing as well to the accumulation of suspended solids in rivers, mining activities are the most likely major contributors.

2. Introduction

2.1 Background

Water is one among important and basic natural resources. The development of this natural resource plays a crucial role in economic and social development processes in the world. While the total amount of water available in the world is constant and is generally said to be adequate to meet all the demands of mankind, its quality causes in general health related problems.

Rivers are characterized by uni-directional current with a relatively high, average flow velocity ranging from 0.1 to 1 m s^{-1}. The river flow is highly variable in time, depending on the climatic situation and the drainage pattern. In general, thorough and continuous vertical mixing is achieved in rivers due to the prevailing currents and turbulence. Lateral mixing may take place only over considerable distances downstream of major confluences.

Each freshwater body has an individual pattern of physical and chemical characteristics which are determined largely by the climatic, geomorphological and geochemical conditions prevailing in the drainage basin and the underlying aquifer. Summary characteristics, such as total dissolved solids, conductivity and redox potential; provide a general classification of water bodies of a similar nature. Mineral content, determined by the total dissolved solids present, is an essential feature of the quality of any water body resulting from the balance between dissolution and precipitation. Oxygen content is another vital feature of any water body because it greatly influences the solubility of metals and is essential for all forms of biological life. The chemical quality of the aquatic environment varies according to local geology, the climate, the distance from the ocean and the amount of soil cover, etc.

The development of biota (flora and fauna) in surface waters is governed by a variety of environmental conditions which determine the selection of species as well as the physiological performance of individual organisms. The primary production of organic matter, in the form of phytoplankton and macrophytes, is most intensive in lakes and reservoirs and usually more limited in rivers. The degradation of organic substances and the associated bacterial production can be a long-term process which can be important in groundwater and deep lake waters which are not directly exposed to sunlight.

2.2 Study Objectives

This study has to establish a reliable estimate of the current level of quality for selected surface water bodies as well as for selected boreholes in the country; together with a clear and reliable understanding of the principal sources of the observed status. Furthermore, collected quality data will be used in the water quality database for future monitoring campaigns of the established water quality roadmap.

3. Methodology

To respond to different objectives of this study, different methodological approaches were used.

3.1. Mapping of sampling sites

To come up with a good presentation of all water sampling points, GIS was used. During its application, the preliminary work was the design of a database environment. A geo database comprising feature datasets and feature classes was created to allow for data base creation and management. Feature classes were composed of catchment boundary, and sub-catchments (with polygon geometry), land use classes and drainage networks in the form of point geometry. The Arc GIS software and GPS coordinates were used for handling all spatial analysis tasks and catchment mapping. The geo database was designed using Arc Catalogue as an Arc GIS application dedicated for spatial database creation and management. Topology was also created for controlling consistency between features sharing common boundaries and for avoiding gaps and overlaps between land units and sub-units. During the design phase of feature datasets, all data sets were projected in the same spatial referencing system for easy harmonization and integration of all datasets to be used.

The catchment mapping was carried out by combining the descriptive and spatial datasets. GIS was used as a tool for delineating catchment and sub-catchment boundaries and performing spatial based analysis of the catchment and its sub-units. Geo-processing functionalities were used for deriving and analysing slope and topography characteristics of the catchments. These functionalities include spatial analysis tools especially for surface analysis. Where required, land cover was extracted on aerial photographs with 25 m accuracy completed by existing topographic map (at 1:50,000) and in addition field trips were taken for ground truthing and control points on the ground. Cartographic toolbox was used for combination of visual variables and annotations for designing and producing illustration maps. The needed data for this step as well as their application are illustrated below:

Table 1: *Needed data and their applications*

Data to be used	Application / analysis
Administration boundaries (cells, Sectors, District)	Administrative delineation of the study area
Digital Elevation Model (DEM)	Catchment delineation, slope and topographic analysis
Hills shape	Slope analysis and hillsides illumination
Aerial photographs	Land cover/Land use analysis and mapping
Topographic map at 1:50,000	Catchment delineation and drainage pattern analysis
Contour lines	Slope analysis and catchment delineation, generating 3D information such as Triangulated Irregular Network (TIN)
Drainage network and wetlands	Hydrograph analysis

During this exercise, pollution sources and water sampling sites were located in their respective catchments.

3.2. Selection of sampling points

The selection of sampling sites was conducted on main water bodies. Review of existing sampling roadmap from former RNRA (2011, 2012 a, 2012 b) which had 46 sampling sites in the entire country covering both the Congo and the Nile basins. Recently in RWFA, 36 new sampling sites from the old sampling roadmap were established in order to have a more representative sampling roadmap which will enable the authority to conduct water monitoring activities on key water bodies in catchment level two. Furthermore, for reasons of medium, long-term and sustainability of the monitoring exercise, RWFA staff and interns were fully involved from the beginning to the end of the monitoring activity. Before going to the field, coordinates, administrative and hydrological locations for each sampling site were generated in order to achieve an effective and accurate sampling.

Sampling was conducted using the upstream to downstream approach in order to have a good and clear evaluation of the water quality. Where two water bodies meet, a triangular water sampling approach was used in order to assess individually the quality of each river alone and after their mixing. Two teams were formed each one having an experienced laboratory technician going together with RWFA staff for water sampling and on field insitu measurements of GPS coordinates, DO, EC, pH, TDS and TSS taken at each sampling site using handheld calibrated equipment.

3.3. Selection of chemical and physical parameters for water quality control

A set of sixteen (16) parameters were selected for this monitoring activity for each sampling site. These are: Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), Potential in Hydrogen (pH), Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Turbidity, Chloride (Cl^-), Sulfate (SO_4^{2-}), Nitrate (NO_3^-), Total nitrogen (TN), Total Phosphorus (TP), Total Dissolved Inorganic Nitrogen (DIN), Total Dissolved Inorganic Phosphorous (DIP), Faecal coliform (F.C) and *Escherishia coli* (E.coli).

The sampling campaign started on the 5th November and ended on the 22nd November 2018 for period I which correspond to the rainy season and for period II, it started on the 4th February and ended on the 22nd February 2019 which correspond to the short dry season. The laboratory analysis was conducted for an additional two weeks and analysis of water samples was conducted according to the standard methods for water and wastewater analysis and obtained results have been discussed based on the standard for potable water (FDEAS 12:2018), the discharged domestic wastewater (FDRS 110:2017) and the discharged industrial wastewater (CD-R-002-2012).

4. Key water bodies

Rwanda's hydrological network is divided into two main river basins: Nile Basin covering 67 % of the Rwandan territory and draining 90 % of the country's waters, and the Congo basin covering 33 % of the Rwandan territory and draining 10 % of the country's water (MINIRENA, 2012).

4.1. Key water bodies in the Congo basin

The Congo basin is mainly composed of two main catchments level one, namely Lake Kivu and Rusizi catchments. Lake Kivu catchment channels its water into Lake Kivu. It is mainly composed of important rivers such as Sebeya, Koko, Pfunda. The surface run-off is flowing on slopes that are relatively steep along Lake Kivu backsides. Along the Crestline, the area is characterized by highlands with steep slopes occupied by Nyungwe national park in the south and Gishwati-Mukura national park in the northern part. The southern part of Congo basin is occupied by Rusizi catchment. The Rusizi catchment is mainly drained by Rusizi and Ruhwa rivers and their tributaries. Rusizi catchment extends to Bugarama region which is the lowest part in Rwanda (900 m).

4.2. Key water bodies in the Nile Basin

The Nile Basin is channeling about 90 % of water flowing in the Rwandan territory. The basin is mainly composed of 7 main catchments level one (Upper Nyabarongo, Lower Nyabarongo, Muvumba, Mukungwa Akanyaru, Lower Akagera and Upper Akagera). The important rivers we found in this basin are: the Nyabarongo, Mwogo, Mbirurume, Muvumba, Mukungwa, Rugezi, Akanyaru and Akagera rivers. Table 2 is illustrating the key water bodies within the catchments of the Congo & Nile basins together with other important particular characteristics.

Table 2: *Main Sampling sites characteristics*

District Catchment Code	Catchment Name	Catchment Area (km^2)	Sampling sites ID	No.	Sampling sites locations	Name and nature of water body	GPS Coordinates		Justifications
							X	Y	
RW-CKIV	Kivu Lake	2,425	CKIV_1_003	1	Kivu Lake/Gisenyi beach	Kivu Lake	-1.70494	29.26199	Upstream
			CKIV_2_004	2	Kivu Lake/Karongi (beach Golf hotel)	Kivu Lake	-2.06174	29.34725459	Mid-point of the Lake
			CKIV_3_003	3	Kivu Lake/Kamembe (port1)	Kivu Lake	-2.48102	28.89582	Downstream
			CKIV_1_001	4	Sebeya river/Nyundo station	Sebeya river	-1.70494	29.26199	Downstream
			CKIV_1_002	5	Sebeya river/Mushabike	Sebeya river	-1.70962	29.36259	Upstream
			CRUS_1_003	6	Rusizi River/Kamanyora bridge	Rusizi River	-2.70757	29.006609	Medium site
RW-CRUS	Rusizi	1.005	CRUS_1-002	7	Rubyiro River/Bridge Bugarama-Ruhwa Road	Rubyiro River	-2.70653	29.03089003	Before discharge into Rusizi
			CRUS_2_001	8	Ruhwa River/Bridge Ruhwa Border	Ruhwa river	-2.73089	29.04101998	Downstream
RW-NNYU	Upper Nyabarongo	3.348	NNYU_3_001	9	Nyabarongo river before Mukungwa	Nyabarongo river	-1.73835	29.65933696	Exit of upper Nyabarongo
			NNYU_3_003	10	Nyabarongo river after receiving Mwogo and Mbirurume	Nyabarongo river	-2.455	30.5	Start of Nyabarongo
			NNYU_2_005	11	Mwogo river upstream	Mwogo river	-2.4564468	29.7046839	Nyabarongo head water
			NNYU_2_006	12	Rukarara upstream	Mwogo affluent	-2.45423	29.45483697	Nyabarongo head water
			NNYU_1_007	13	Mbirurume	Mbirurume river	-2.2059663	29.5613268	Downstream
				14	Secoko river before discharging into Nyabarongo				
						Secoko river	-2.00818	29.62644	Secoko river before discharging into Nyabarongo

RW-NNYL	Lower Nyabarongo	3,305	NNYL_2_002	15	Nyabarongo river/Ruliba	Nyabarongo downstream	-1.96252	30.00366798	Mid- Nyabarongo sampling site
			NNYL_1_003	16	Nyabugogo river/downstream	Nyabugogo river/Nemba	-1.94728	30.02133301	Downstream of water body
			NNYL_1_005	17	Nyabugogo river/Upstream	Nyabugogo river	-1.79242	30.15507096	Nyabugogo upstream
			NNYL_1_006	18	Muhazi lake upstream (Rukara Sector)	Muhazi lake	-1.85905	30.49025799	Upstream of the lake
			NNYL_1_007	19	Muhazi lake downstream (Rwesero)	Muhazi lake	-1.7918764	30.1550141	Downstream point of the lake
			NNYL_2_008	20	Kayonza-Mukarange-Bwiza-Abisunganye	Borehole	556 351	4 790 060	Borehole
RW-NMUV	Muvumba	1,592	NMUV_2_001	21	Muvumba at Kagitumba	Muvumba river	551147	4883638	Catchment exit point
			NMUV_2_002	22	Warufu river	Muvumba affluent	-1.4322525	30.2755256	Mid-point
			NMUV_2_003	23	Muvumba after mix with warufu	Muvumba river	-1.2922779	30.3191433	Head water
			NMUV_2_004	24	Muvumba entering Rwanda from uganda	Muvumba river	-1.3556833	30.161379	Upstream
RW-NMUK	Mukungwa	1.902	NMUK_2_001	25	Mukungwa /Nyakinama gauging station	Mukungwa River	-1.55347	29.64415801	Medium site
			NMUK_2_002	26	Mukungwa /Before confluence with Nyabarongo	Mukungwa River	-1.73835	29.65933696	Exit of NMUK
			NMUK_1_001	27	Rugezi/Before discharging into Burera Lake	Rugezi river	-1.42158	29.83255503	Head water
RW-NAKN	Akanyaru	3,384	NAKN_3_001	28	Akanyaru/Gihinga site	Akanyaru river	-2.07545	30.0189	Exit of NAKN
			NAKN_1_002	29	Akanyaru/Border with Birundi	Akanyaru river	-2.80102	29.58008	Medium site
RW-NAKL	Lower Akagera	4.288	NAKL_1_001	30	Akagera /Rusumo border	Akagera river	-2.38468	30.77969399	Medium site
			NAKL_1_002	31	Kayonza-Mwiri-Nyamugari-Kabukeye	Artesian well	-1.86462	30.59882	Artesian well

			NAKL_1_003	32	Gatsibo-rugarama-Kanyangese-Rebero	Borehole	545 854	4 813 000	Borehole
			NAKL_1_004	33	Gatsibi-Kabarore-Simbwa-Ruhuha	Borehole	542 944	4 823 449	Borehole
RW-NAKU	Upper Akagera	2,941	NAKU_2_002	34	Akagera/Kanzenze at bridge	Akagera river	-2.06226	30.08668	Akagera upstream

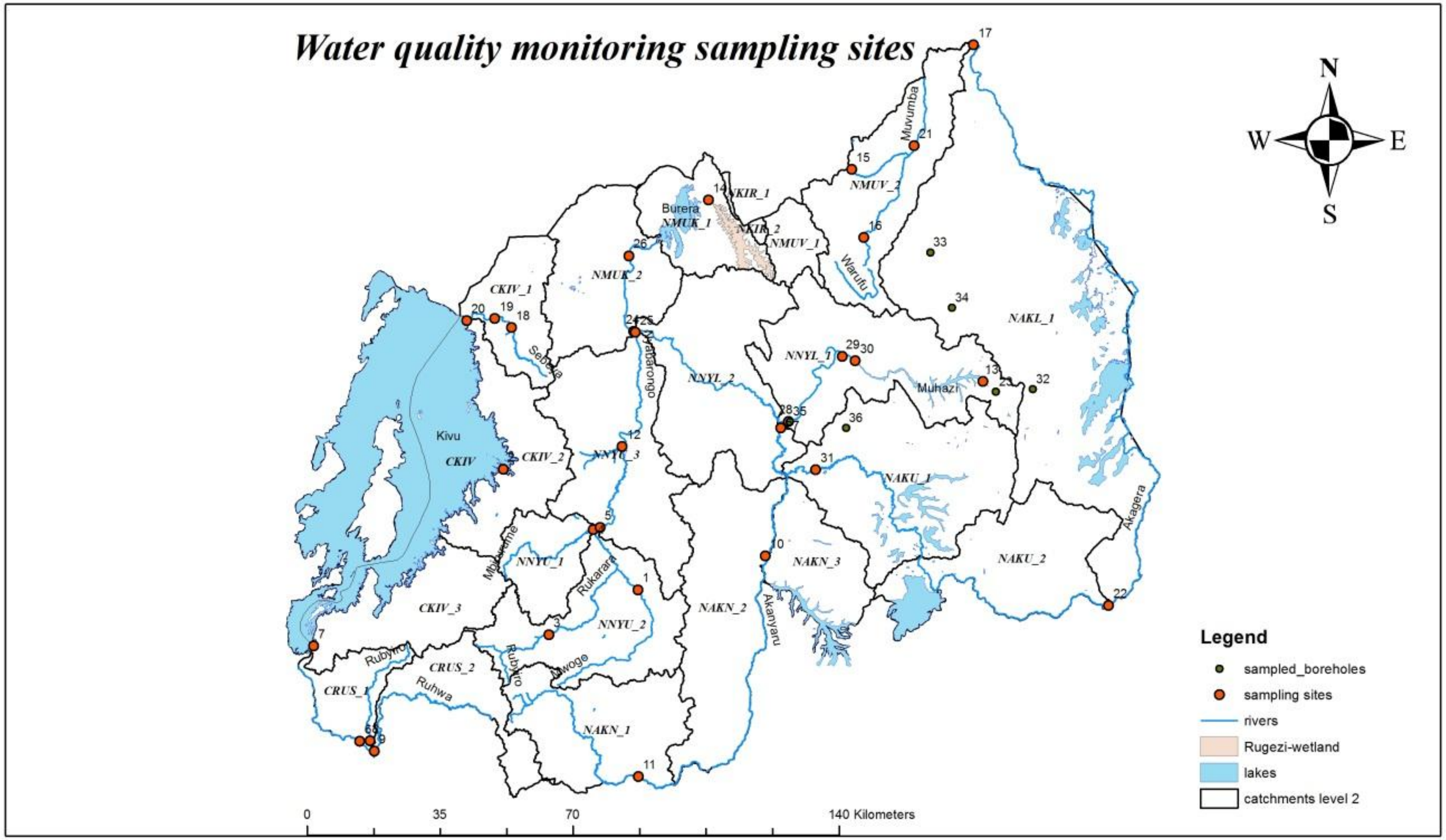


Figure 1 : *Water Quality monitoring sampling sites in Rwanda*

Table 3: *Water Quality results*

This table below is providing data on water quality collected during period I(short rainy season) in December 2018 and period II (dry short *season) in March 2019.*

	GPS Coordinators		D.O (%)		pH		Turbidity (NTU)		Conductivity (µs/cm)		TDS (mg/l)		TSS (mg/l)	
	X	***Y***	***P. I***	***P. II***	***P. I***	***P. II***	***P. I***	***P. II***	***P. I***	***P. II***	***P. I***	***P. II***	***P. I***	***P. II***
1. Mwogo River Up	2.34728	29.665	60.3	56.7	6.8	7.0	416.0	105.0	55	73	27	37	275	40
2. Kivu Lake at Karongi (Beach Golf Hotel)	2.06146	29.34721	97.6	103.7	9.0	8.9	2.6	3.9	1158	1030	568	489	8	1
3. Rukarara River Upstream	2.45395	29.45495	99.2	102.1	7.2	7.5	22.8	48.3	25	31	14	17	9	16
4. Mbirurume River Downstream	2.20426	29.55975	98.3	97.0	7.2	7.4	191.0	120.0	47	51	23	25	103	57
5. Nyabarongo River after receiving Mwogo and Mbirurume Rivers	2.1994	29.57589	94.5	93.2	7.2	7.3	353.0	176.0	44	52	22	25	183	78
6. Rusizi River at Kamanyola Bridge	2.70689	29.0069	95.8	97.6	9.1	9.0	27.8	61.0	1112	932	558	459	18	22
7. Kivu Lake at Kamembe Port	2.48035	28.89748	97.4	99.4	9.1	9.0	2.8	3.2	1123	984	542	480	< 1	1
8. Rubyiro River at Bridge Bugarama - Ruhwa Road	2.70612	29.03118	88.4	92.2	7.5	7.3	357.5	250.0	221	183	109	88	217	131
9. Ruhwa River at bridge Ruhwa border	2.73086	29.041	93.4	99.5	7.3	7.1	557.5	399.0	65	56	33	28	275	213
10. Akanyaru River Gihinga	2.26683	29.96704	86.4	39.2	6.9	6.9	429.0	405.0	67	84	32	40	255	165
11. Akanyaru River border to Burundi	2.79163	29.66645	99.1	101.9	6.8	7.5	11600.0	1055.0	28	35	15	17	3625	389
12. Secoko River before discharging into Nyabarongo	2.00726	29.62813	89.3	97.1	7.2	6.8	1820.0	920.0	33	39	16	18	1617	417
13. Muhazi Upstream	1.85218	30.48203	89.3	104.3	8.6	8.7	1.9	5.9	527	473	254	223	4	2
14. Rugezi before discharging into Burera Lake	1.42133	29.83245	50.2	41.3	5.9	6.3	21.4	15.9	33	30	18	17	10	8
15. Muvumba River entering Rwanda from Uganda	1.34805	30.17089	91.6	97.5	7.4	7.3	544.0	175.0	153	132	81	68	320	79
16. Warufu River	1.51034	30.19944	92.4	66.5	7.4	6.9	547.0	81.0	112	92	55	44	315	32
17. Muvumba at Kagitumba	1.05257	30.45974	85.3	99.5	7.8	7.4	460.0	120.0	279	238	134	115	303	59
18. Sebeya River at Musabike	1.7238	29.36636	97.2	100.0	7.0	7.0	1865.0	1390.0	65	67	35	35	854	605
19. Sebeya River at Nyundo Station	1.70253	29.32707	95.2	102.6	7.4	7.5	2015.0	1080.0	72	76	39	40	1017	480
20. Kivu Lake Gisenyi Beach	1.70765	29.2607	111.4	119.6	9.2	9.1	2.3	6.2	973	985	484	475	1	1
21. Muvumba after mixing with Warufu	1.29241	30.31907	88.5	90.7	7.2	7.0	505.0	148.0	200	192	103	99	318	68
22. Akagera Rusumo Border	2.38473	30.77935	38.9	18.0	7.7	6.5	424.0	96.8	137	122	70	59	256	52
23. Mukungwa iver Before receiving Nyabarongo	1.73373	29.65553	98.8	101.6	8.2	8.4	546.0	131.0	270	315	141	162	344	54

24. Nyabarongo River before receiving Mukungwa	1.73567	29.6592	92.1	98.1	7.7	7.4	1267.0	690.0	41	44	20	21	744	265
25. Mukungwa River at Nyakinama gaugng station	1.55369	29.64424	95.7	91.3	8.1	8.6	50.8	22.5	248	293	129	151	22	12
26. Nyabarongo at Ruliba	1.9626	30.00369	90.5	96.9	7.9	7.9	1080.0	921.0	174	142	87	71	662	321
27. Nyabugogo River downstream	1.94741	30.02146	81.8	81.6	8.2	7.8	464.0	405.0	297	271	149	134	314	168
28. Nyabugogo River Upstream	1.79237	30.14936	78.2	77.5	7.5	7.5	4.0	28.1	457	390	223	191	4	6
29. Muhazi Downstream	1.80338	30.18005	101.4	77.4	8.5	7.9	6.9	12.8	490	416	234	196	13	4
30. Akagera at Kanzenze Bridge	2.06215	30.08637	58.8	78.3	7.4	7.1	2010.0	633.0	139	125	68	63	1010	241
31. Borehole at Gatsibo-Kabarore-Simbwa-Ruhuha	1.54556	30.35728	63.1	33.9	6.5	6.2	2.1	7.7	344	244	164	115	1.0	3.0
32. Borehole at Kayonza-Mukarange-Agatebe	1.87684	30.51283	51.6	60.1	6.1	6.1	2.0	4.2	184	162	86	76	1.0	1.0
33. Artesian Well	1.87051	30.59981	20.1	18.3	6.4	6.2	2.0	0.8	156	171	73	80	1.0	<1
34. Borehole at Gatsibo-Rugarama-Kanyangese-Umunini	1.6771	30.4087	36.4	0.0	6.2	0.0	1.8	0.0	458	0	225	0	1.0	0.0
35. Public Borehole at Giticyinyoni	1.94817	30.2527	61.9	54.4	5.9	5.7	1.2	3.2	308	297	154	140	1.0	4.0
36. Public Borehole at Nyandungu	1.96322	30.15775	46.6	73.1	6.0	5.6	1.4	1.8	348	282	170	133	1.0	4.0

	DIN (mg/l)		Nitrate (mg/l)		T.N (mg/l)		DIP (mg/l)		T.P (mg/l)	
	P. I	***P. II***	***P. I***	***P. II***	***P. I***	***P. II***	***P. I***	***P. II***	***P. I***	***P. II***
1. Mwogo River Up	3.0	3.5	1.3	1.7	3.9	9.0	0.7	0.7	1.4	1.5
2. Kivu Lake at Karongi (Beach Golf Hotel)	3.2	3.2	1.8	1.5	4.3	7.2	0.6	0.7	0.7	0.9
3. Rukarara River Upstream	3.1	3.8	1.3	1.5	3.8	9.6	0.7	0.7	0.9	0.9
4. Mbirurume River Downstream	3.9	5.1	2.3	2.4	5.3	9.1	0.4	0.4	0.9	0.9
5. Nyabarongo River after receiving Mwogo and Mbirurume Rivers	3.7	5.1	1.1	2.2	4.6	8.9	0.9	0.8	1.3	1.3
6. Rusizi River at Kamanyola Bridge	3.1	3.6	1.4	1.8	4.5	6.6	0.4	0.4	0.7	0.7
7. Kivu Lake at Kamembe Port	3.1	3.8	1.8	2.0	4.3	7.2	0.8	0.8	1.1	1.0
8. Rubyiro River at Bridge Bugarama - Ruhwa Road	3.1	4.2	1.2	2.0	4.6	9.6	0.6	0.6	1.0	1.0
9. Ruhwa River at bridge Ruhwa border	3.4	4.8	1.3	2.7	4.7	8.5	1.3	1.4	1.5	1.4
10. Akanyaru River Gihinga	4.4	5.1	1.2	1.4	5.8	9.4	1.1	1.2	1.6	1.7
11. Akanyaru River border to Burundi	3.6	4.4	2.5	2.8	6.0	7.9	1.5	1.5	2.1	1.8
12. Secoko River before discharging into Nyabarongo	6.8	6.1	2.3	2.8	7.4	6.8	2.7	2.2	4.5	3.2
13. Muhazi Upstream	3.3	4.5	2.5	2.7	5.1	8.1	0.4	0.5	0.7	0.7
14. Rugezi before discharging into Burera Lake	3.4	5.4	1.0	2.6	4.2	7.8	0.2	0.2	0.7	0.8

15. Muvumba River entering Rwanda from Uganda	4.4	4.5	1.9	2.1	6.9	7.5	0.6	0.6	0.8	0.8
16. Warufu River	3.7	4.1	1.0	1.4	5.1	6.6	0.5	0.6	0.9	0.9
17. Muvumba at Kagitumba	3.4	3.7	1.5	1.8	4.9	8.6	0.6	0.6	1.0	1.2
18. Sebeya River at Musabike	3.4	5.5	1.9	2.0	5.5	8.9	0.4	0.5	1.1	1.2
19. Sebeya River at Nyundo Station	4.7	5.7	2.5	2.6	4.8	8.7	0.4	0.4	1.3	1.2
20. Kivu Lake Gisenyi Beach	2.6	3.0	1.6	1.8	3.6	8.0	0.8	1.0	1.1	1.2
21. Muvumba after mixing with Warufu	3.4	3.8	1.5	1.9	5.4	8.7	0.2	0.6	1.0	1.0
22. Akagera Rusumo Border	3.2	3.1	1.7	1.6	4.3	7.7	0.8	0.7	1.0	1.1
23. Mukungwa iver Before receiving Nyabarongo	3.6	4.5	1.5	1.8	4.4	8.4	0.3	0.4	1.1	1.0
24. Nyabarongo River before receiving Mukungwa	3.7	5.3	1.1	1.4	4.8	7.1	0.4	0.5	1.1	0.9
25. Mukungwa River at Nyakinama gaugng station	2.2	2.8	0.8	1.0	3.9	7.8	0.2	0.3	0.8	0.8
26. Nyabarongo at Ruliba	4.2	4.2	1.5	1.5	5.4	8.8	0.6	0.6	0.8	0.9
27. Nyabugogo River downstream	4.8	4.7	2.0	1.9	6.0	7.9	0.6	0.7	0.7	0.8
28. Nyabugogo River Upstream	3.4	3.7	2.0	2.0	5.1	8.8	1.3	1.4	1.5	1.4
29. Muhazi Downstream	4.1	4.2	2.3	2.2	4.5	8.8	1.7	1.8	2.2	2.0
30. Akagera at Kanzenze Bridge	3.5	4.1	1.0	1.5	4.8	8.5	0.9	1.0	1.0	1.0
31. Borehole at Gatsibo-Kabarore-Simbwa-Ruhuha	2.2	2.0	1.8	2.3	3.8	7.2	0.2	0.2	0.4	0.4
32. Borehole at Kayonza-Mukarange-Agatebe	4.4	2.6	1.4	1.8	3.2	7.2	0.2	0.3	0.4	0.4
33. Artesian Well	2.2	2.0	0.6	0.6	3.1	7.6	0.1	0.1	0.7	0.8
34. Borehole at Gatsibo-Rugarama-Kanyangese-Umunini	4.4	2.6	3.3	0.0	6.5	0.0	0.3	0.0	0.9	0.0
35. Public Borehole at Giticyinyoni	2.2	2.0	7.9	8.1	10.8	12.5	0.2	0.7	0.8	1.3
36. Public Borehole at Nyandungu	4.4	2.6	7.6	7.1	11.3	10.7	0.7	0.2	1.2	0.8

	Chloride (mg/l)		Sulphate (mg/l)		BOD (mg/l O_2)		F.C (Cfu/100ml)		E.C (Cfu/100ml)	
	P. I	***P. II***	***P. I***	***P. II***	***P. I***	***P. II***	***P. I***	***P. II***	***P. I***	***P. II***
1. Mwogo River Up	1.6	5.0	20.8	23.5	2.4	2.3	2 x 10^{2}	3 x 10^{2}	5 x 10^{1}	6 x 10^{1}
2. Kivu Lake at Karongi (Beach Golf Hotel)	20.7	25.8	16.7	16.8	8.2	7.0	2 x 10^{2}	2 x 10^{3}	5 x 10^{1}	1 x 10^{2}
3. Rukarara River Upstream	2.2	7.9	2.2	3.5	2.7	2.0	6 x 10^{1}	2 x 10^{1}	3 x 10^{1}	7 x 10^{0}
4. Mbirurume River Downstream	2.2	9.8	11.0	12.3	1.4	2.0	3 x 10^{2}	3 x 10^{3}	6 x 10^{1}	9 x 10^{1}
5. Nyabarongo River after receiving Mwogo and Mbirurume Rivers	2.9	8.0	13.5	11.2	5.1	2.0	1 x 10^{2}	4 x 10^{2}	4 x 10^{1}	6 x 10^{1}

6. Rusizi River at Kamanyola Bridge	20.1	27.6	20.7	20.6	10.0	6.9	9×10^1	3×10^4	4×10^1	6×10^2
7. Kivu Lake at Kamembe Port	20.1	29.3	18.0	17.8	8.2	7.2	2×10^2	5×10^4	6×10^1	7×10^2
8. Rubyiro River at Bridge Bugarama - Ruhwa Road	6.7	12.8	15.2	28.5	16.4	13.4	3×10^1	8×10^3	1×10^1	3×10^2
9. Ruhwa River at bridge Ruhwa border	3.5	6.1	11.8	9.5	17.6	14.8	1×10^2	9×10^4	4×10^1	6×10^2
10. Akanyaru River Gihinga	2.9	7.9	17.8	25.3	3.1	4.5	2×10^1	5×10^2	1×10^1	2×10^2
11. Akanyaru River border to Burundi	8.0	13.8	14.3	15.6	15.3	2.0	7×10^2	7×10^2	3×10^2	5×10^1
12. Secoko River before discharging into Nyabarongo	4.1	7.2	9.5	11.6	15.6	14.3	7×10^1	7×10^4	1×10^1	4×10^4
13. Muhazi Upstream	78.0	83.3	12.0	18.3	9.0	6.3	3×10^2	8×10^4	1×10^2	8×10^2
14. Rugezi before discharging into Burera Lake	4.8	7.4	8.3	21.0	6.6	18.0	8×10^2	5×10^4	4×10^2	2×10^3
15. Muvumba River entering Rwanda from Uganda	12.4	17.5	17.3	21.3	9.6	6.7	2×10^1	3×10^4	1×10^1	3×10^2
16. Warufu River	11.1	12.9	16.2	18.5	10.4	7.3	1×10^3	5×10^5	4×10^2	7×10^3
17. Muvumba at Kagitumba	23.9	26.7	28.7	37.3	11.6	7.7	2×10^2	2×10^5	1×10^2	8×10^3
18. Sebeya River at Musabike	4.1	9.0	23.0	28.0	8.9	8.9	1×10^2	5×10^6	5×10^1	8×10^3
19. Sebeya River at Nyundo Station	3.5	8.8	34.2	33.0	7.5	11.3	3×10^2	2×10^3	2×10^2	6×10^2
20. Kivu Lake Gisenyi Beach	22.0	26.7	18.7	15.6	5.4	4.4	1×10^2	3×10^6	7×10^1	1×10^4
21. Muvumba after mixing with Warufu	15.6	23.9	25.3	30.0	11.2	7.8	4×10^0	3×10^5	$< 1 \times 10^0$	1×10^4
22. Akagera Rusumo Border	3.5	5.6	22.0	17.2	11.6	2.0	3×10^2	7×10^5	2×10^2	2×10^4
23. Mukungwa iver Before receiving Nyabarongo	4.8	8.8	12.8	13.6	9.2	10.1	3×10^2	6×10^6	2×10^2	1×10^4
24. Nyabarongo River before receiving Mukungwa	5.4	8.0	29.7	29.0	7.2	8.4	6×10^2	7×10^6	2×10^2	1×10^4
25. Mukungwa River at Nyakinama gaugng station	4.1	8.9	11.3	13.1	6.6	5.1	4×10^2	3×10^3	2×10^2	1×10^2
26. Nyabarongo at Ruliba	30.3	26.9	36.1	33.5	7.7	9.1	9×10^1	5×10^4	5×10^1	5×10^2
27. Nyabugogo River downstream	50.0	55.0	25.9	34.5	17.0	6.0	1×10^3	7×10^3	9×10^2	2×10^2
28. Nyabugogo River Upstream	90.8	89.9	11.1	12.5	4.9	2.0	3×10^1	2×10^3	1×10^1	5×10^2
29. Muhazi Downstream	94.6	96.5	15.0	34.6	2.7	2.0	1×10^2	6×10^2	6×10^1	1×10^2
30. Akagera at Kanzenze Bridge	32.2	36.5	32.3	30.8	5.6	5.1	8×10^2	9×10^4	1×10^2	2×10^2
31. Borehole at Gatsibo-Kabarore-Simbwa-Ruhuha	10.1	16.9	21.0	29.1	2.2	2.0	8×10^1	1×10^5	2×10^1	6×10^2
32. Borehole at Kayonza-Mukarange-Agatebe	12.4	13.9	15.2	20.8	2.1	2.0	3×10^1	1×10^3	1×10^1	7×10^2
33. Artesian Well	3.5	8.3	4.2	6.8	2.0	0.0	2×10^2	1×10^3	1×10^2	9×10^2
34. Borehole at Gatsibo-Rugarama-Kanyangese-Umunini	49.4	0.0	8.2	0.0	2.2	15.8	6×10^2	NF	4×10^2	NF
35. Public Borehole at Giticyinyoni	27.1	57.5	34.0	23.2	2.0	4.4	$< 1 \times 10^0$	$<1 \times 10^0$	$< 1 \times 10^0$	Absence

36. Public Borehole at Nyandungu	62.1	28.3	18.4	33.6	5.6	5.1	2×10^0	$<1x\ 10^0$	$< 1 \times 10^0$	Absence

P. I: Period I and P. II: Period II; NF: Not functionning

5. Water quality results and interpretation

Water quality was estimated by looking at a set of sixteen selected parameters and which inform on major water quality issues in our country. Those include the Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), Potential in Hydrogen (pH), Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Turbidity, Chloride (Cl^-), Sulfate (SO_4^{2-}), Nitrate (NO_3^-), Total nitrogen (TN), Total Phosphorus (TP), Total Dissolved Inorganic Nitrogen (DIN), Total Dissolved Inorganic Phosphorous (DIP), Fecal coliform (FC) and Escherishia coli (E.C). Table 4 provides a brief description of each monitored parameters following the standards for potable water (FDEAS 12:2018), the discharged domestic wastewater (FDRS 110:2017) and the discharged industrial wastewater (CD-R-002-2012).

Table 4: *Standard of the parameters monitored*

Nº	Parameter Name	Parameter Short name	Natural potable water (FDEAS 12:2018)	Discharged domestic wastewater (FDRS 110:2017)	Discharged industrial wastewater (CD-R-002-2012)	Unit	Target Type
1	Biochemical Oxygen Demand	BOD_5	-	50	50	mg/l	Higher
2	Dissolved Oxygen	DO	68*	68*	68*	%	Lower
3	Potential in Hydrogen	pH	5.5 – 9.5	5 – 9	5 – 9	-	Range
4	Electrical conductivity	EC	2500	-	-	µS/cm	Higher
5	Dissolved inorganic Nitrogen	DIN	30*	30*	30*	mg/l	Higher
6	Dissolved Inorganic Phosphorous	DIP	5*	5*	5*	mg/l	Higher
7	Total Phosphorus	TP	-	5	-	mg/l	Higher
8	Total Dissolved Solid	TDS	1500	1500	2000	mg/l	Higher
9	Total Suspended Solid	TSS	ND	50	50	mg/l	Higher
10	Turbidity	-	25	-	-	NTU	Higher
11	Chloride	Cl^-	250	-	-	mg/l	Higher
12	Total Nitrogen	TN	-	30	-	mg/l	Higher
13	Nitrate	NO_3^-	45	20	-	mg/l	Higher
14	Sulphate	SO_4^{2-}	400	500	-	mg/l	Higher
15	Fecael Coliform	F.C	ND	< 400	400	CFU/100ml	Higher
16	Escherichia Coli	E.Coli	ND	4*	4*	CFU/100ml	Higher

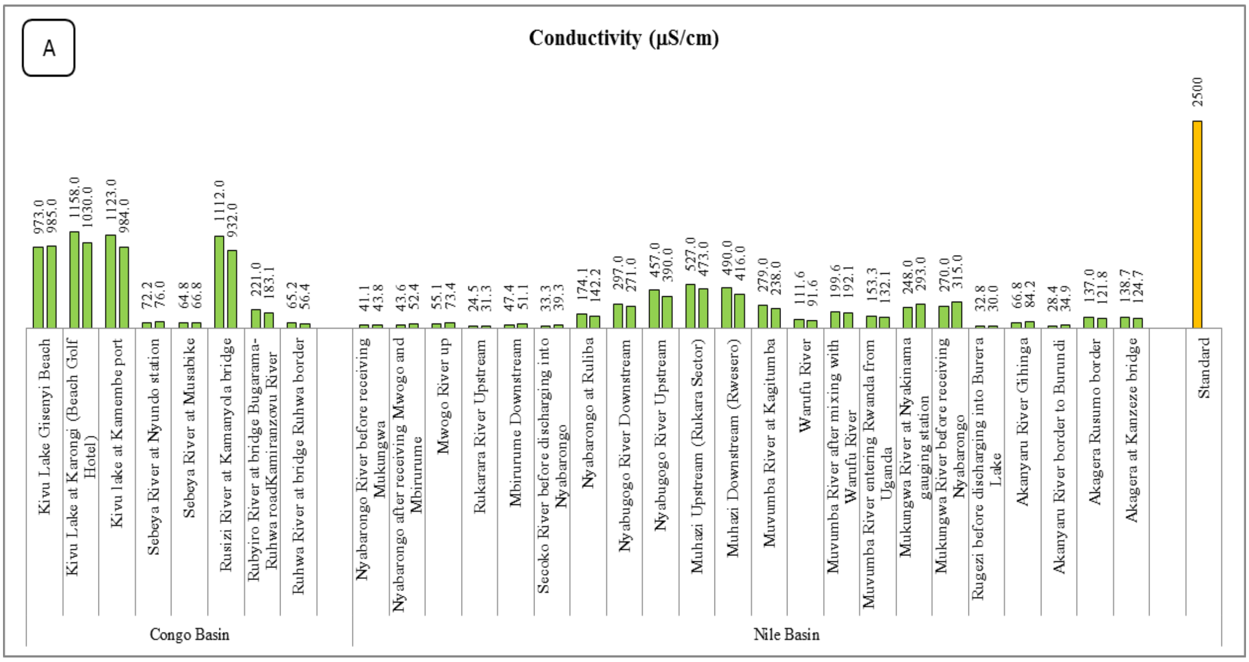
*: standard limit taken from "Water Pollution Baseline Study (2017)"; ND: not detectable

Measurements of Hydrogen potential (pH), Electro conductivity (EC), total dissolved solids (TDS), Total Suspended Solid (TSS), Turbidity and percentage dissolved oxygen (DO in %) were conducted in situ. While dissolved inorganic nitrogen (DIN) which is the summation of the concentration of Ammonia-nitrogen plus nitrite-nitrogen concentration and nitrate-nitrogen concentration, dissolved inorganic phosphorus (DIP), BOD, Sulphate, and Escherichia coli (E. coli were analysed in laboratory using samples that were collected following the laboratory Standard Operating Procedures (SOPs) for both sampling and analysis.

During the sampling period, key characteristics of the sampling sites were noted. Those include but were not limited to water appearance, presence of algae or vegetation in a water body (e.g: water hyacinth), sediments, etc. Water samples were collected in November for all sampling sites.

1. Electrical Conductivity (EC)

Results from this survey showed the Electric Conductivity (EC) varying from 24 to 1158 µS/cm. Significant differences between sites in conductivity values were observed ($P < 0.05$) when comparing period I to period II ($P = 0.016$). A 100 % compliance with the Rwandan standard was observed in all monitoring sites, the recorded values were below the standard limit of 2500 µS/cm (see Figure 2). In general, slightly higher values were recorded in the rainy season (period I) when compared to the dry season (period II). Electrical conductivity is a measure of the ability of water to conduct an electric current. It is sensitive to variations in dissolved solids, mostly mineral salts. The conductivity of most freshwaters ranges from 10 to 1000 µS/cm but may exceed 1000 µS/cm especially in polluted waters, or those receiving large quantities of land run-off. In addition to being a rough 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 (Chapman, 1996).



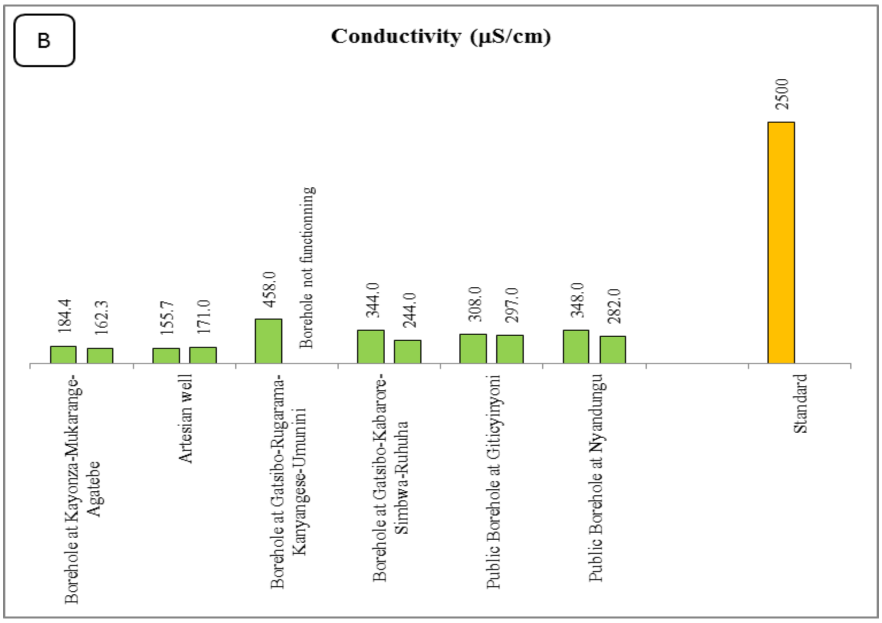


Figure 2: *Variation of conductivity in all monitoring sites for period I & II (A) for surface water & (B) for ground water. The yellow colour indicates the standard value; the green colour indicates lower conductivity values recorded when compared to the standard limit respectively.*

2. Dissolved Oxygen (DO)

Results from this survey showed in general higher DO values in 23 monitoring sites. No significant differences between sites were observed ($P > 0.05$) when comparing period I to period II ($P = 0.556$). Recorded values varied from 78.2 to 119.4 % of saturation; this is representing 63.8% of compliance with the limit of 68 % oxygen penetration in a surface water. These higher values of oxygen when compared to the standard limit is good for the maintenance of aquatic life and also for the self purification process of these water bodies. In the other remaining 13 sites, representing 36.1 % of non compliance with the standard limit, recorded DO values varying between 11.4 and 66.5 % of saturation which is below the standard limit of oxygen penetration of 68 %. This was mainly observed for boreholes and artesian well; for Rugezi wetland like Rugezi and Mwogo and Akagera Rivers where the water is covered by vegetation like Water hyacinth which is mainly preventing oxygen penetration from the atmosphere (see Figure 3).

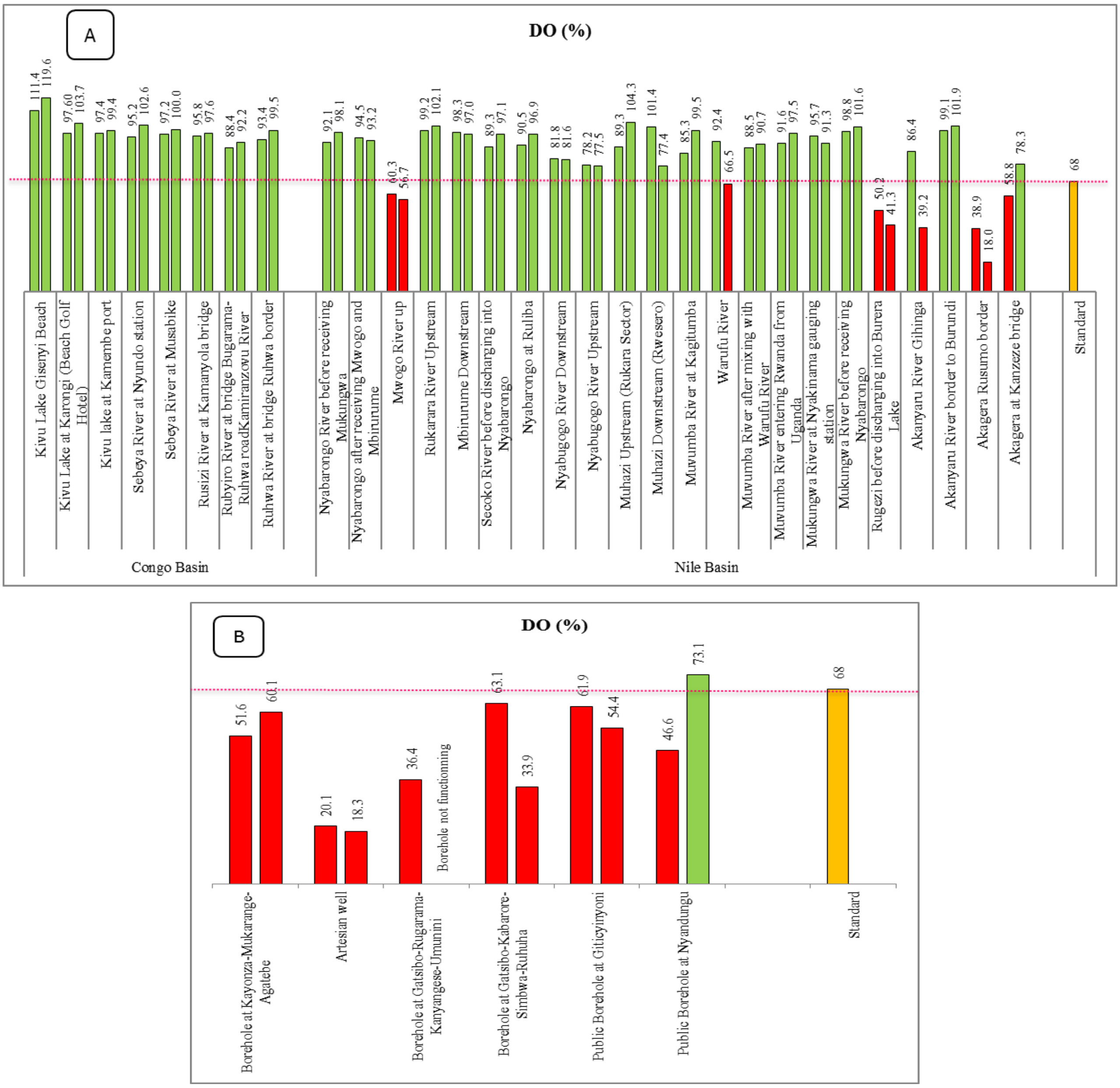


Figure 3: *Variation of Dissolved Oxygen for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow colour indicates the standard value; the red and green colours indicate lower and higher DO values recorded when compared to the standard limit respectively.*

Normally oxygen is essential to all forms of aquatic life, including those organisms responsible for the self-purification processes in natural waters. The oxygen content of natural waters varies with temperature, salinity, turbulence, the photosynthetic activity of algae and plants, and atmospheric pressure. Oxygen is needed because it is required for the metabolism of aerobic organisms, influences inorganic chemical reactions, maintains several grades of water like taste, degree of asepsis and consumed from decomposition of organic matters (Chapman, 1996). 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 (UNEP, 2006).

3. Total Dissolved Solids (TDS)

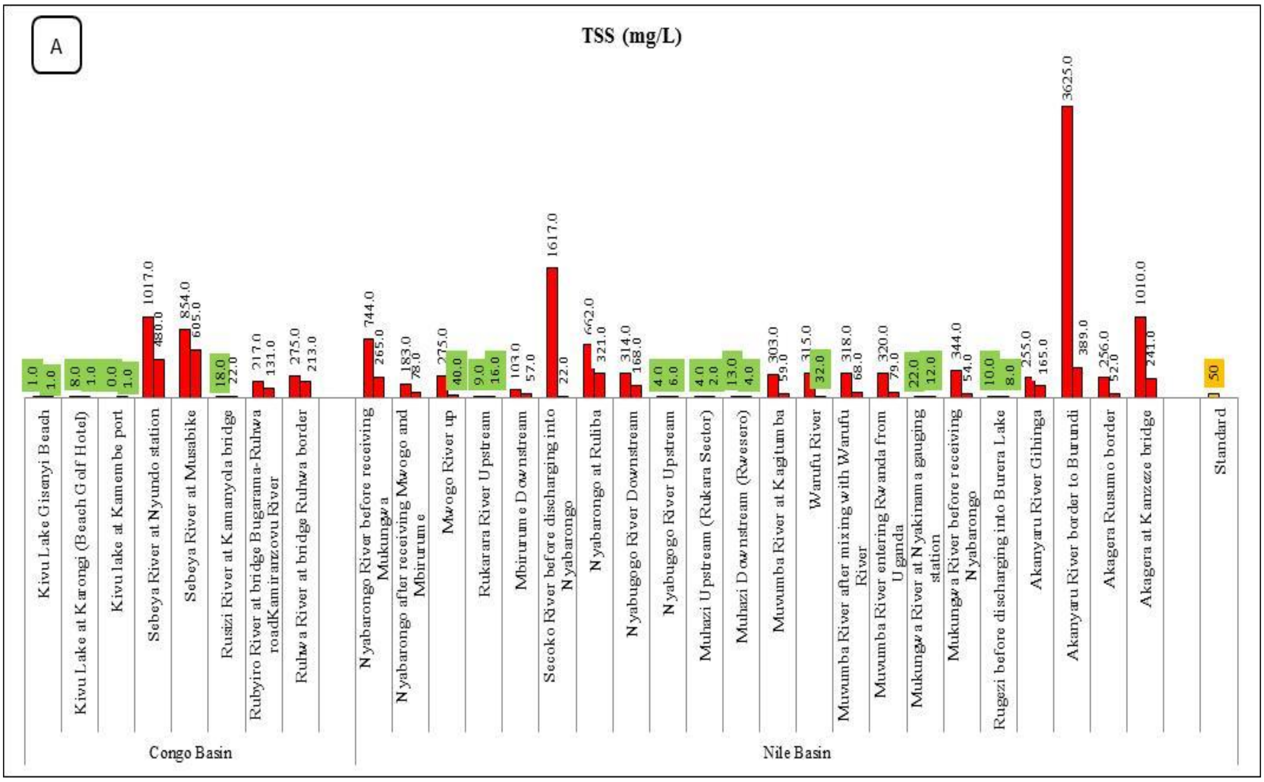
Result from this survey showed TDS varying from 13.94 to 568 mg/l. Significant differences between sites were observed ($P < 0.05$) when comparing period I to period II ($P = 0.009$). Recorded values were below the standard limit of 1500 mg/l in all monitoring sites, which is representing a 100 % compliance with the Rwandan standard (see Figure 4).

Figure 4: *Variation of total dissolved solid for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow colour indicates the standard value; the green colour indicates lower TDS values recorded when compared to the standard limit respectively.*

4. Total Suspended Solids (TSS)

The Total Suspended Solids (TSS) recorded in this survey were high in all sites with values varying between 1 and 3625 mg/l. Significant differences between sites ($P < 0.05$) were observed when comparing period I to period II ($P = 0.011$). The recommended standard for TSS in Rwanda for potable water is not detectable. For discussion purpose we have used the limit for TSS given in the discharged of domestic and industrial wastewater which is 50 mg/l as the limit for natural potable water is hard to be met in nature. For all monitoring sites 50 % are not compliying with the Rwandan standards whereas the other 50 % are complying with TSS standard (see Figure 5). Seasonal variation shows a sharp decrease in TSS from period I to period II. This is mainly explain by the dry season and non occurance of soil erosion and surface run off which are in general the main factor influencing high TSS observed in surface water during the rainy season. In general higher TSS values were found at Akanyaru River border to Burundi, Secoko River before discharging into Nyabarongo, Sebeya River at Musabike, Sebeya River at Nyundo Station, Akagera at Kanzenze bridge and the Nyabarongo River before receiving Mukungwa River. Below pictures are showing the sediment transportation within Akanyaru and Sebeya Rivers which is noticeable by the yellow brown colour of the water. The measure of TSS in surface water allows for an estimation of sediment transport, which can have significant effects in downstream receiving waters.

Picture 1: *Variation of TSS in Akanyaru River border to Burundi (left side picture) and Sebeya River at Musabike (right side picture) where sediment transportation is noticeable by the brownish and yellowish developed colour showing land heavy load within rivers waters.*



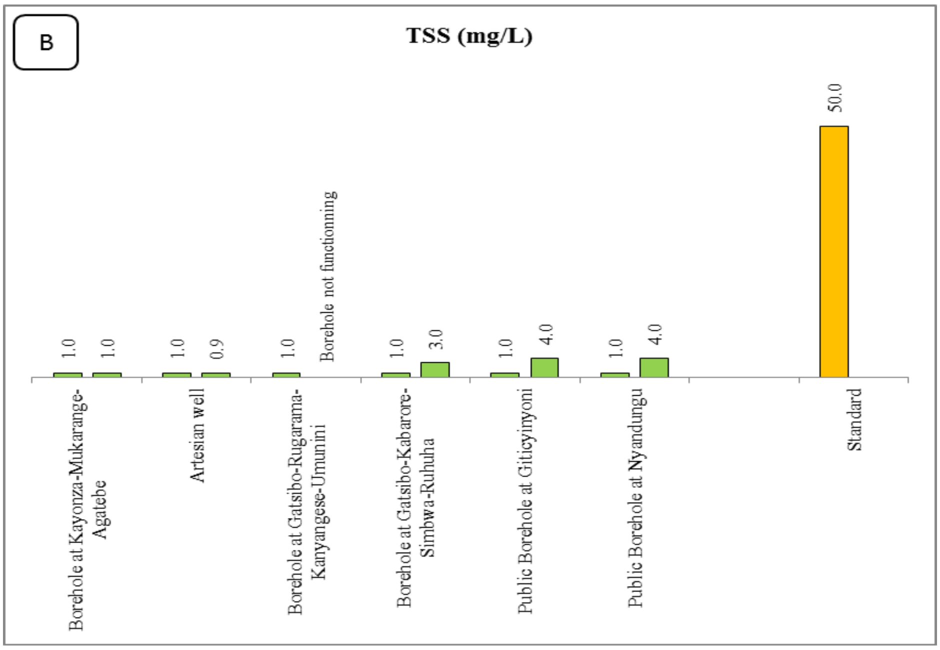
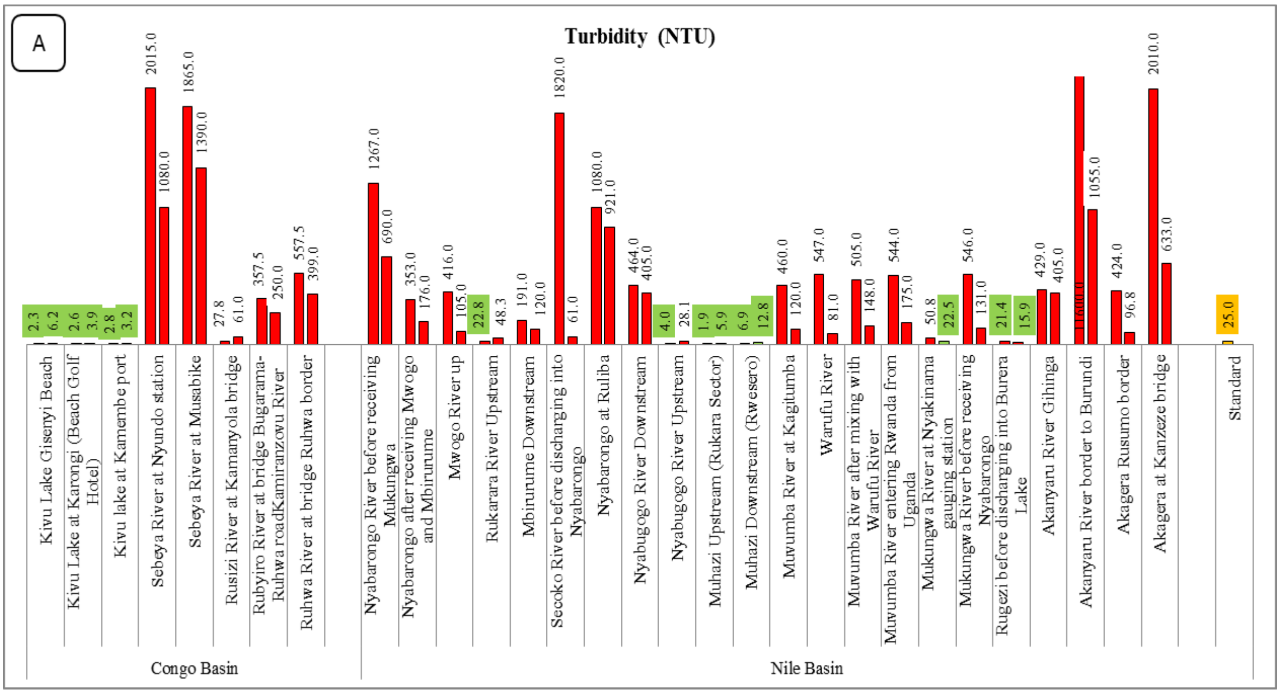


Figure 5: *Variation of total suspended solid for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow colour indicates the standard value; the red and green colours indicate higher and lower TSS values recorded when compared to the standard limit respectively.*

The presence of high values of TSS in Akanyaru river border to Burundi, Sebeya and Secoko rivers are attributed to the fact that in these river catchments there are agricultural activities on hill side combined with intensive unsustainable mining activities mainly for Sebeya being done from its source in Muhanda Sector of Ngororero District and Nyabirasi sector of Rutsiro District but also downstream in Kanama and Nyundo Sector of Rubavu District. Even if agricultural activities are also contributing as well to the accumulation of suspended solids in rivers, mining activities are the most likely major contributors.

5. Turbidity

Results from this survey showed 61% of monitored rivers presenting higher turbidity values when compared to the standard limit. Only 39 % of monitored sites have presented values below the standard limit. No significant differences between sites ($P > 0.05$) were observed when comparing period I to period II ($P = 0.082$). In general recorded turbidity values were varying between 1.2 and 11600 NTU. A sharp decrease in turbidity values were noticed in some sampling sites when comparing period I to period II. This was directly linked with the seasonal variation between the rainy and dry season. The highest turbidity value was found at Akanyaru river border to Burundi with 11,600 NTU and the lowest was found at the public borehole at Giticyinyoni with 1.2 NTU (see Figure 6). Turbidity was high in some area during this water quality monitoring activity mainly due to the fact of flash flood occurring after rain fall case of Kanzeze and Akanyaru border to Burundi.



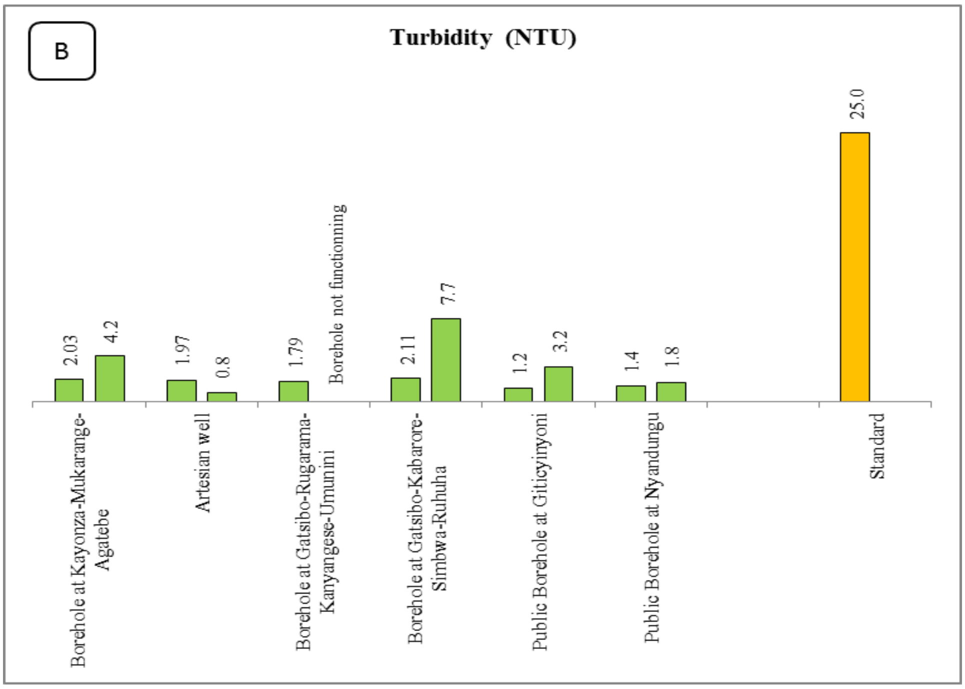


Figure 6: *Variation of turbidity for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow colour shows the standard limit; the red and green colours are showing the recorded higher and lower turbidity concentrations respectively.*

Considering that the presence of suspended solids is linked to the turbidity of rivers, this explains the fact that the same rivers with the highest concentration of suspended solids are the ones with the highest turbidity and this is caused by the same factors as described in the section above.

6. pH Value

Results from this study showed a 100% compliance with the Rwandan standard in all monitoring sites. No significant differences between sites ($P > 0.05$) were observed when comparing period I to period II ($P = 0.131$). All recorded pH values were within the minimum and maximum pH limits as shown in Figure 7. Borehole water were in general sligthly acidic, this could be explain by oxygen depletion underground while surface water were sligthly basic due to atmospheric oxygen penetration combine with photosynthetic algal activity in surface water.

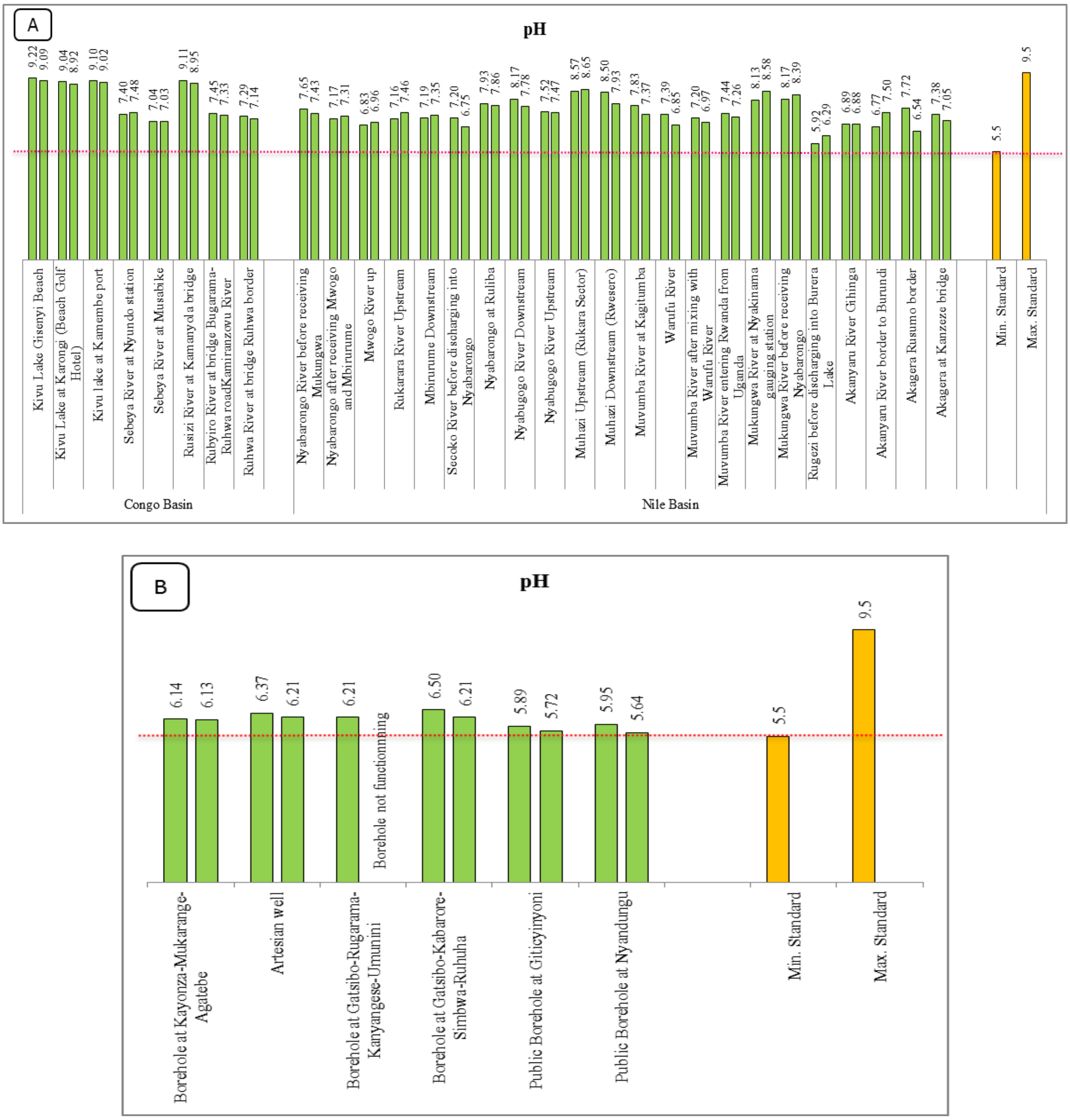
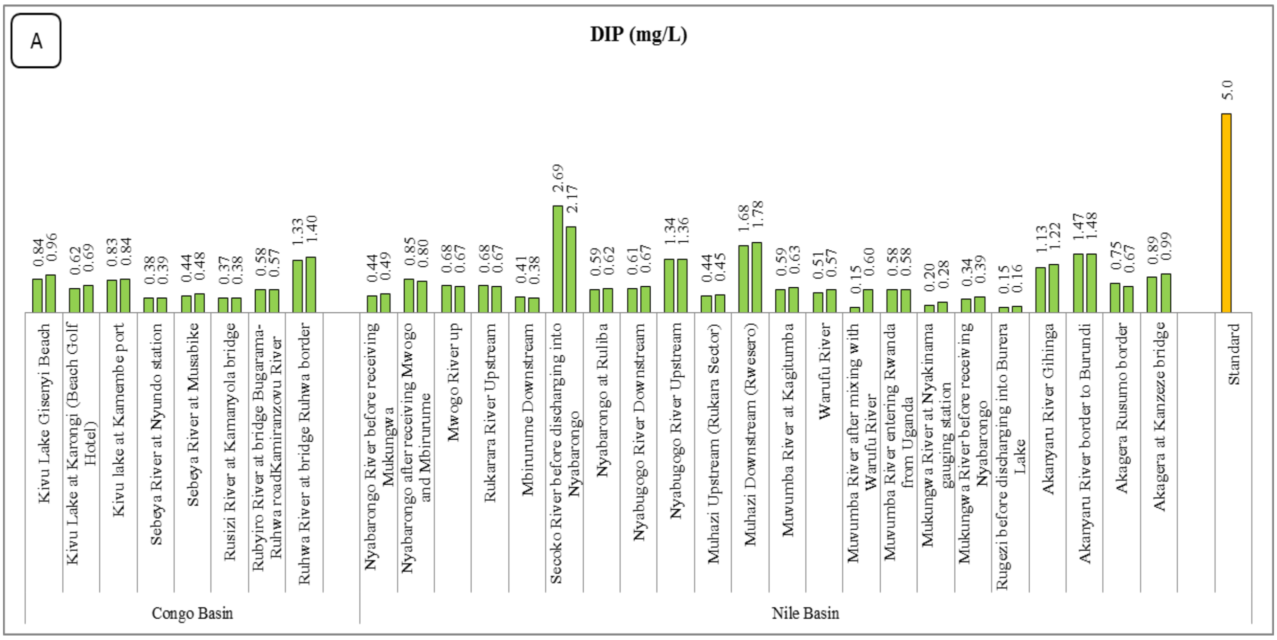


Figure 7: *Variation of the pH recorded for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow colour indicates the minimum and maximum standards limits; the green colour indicates pH value within the acceptable standard limits.*

7. Dissolved Inorganic Phosphorous (DIP)

Results from this survey showed a 100 % compliance with the standard limit of 5 mg/l for DIP. No significant differences between sites ($P > 0.05$) were observed when comparing period I to period II ($P = 0.517$). Recorded values were varying between 0.13 and 2.69 mg/l as shown in Figure 8. Differences observed between ground water and surface water in terms of inorganic phosphorus may be explained by inputs coming from anthropogenic activities mainly polluting surface water.



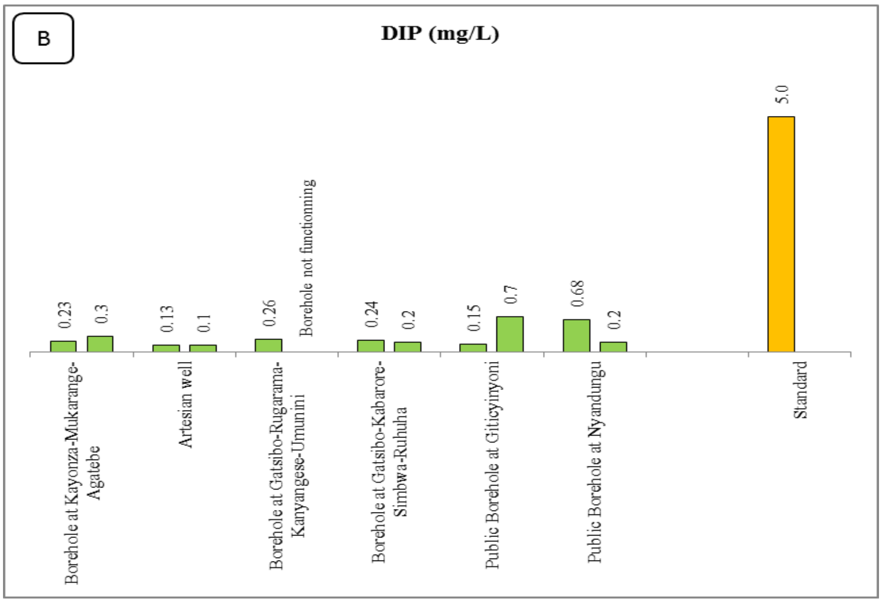


Figure 8: *Variation of Dissolved Inorganic Phosphorus (DIP) for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow colour indicates the standard value; the green colour indicates the lower DIP values recorded when compared to the standard limit.*

Phosphorus exists in water in either a particulate phase or a dissolved phase. Particulate matter includes living and dead plankton, precipitates of phosphorus, phosphorus adsorbed to particulates and amorphous phosphorus. The dissolved phase includes inorganic phosphorus and organic phosphorus. Phosphorus in natural waters is usually found in the form of phosphates (PO_4^{-3}). Phosphates can be in inorganic form (including orthophosphates and polyphosphates), or organic form (organically-bound phosphates).

8. Total Phosphorus (TP)

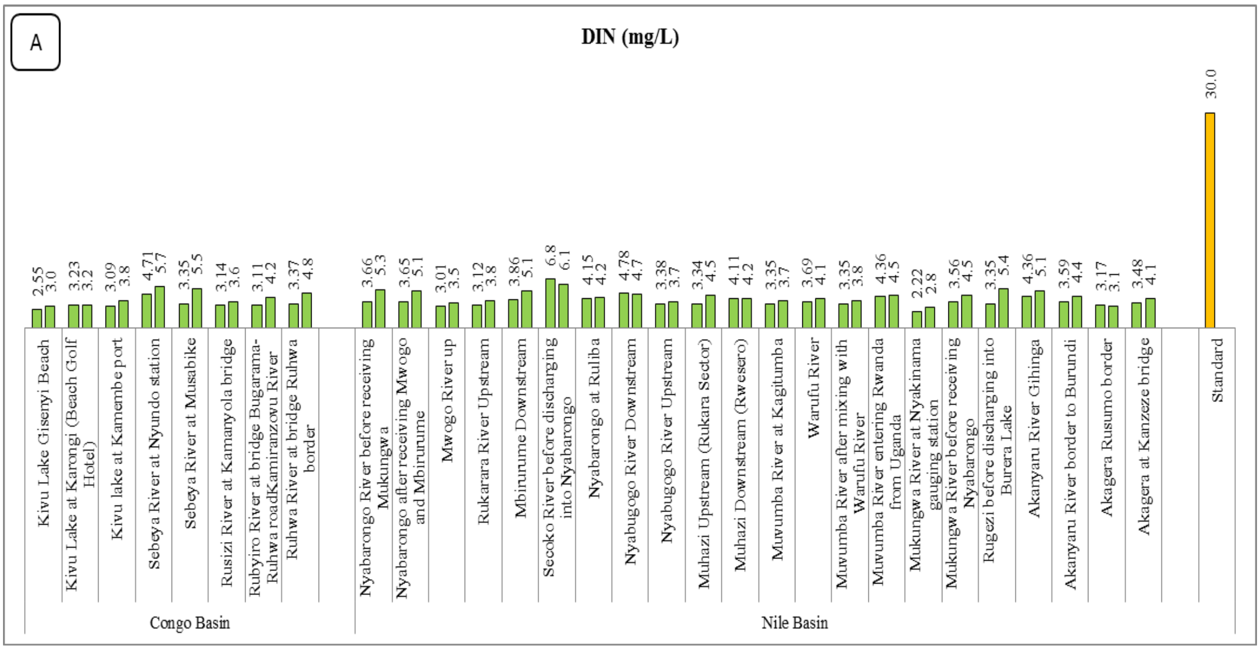
Results from this survey showed a 100 % of total phosphorus compliance with the standard. No significant differences between sites ($P > 0.05$) were observed when comparing period I to period II ($P = 0.427$). All recorded values were below the standard limit in all monitoring sites see Figure 9. However, standards used in Germany for water resource management (2013), for TP the standard limit is very strict with a limit value of ≤ 0.3 mg/l for good water status and a maximum of > 1.20 mg/l as bad water status.

Figure 9: *Variation of Total Phosphorus for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow colour indicates the standard value; the green colour indicates the lower TP values recorded when compared to the standard limit.*

Phosphorus 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. Natural sources of phosphorus are mainly the weathering of phosphorus-bearing rocks and the decomposition of organic matter. Domestic wastewaters (particularly those containing detergents), industrial effluents, fertilizer and run-off contribute to elevated levels in surface waters. 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. In most natural surface waters, phosphorus ranges from 0.005 to 0.020 mg/L (Chapman, 1996). Phosphorus is considered to be the primary drivers of eutrophication of aquatic ecosystems, where increased nutrient concentrations lead to increased primary productivity. The high quantity of Total phosphorus may come from the rock alteration and may also be due to the use of industrial fertilizers and / or decay of matters.

9. Dissolve Inorganic Nitrogen (DIN)

Results from this study showed a 100 % compliance of the dissolved inorganic nitrogen (DIN) in all monitoring sites were below the standard limit of 30 mg/l. Significant differences between sites ($P < 0.05$) were observed when comparing period I to period II ($P = 0.003$). Recorded concentrations were varying between 1.81 and 8.06 mg/l as shown in Figure 10.



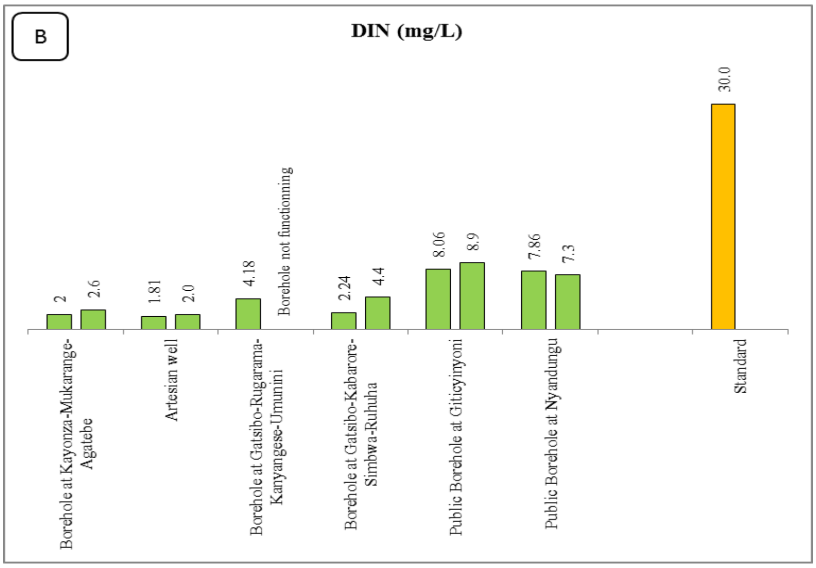


Figure 10: *Variation of Dissolved Inorganic Nitrogen (DIN) for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow colour indicates the standard value; the green colour indicates the lower DIN values recorded when compared to the standard limit.*

Dissolved inorganic nitrogen (DIN) is comprised of nitrate plus nitrite and ammonium. These forms of nitrogen are readily available to phytoplankton and often control the formation of blooms.

10. Total nitrogen (TN)

Results from this study showed a 100 % compliance of the total nitrogen (TN) in all monitoring sites were below the standard limit of 30 mg/l. Significant differences between sites ($P < 0.05$) were observed when comparing period I to period II ($P = 0.000$). Recorded concentrations were varying between 3.1 and 11.3 mg/l as shown in Figure 11. Standards used in Germany for water resource management (2013), for TN the standard limit is set at a value of ≤ 6 mg/l for good water status and a maximum of > 24 mg/l as bad water status.

Figure 11: *Variation of Total Nitrogen for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow colour indicates the standard value; the green colour indicates lower TN values recorded when compared to the standard limit respectively.*

Total Nitrogen is an essential nutrient for plants and animals. However, an excess amount of nitrogen in a waterway may lead to low levels of dissolved oxygen and negatively alter various plant life and organisms. Sources of nitrogen include: wastewater treatment plants, runoff from fertilized lawns and croplands, failing septic systems, runoff from animal manure and storage areas, and industrial discharges that contain corrosion inhibitors.

11. Nitrate Nitrogen (NO_3-N)

Results from this study showed a 100 % compliance of the nitrate concentration in all monitoring sites were below the standard limit of 30 mg/l. No significant differences between sites ($P > 0.05$)

were observed when comparing period I to period II (P = 0.087). Recorded concentrations were varying between 0.58 mg/l and 7.89 mg/l as shown in Figure 12. Standards used in Germany for water resource management (2013), for NO_3-N the standard limit is set at a value of ≤ 5 mg/l for good water status and a maximum of > 20 mg/l as bad water status.

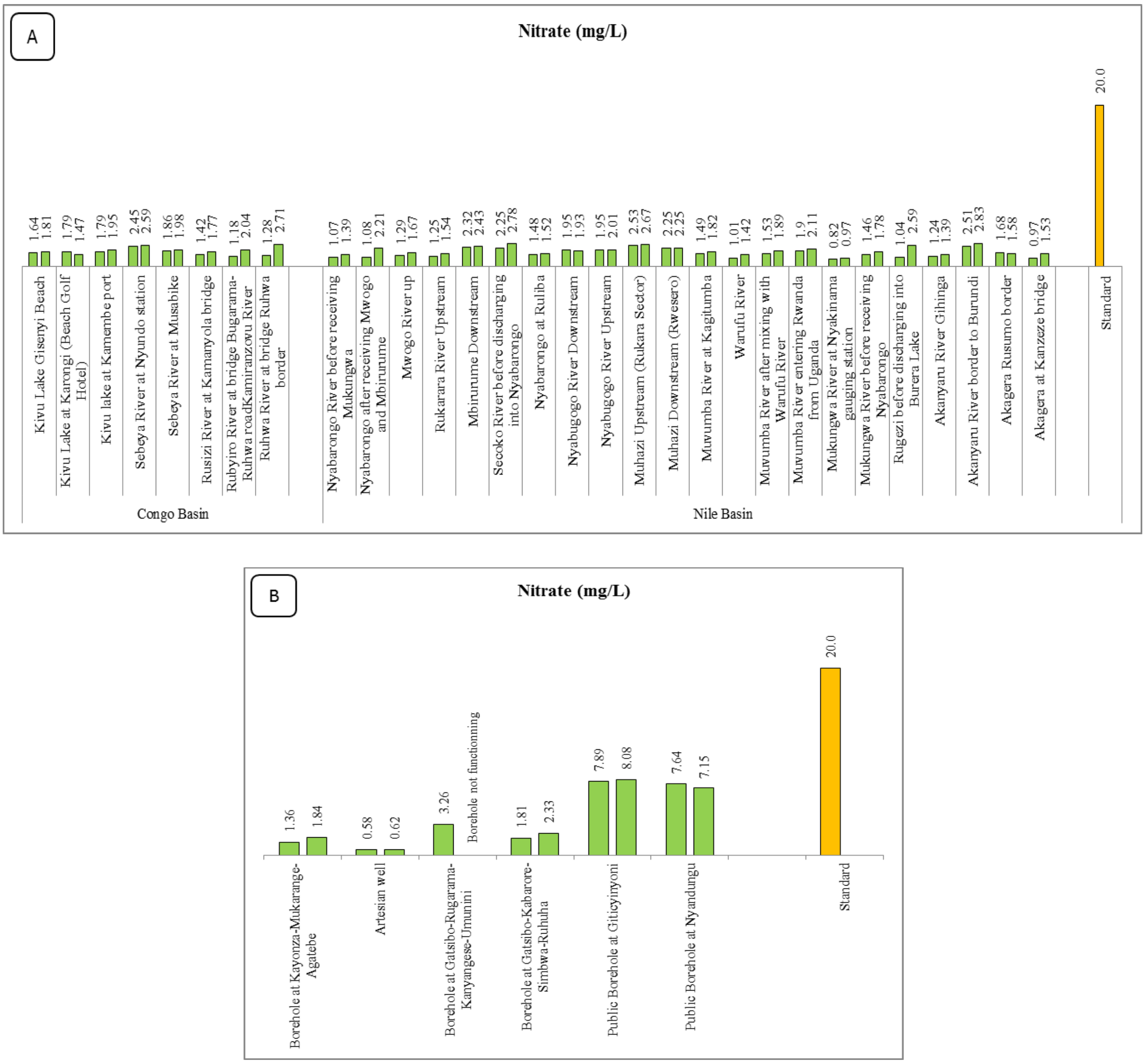
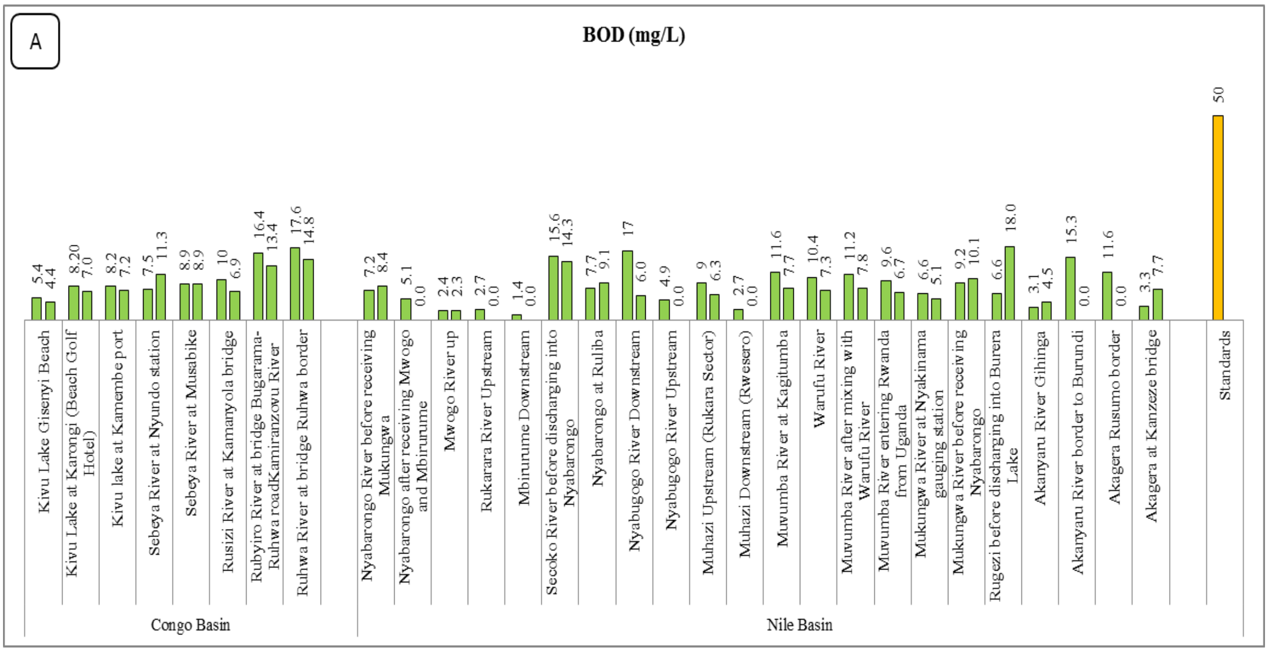


Figure 12: *Variation of Nitrate in all monitoring sites for period I & II (A) for surface water & (B) for ground water. The yellow colour indicates the standard value; the green colour indicates the lower nitrate values recorded when compared to the standard limit.*

The nitrate ion (NO_3^-) is the common form of combined nitrogen found in natural waters. It may be biochemically reduced to nitrite (NO_2^-) by de-nitrification processes, usually under anaerobic conditions. The nitrite ion is rapidly oxidized to 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. Natural concentrations, which seldom exceed 0.1 mg/LNO_3, may be enhanced by municipal and industrial waste-waters, including leachates from waste disposal sites and sanitary landfills. In rural and suburban areas, the use of inorganic nitrate fertilizers can be a significant source. When influenced by human activities, surface waters can have nitrate concentrations up to 5 mg/L NO_3^-, but often less than 1 mg/L NO_3-N. Concentrations in excess of 5 mg/L NO_3 usually indicate pollution by human or animal waste, or fertilizers run-off.

12. Biochemical Oxygen Demand (BOD)

Results from this study showed a 100 % compliance of the biochemical oxygen demand concentrations in all monitoring sites were below the standard limit of 50 mg/l. No significant differences between sites ($P > 0.05$) were observed when comparing period I to period II ($P = 0.235$). Recorded concentrations were varying between 1.4 mg/l and 17.6 mg/l as shown in Figure 13.



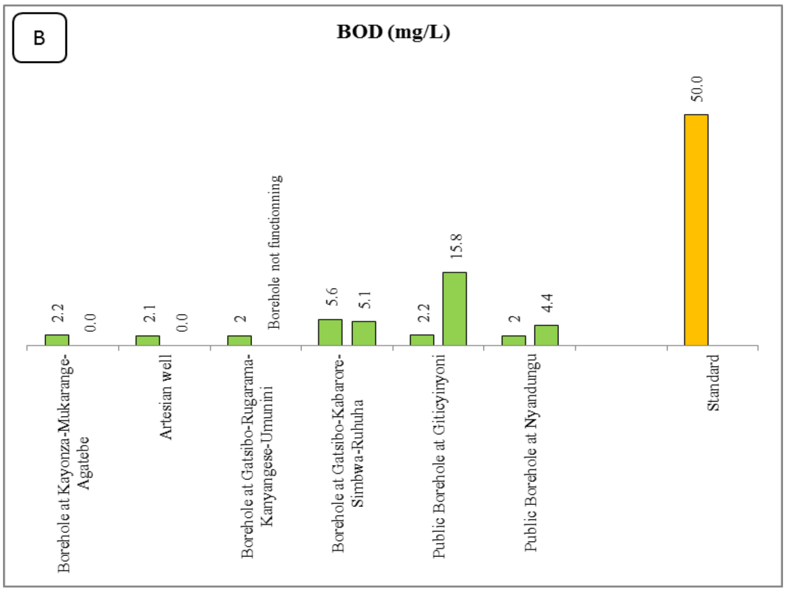


Figure 13: *Variation of Biological Oxygen Demand for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow colour indicates the standard value; the green colour indicates lower BOD values recorded when compared to the standard limit respectively.*

Biochemical Oxygen Demand (BOD) is common measure of water quality that reflects the degree of organic matter pollution of a water body. BOD is a measure of the amount of oxygen removed from aquatic environments by aerobic micro-organisms for their metabolic requirements during the breakdown of organic matter (UNEP, 2006). In low concentration BOD indicates polluted water (http://www.enotes.com/public-health-encyclopedia/biological-oxygen). Systems with high BOD tend to have low dissolved oxygen concentrations. Increased BOD can result in the death of fish and other living aquatics (UNEP, 2006). Unpolluted waters typically have BOD values of 2 mg/L O_2 or less, whereas those receiving wastewaters may have values up to 10 mg/L O_2 or more, particularly near to the point of wastewater discharge.

13. Chloride

Results from this study showed a 100 % compliance of chloride concentrations in all monitoring sites were below the standard limit of 250 mg/l. No significant differences between sites (P > 0.05) were observed when comparing period I to period II (P = 0.231). Recorded concentrations were varying between 1.6 mg/l and 94.6 mg/l as shown in Figure 14.

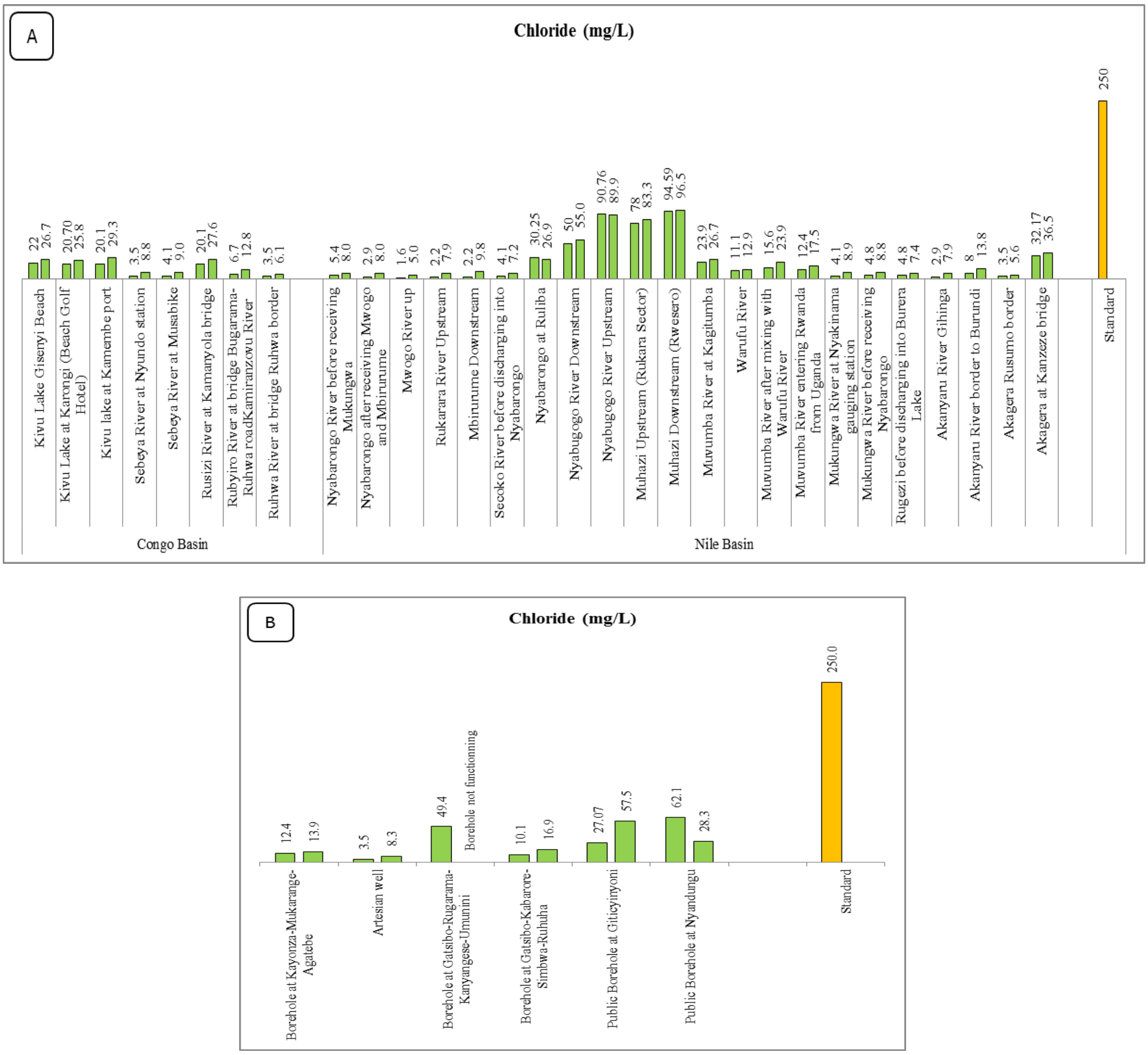
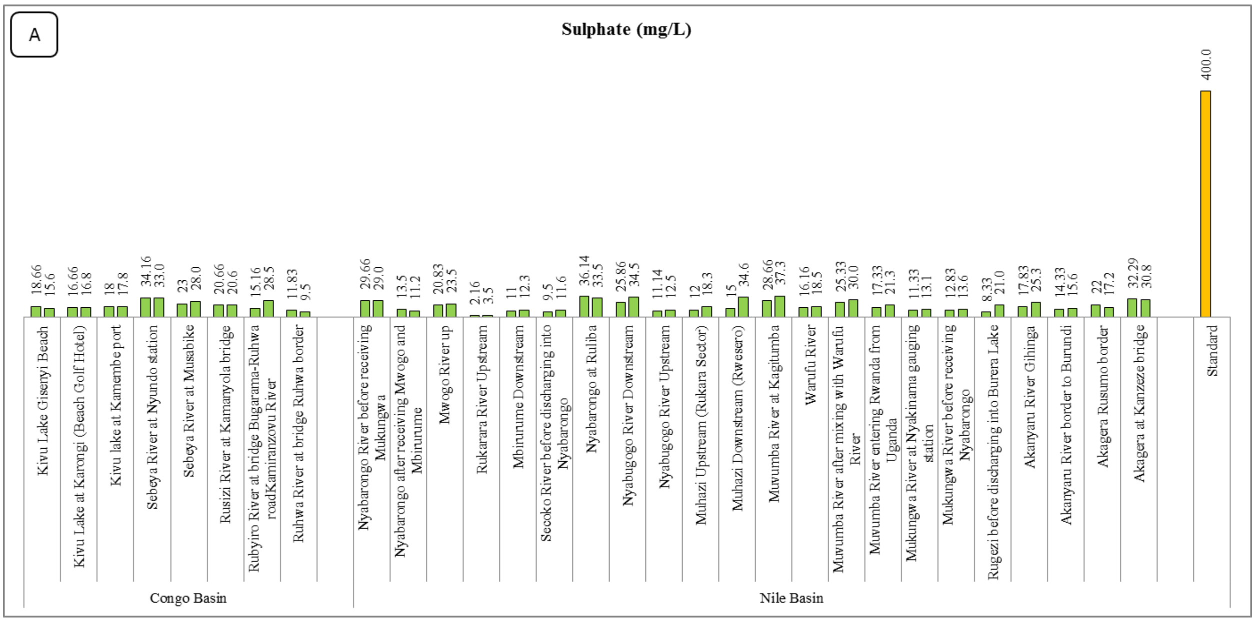


Figure 14: *Variation of chloride concentrations for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow colour indicates the standard value; the green colour indicates lower Cl⁻ values recorded when compared to the standard limit respectively.*

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 of oceanic aerosols, 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 discharges in water bodies.

14. Sulphate

Results from this study showed a 100 % compliance of sulphate concentrations in all monitoring sites were below the standard limit of 400 mg/l. Significant differences between sites ($P < 0.05$) were observed when comparing period I to period II ($P = 0.012$). Recorded concentrations were varying between 2.16 mg/l and 36.14 mg/l as shown in Figure 15.



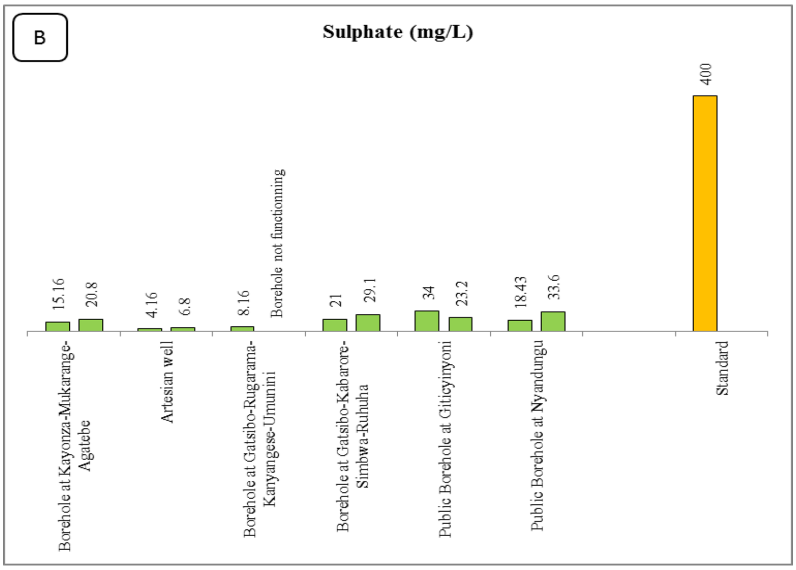
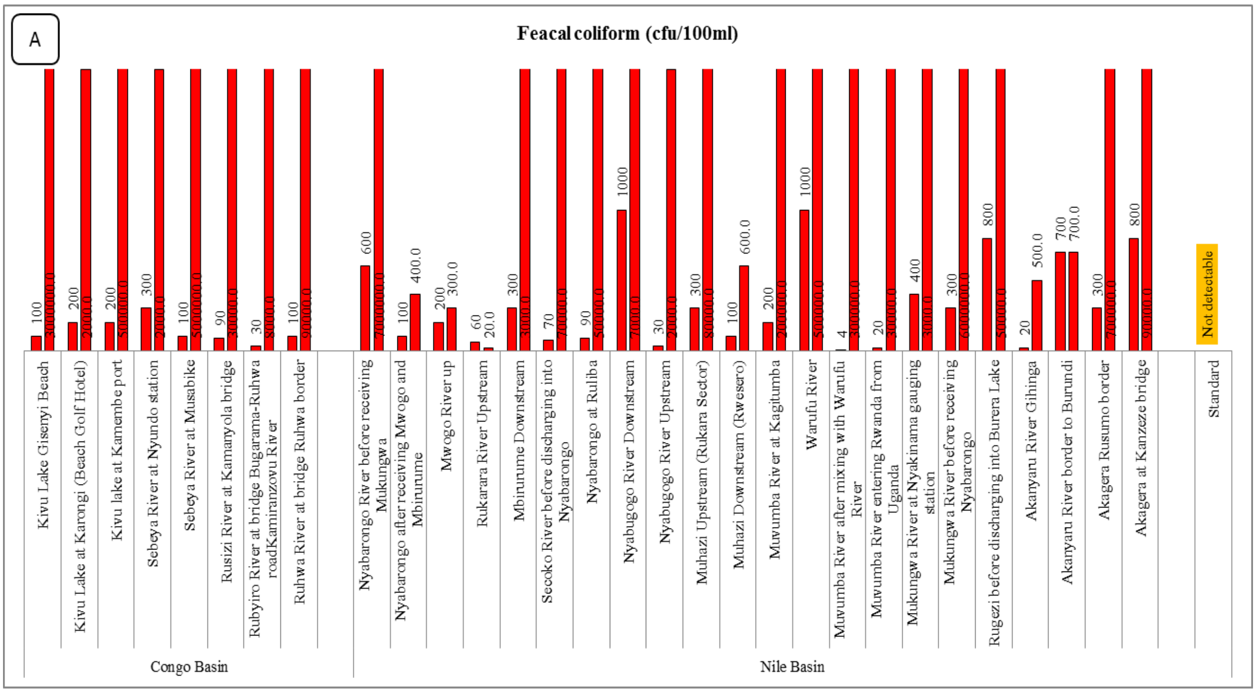


Figure 15: *Variation of sulphate concentrations for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow colour indicates the standard value; the green colour indicates lower SO_4^{2-} values recorded when compared to the standard limit respectively.*

Sulphate is naturally present in surface waters as SO_4^{2-}. It arises from the atmospheric deposition of oceanic aerosols and the leaching of sulphur compounds, either sulphate minerals such as gypsum or sulphide minerals such as pyrite, from sedimentary rocks. It is the stable oxidized form of sulphur and is readily soluble in water (with the exception of lead, barium and strontium sulphates 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 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 1,000 mg/L near industrial discharges or in arid regions where sulphate minerals, such as gypsum, are present. High concentrations (> 400 mg/L) may make water unpleasant to drink.

15. Faecal coliform

Results from this study showed a 97.2 % non-compliance of faecal coliform concentration in water bodies when compared to Rwandan standard limit for natural potable water; requiring this parameter to be no detectable in water. Significant differences between sites ($P < 0.05$) were observed when comparing period I to period II ($P = 0.028$). Recorded concentrations were varying from < 1 to 7000000 CFU / ml as shown in Figure 16.



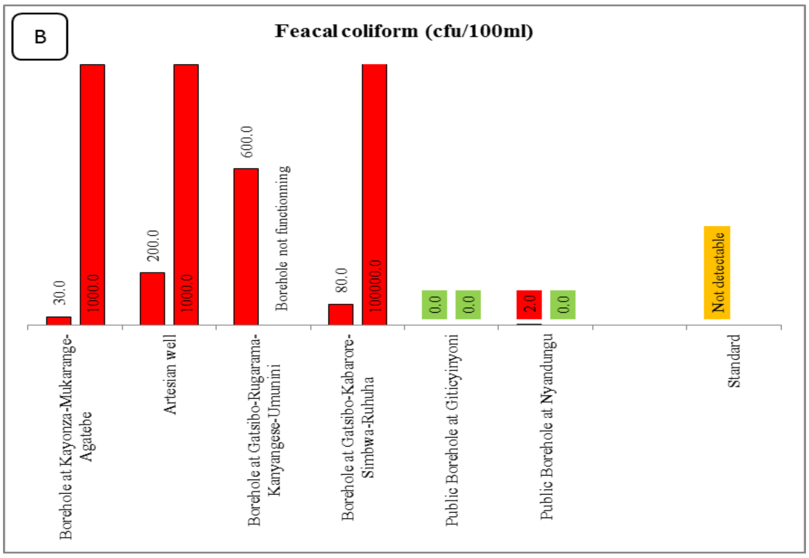


Figure 16: *Variation of faecal coliform for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow color indicates the standard value; the red and green colors indicate the higher and lower faecal coliform values recorded when compared to the standard limit respectively.*

Coliforms come from human and animal wastes (faeces). During rainfalls, snow melts, or other types of precipitation, faecal bacteria may be washed into rivers, streams, lakes, or ground water. When these waters are used as sources of drinking water and the water is not treated or inadequately treated, faecal bacteria may end up in drinking water. Breaks in sewage infrastructure and septic failures also can lead to contamination. A group of bacteria predominantly inhabiting the intestines of man or animals but also found in soil and commonly used as indicators of the possible presence of pathogenic organisms. The presence of coliform bacteria in water is an indicator of possible pollution by faecal material (UNEP, 2006).

16. E-coli

Results from this study showed a 91.6 % non-compliance of Escherichia coli (E.coli) concentration in water bodies when compared to Rwandan standard limit for natural potable water; requiring this parameter to be no detectable in water. Significant differences between sites ($P < 0.05$) were observed when comparing period I to period II ($P = 0.009$). Recorded concentrations were varying from < 1 to 40000 CFU / ml as shown in Figure 17.

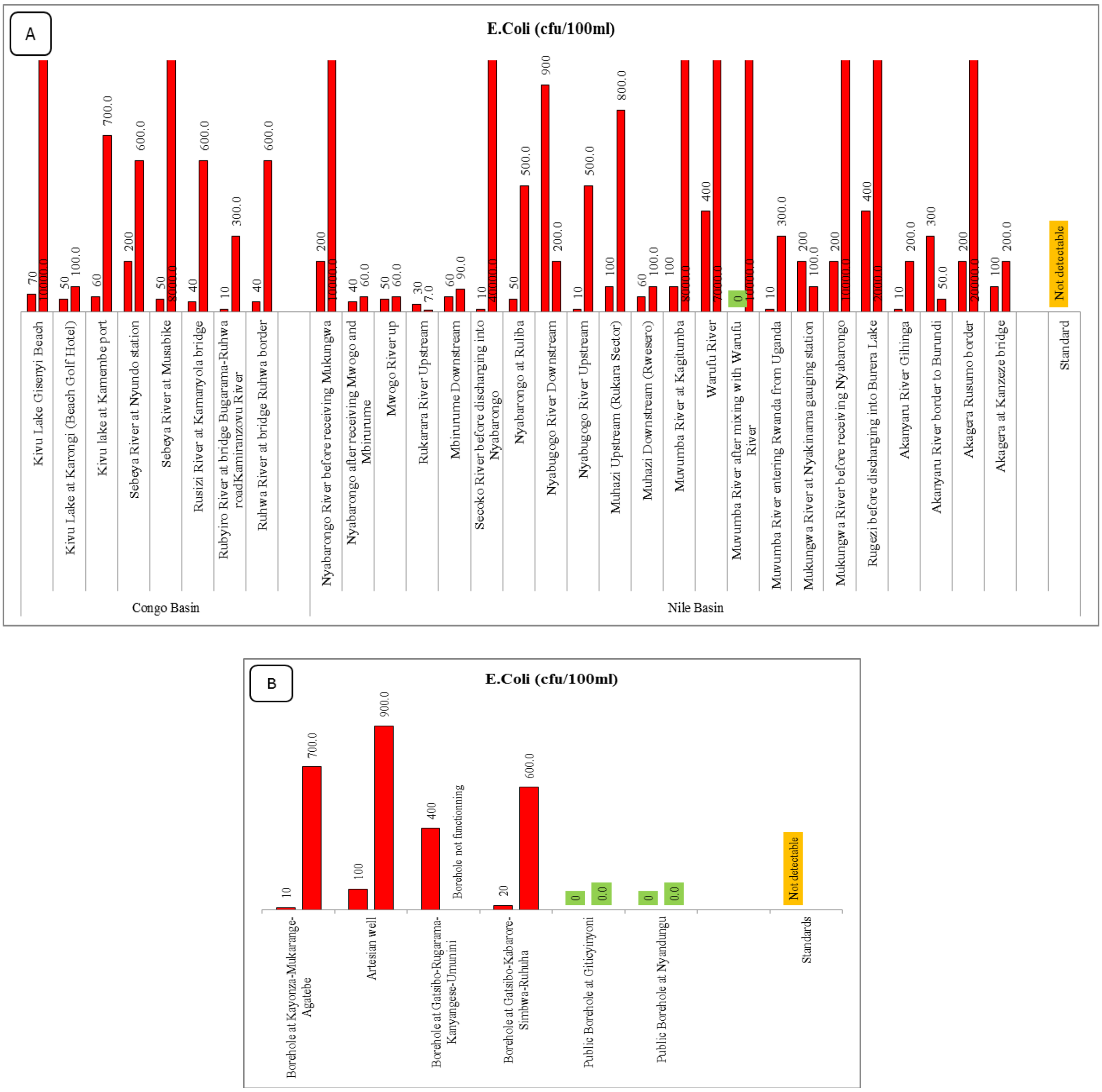


Figure 17: *Variation of E. coli for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow colour indicates the standard value; the red and green colours indicate the higher and lower E. coli values recorded when compared to the standard limit respectively.*

Escherichia coli, commonly called E. coli, is one of the most common species of coliform bacteria. It is a normal component of the large intestines in humans and other warm-blooded animals, and it's found in human sewage in high numbers. E. coli is used as an indicator organism because it is easily cultured, and its presence in water in defined amounts indicates that sewage may be present. If sewage is present in water, pathogenic or disease-causing organisms may also be present and affect consumers by causing diseases such as diarrhoea; typhoid fever even death if not treated (Prescott, 2009).

4. General interpretation of water quality results

From all recorded data on this water quality survey period I, it was observed that among the sixteen (16) monitored parameters, eleven (11) parameters representing 68.75 % in general were below or within the recommended standard limits in all monitoring sites countrywide. These are: Biochemical oxygen demand (BOD), Chloride (Cl^-), dissolved inorganic phosphorus (DIP), dissolved inorganic nitrogen (DIN), electro conductivity (EC), nitrate (NO_3^-), hydrogen potential (pH), total nitrogen (TN), total phosphorus (TP), total dissolve solids (TDS) and sulphate (SO_4^{2-}).

For the remaining five (5) parameters representing 31.25 % were out of the recommended standard limits for few or many of selected monitoring sites. These are: Dissolved oxygen (DO), *Escherichia coli* (*E. coli*), Feacal coliform (FC), Total Suspended Solids (TSS) and Turbidity are almost always out of the acceptable tolerance limits for natural potable water. The trends in turbidity of Rivers were found to be always correlated to the concentration of Total Suspended Solids whereas the concentration in total dissolved solids was always very low, and this meaning that the turbidity of the monitored rivers largely depends on the accumulation of suspended solids. The most turbid rivers were found to be the Akanyaru River border to Burundi, Secoko River before discharging into Nyabarongo, Sebeya River at Musabike, Nyabarongo River before receiving Mukungwa and Akagera at Kanzenze bridge. The concentrations of *E-coli* and Feacal coliform are alarming and high in many of the monitored sites and this is directly linked with poor sanitation practices in both urban and rural areas.

The presence of high values of TSS for Sebeya River are mainly attributed to the Rver catchment facing intensive mining activities. Intensive unsustainable mining activities are being done from its source in Muhanda Sector of Ngororero District and Nyabirasi Sector of Rutsiro District but also downstream in Kanama and Nyundo Sector of Rubavu District.

4.1. Common natural and anthropogenic factors affecting water quality in different catchments

In general, the quality of any surface water is a function of either or both natural influences and human activities. Without human influences, water quality would be determined by the weathering of bedrock minerals, by the atmospheric processes of evapotranspiration and the deposition of dust and salt by wind, by the natural leaching of organic matter and nutrients from soil, by hydrological factors that lead to runoff, and by biological processes within the aquatic environment that can alter the physical and chemical composition of water (UNEP, 2006).

However, the water quality in Rwanda is mainly affected by human induced factors like soil erosion from agriculture and mining activities, lack of wastewater treatment facilities, application of pesticides and fertilizers, etc.

4.2. Erosion and Sedimentation

The increase in population while the cultivated land remains constant has led to extension of agriculture to steeply sloping land areas with shallow soils that require higher standards of management if their resources are to be conserved. Unfortunately, they are poorly utilized by farmers with limited capacity for their sustainable management and this leads to the loss of a large amount of soil from agricultural lands which end up causing the siltation of Rivers (USAID, 2008).

Picture 2: *Erosion and sediment transport in Secoko River (left side picture) and in Sebeya River at Pfunda Tea factory (right side picture) for protecting the factory against stones and soil transport within Sebeya River which have been destroying and flooding the factory compound for years.*

On the other hand, unsustainable mining activities being carried out in most of the catchments are also highly contributing to the siltation of Rivers and this can be illustrated by the high turbidity of Rivers even in the absence of rain which normally conveys soil from agricultural lands into water bodies (MINIRENA, 2011).

Results obtain from sampling period I and II were tested for any correlation between Turbidity and TSS, TDS and Conductivity, Turbidity and E. Coli and finally between DO and BOD. Results obtained showed a strong positive correlation between Turbidity and TSS, TDS and Conductivity as shown on table 5. Correlation is a technique for investigating the relationship between two quantitative, continuous variables. Pearson's correlation coefficient (r) is a ***measure of the strength of the association*** between the two variables. Positive correlation indicates that both variables increase or decrease together, whereas negative correlation indicates that as one variable increases, so the other decreases.

Table 5: Pearson correlation coefficient for some important parameters

Parameters tested	***Pearson's correlation coefficient (r)***	
	Period I	***Period II***
DO & BOD	0.35948	0.23428
TDS & Conductivity	0.99965	0.99959
Turbidity & E. Coli	0.16927	-0.03441
Turbidity & TSS	0.95664	0.99201

4.3. No existing and insufficient wastewater treatment facilities

Although the Government of Rwanda, through the Ministry of Infrastructure and its affiliated Water and Sanitation Corporation Ltd (WASAC) and the City Council of Kigali are undertaking measures to deal with wastewater management in cities, especially in the City of Kigali, in order to improve urban sanitation as well as protecting the environment, the problem of wastewater effluents from different sources like industries, public and private institutions as well as households still remains high for all the cities in the country (Umubyeyi, 2008).

This is aggravated by the fact that the country's cities have been growing fast over the recent years, Kigali City being the leading one followed by secondary cities (Huye, Muhanga, Musanze, Rubavu, Nyagatare and Rusizi). Although the growth of these cities is perceived under different perspectives as a positive development, this urbanization process is likely to cause serious negative impacts on the environment, particularly on water quality of both surface water and groundwater. In fact, the current practice is that hotels, schools and multiple-store buildings are supposed to have their own sewerage systems, but unfortunately in most cases, they discharge untreated wastewater directly into the environment.

Furthermore, the excessive use of septic tanks and soak ways could lead to groundwater contamination and needs to be investigated deeply. Adequate monitoring measures and systems are required for existing treatment facilities to ensure that they comply with safe environmental standards (Nhapi et al., 2011).

The poor sanitation practices mainly resulting in open defecation on hill side is also one bad practice which is impacting on the microbial water quality status countrywide. In order to have this issue well addressed, there is an urgent need for many institutions (MOH, MOE, MININFRA, MINALOC, REMA and RURA) to work hand in hand to improve the country water status. This requires concerted efforts in building ECOSAN toilets where they are not built. Where they do exist, we need to do more awareness campaign among our local population and travelers on their use. For existing toilet built in wetlands, we have to relocate them elsewhere. For farmers, we need to train them on making good compost after allowing it sufficient time for complete decomposition. This will allow complete destruction of pathogenic microorganisms. It is also advised to REMA and RURA to conduct regularly compliance monitoring of wastewater as control and preventive tool.

The above mentioned negative impacts by the effluents of different institutions were confirmed by many research initiatives that were conducted in Rivers receiving these influents like the Nyabugogo River, and the parameters that exceeded the standards included heavy metals (Sekomo et al., 2011), such as BOD_5, COD, TN, TP, pH and E-coli (Nhapi et al., 2011).

Measurements of DO and BOD in all water bodies have provided important information on the status of monitored water bodies. Normally DO measurement shows the water status mainly looking at the aquatic life maintenance and the self-purification capacity of the water body. Therefore, the higher DO content generally recorded in all water streams is good for the aquatic life as well as for the self-purification capacity of water streams. Regarding the BOD content, it is placing generally all water streams in the category of ***"Poor: Somewhat Polluted"*** which is usually indicating that organic matter is present and bacteria are decomposing this waste. In general recorded values for DO and BOD are correlating as we have higher DO values. A low correlation values were calculated for the present set of data see table 5. Normally in water phase, DO and BOD are two parameters which varies in the opposite direction one to another. When the DO increases, the BOD decreases.

4.4. Application of chemical fertilizers and pesticides

Although the application of fertilizers and pesticides is very important for agricultural production, their inadequate application, for example applying them to a land which is exposed to soil erosion, can be a serious threat to the water quality, especially by causing the accumulation of nutrients in water bodies which result in their euthrophication. The major risk associated with the eutrophication of water bodies is a depletion of dissolved oxygen in the water which however is indispensable for the life of aquatic organisms (REMA, 2014).

4.5. Rainfall

The Rwandan rainfall pattern is bi-seasonal having two rainy periods, the first from March to May and the less intense, second wet season from mid-September or early October through December.

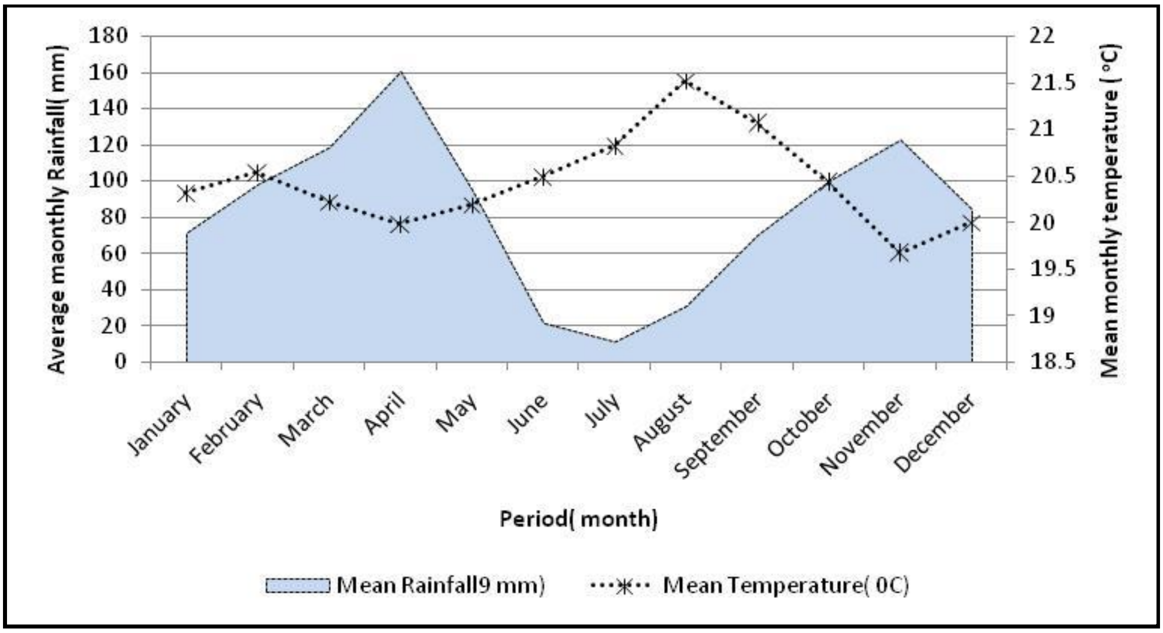


Figure 18: *Annual distribution of rainfall (Source MINIRENA, 2013)*

More specifically, the country experiences four "seasons" annually:

❖ A short dry season, mid-December to February: characterized by occasional light rainfall. This period can vary from dry to moderately wet with the rainfall accounting for 18 % of the annual total.

❖ A long rainy season from March to May: This is the wettest season of the year delivering 40 % of the annual rainfall. This season usually ends around mid-May.

❖ A long dry season from June to mid - September: This season is characterized by little to no rainfall, particularly in highlands. The rain that is received accounts for less than 12 % of annual total. Usually this period often begins in mid-May.

❖ A short rainy season from mid - September to mid- December: This season is characterized by 30 % of the annual rainfall.

The analysis conducted in some rivers of the country showed a strong correlation between the rainfall distribution and certain physical parameters of water quality.

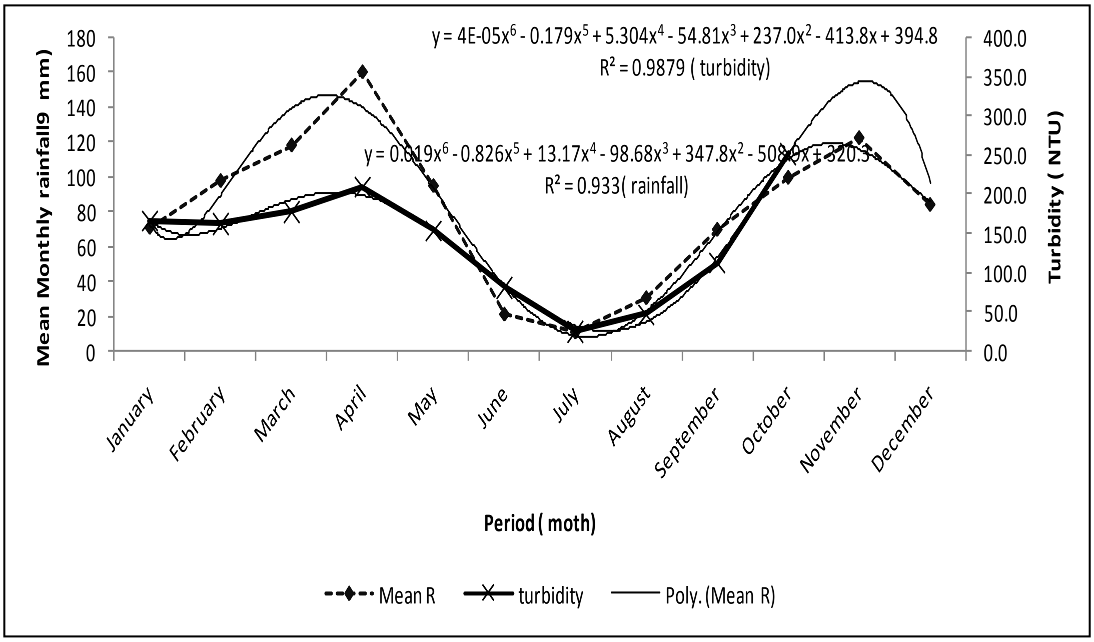
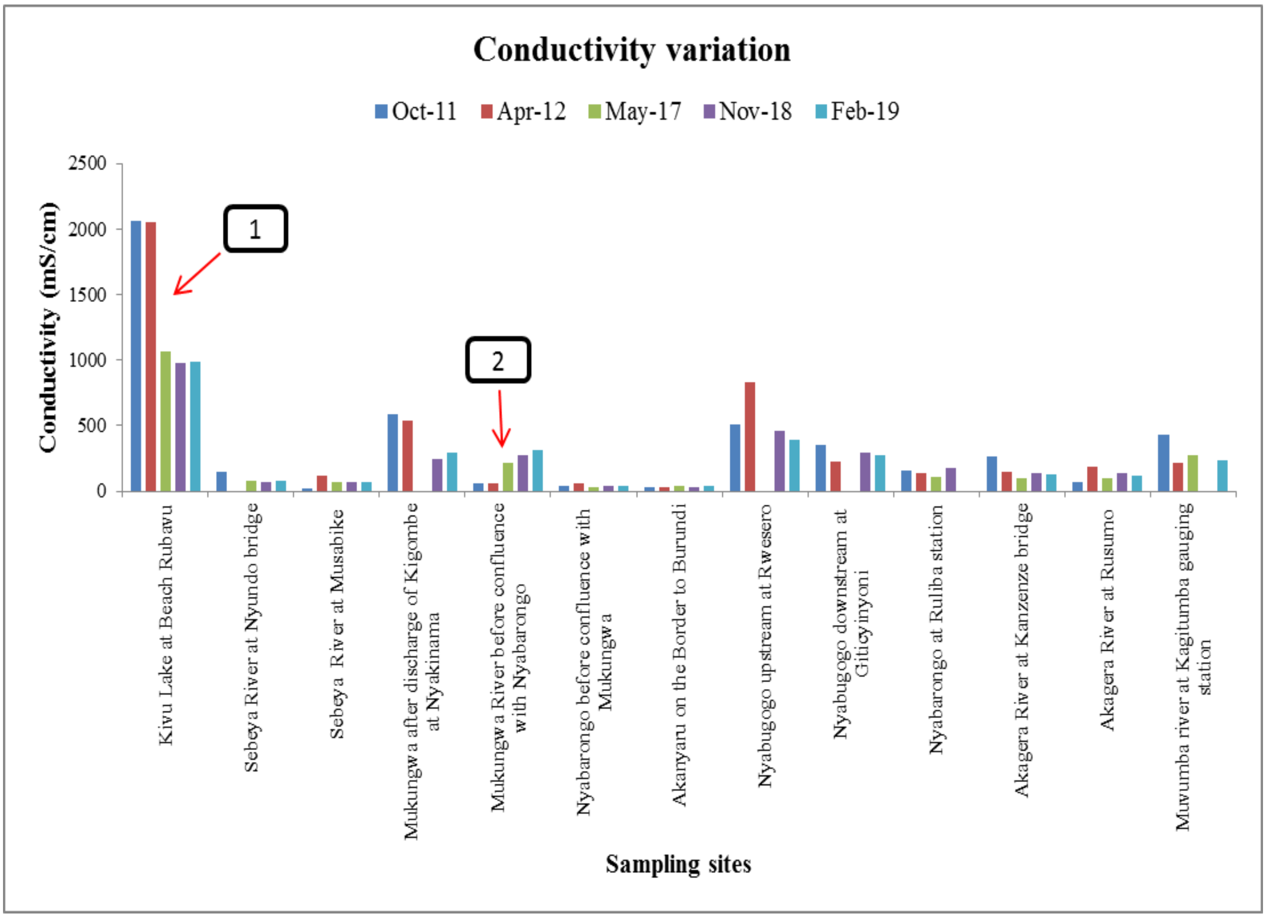


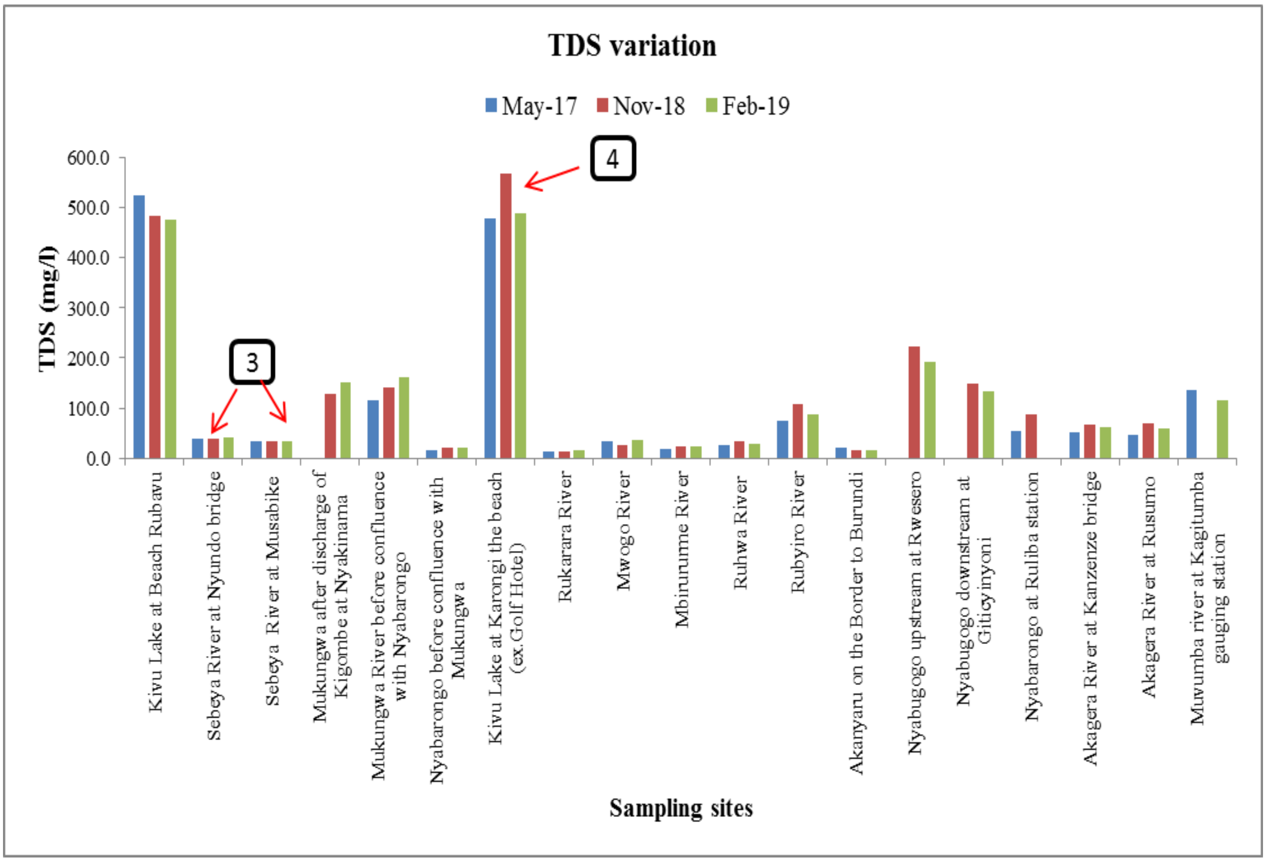
Figure 19: *Relationship between Rainfall and turbidity of Yanze river (Source: MINIRENA, 2012)*

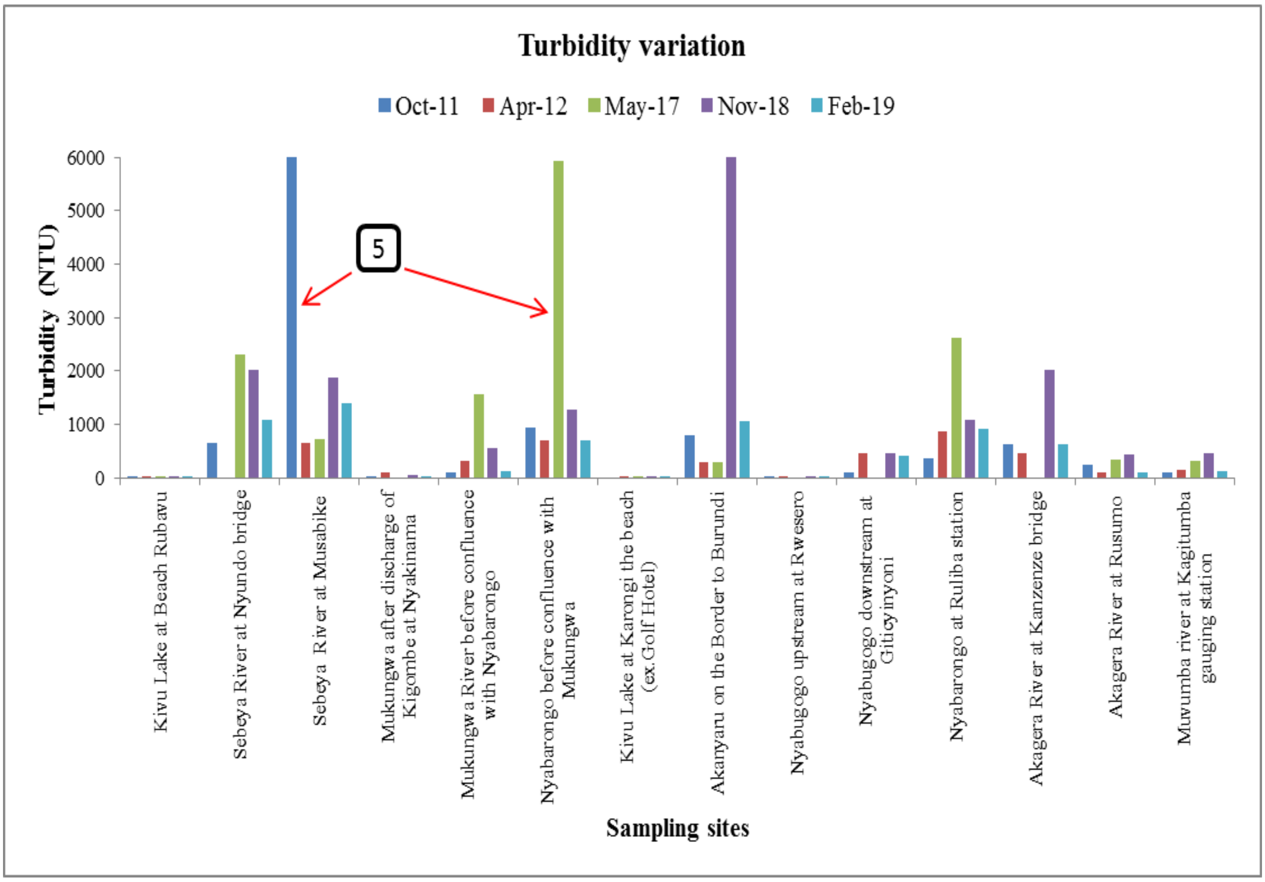
One of the examples is the Yanze River, with influents of Nyabarongo River, for which the analysis showed a similar trend between intra-annual variation of rainfall and intra-annual variation of turbidity.

4.6. Variation of some parameters over years (Trend analysis)

Water quality of a given water bady is mainly affected by activities around the water stream and the season variation. In this report we have been interested in looking at the trend that some parameters of interest would be when comparing data which have been collected for a period of five years as shown in the brackets (2011, 2012, 2017, 2018 and 2019). The trend analysis has been conducted for very sensitive parameters like Turbidity and not very sensitive parameters like Conductivity and TDS. Combined data for a maximum of five years have shown five differents trends: 1. Decreasing trend, 2. Increasing trend, 3. Linear trend, 4. Combined increase decreasing trend and 5. Polynomial trend (see Figure below on Conductivity, TDS and Turbidity variations). Observed trends can be used as a tool for evaluation of impact that earlier watershed and hillside protection activities are showing in the improvement or degradation of water quality at a catchment or basin level.




TDS variation
May-17
Nov-18
Feb-19
TDS (mg/l)
600.0
500.0
400.0
300.0
200.0
100.0
0.0
3
4
Kivu Lake at Beach Rubavu
Sebeya River at Nyundo bridge
Sebeya River at Musabike
Mukungwa after discharge of Kigombe at Nyakinama
Mukungwa River before confluence with Nyabarongo
Nyabarongo before confluence with Mukungwa
Kivu Lake at Karongi the beach (ex.Golf Hotel)
Rukarara River
Mwogo River
Mbirurume River
Ruhwa River
Rubyiro River
Akanyaru on the Border to Burundi
Nyabugogo upstream at Rwesero
Nyabugogo downstream at Giticyinyoni
Nyabarongo at Ruliba station
Akagera River at Kanzenze bridge
Akagera River at Rusumo
Muvumba river at Kagitumba gauging station
Sampling sites


Turbidity variation
Oct-11
Apr-12
May-17
Nov-18
Feb-19
Turbidity (NTU)
6000
5000
4000
3000
2000
1000
0
5
Kivu Lake at Beach Rubavu
Sebeya River at Nyundo bridge
Sebeya River at Musabike
Mukungwa after discharge of Kigombe at Nyakinama
Mukungwa River before confluence with Nyabarongo
Nyabarongo before confluence with Mukungwa
Kivu Lake at Karongi the beach (ex.Golf Hotel)
Akanyaru on the Border to Burundi
Nyabugogo upstream at Rwesero
Nyabugogo downstream at Giticyinyoni
Nyabarongo at Ruliba station
Akagera River at Kanzenze bridge
Akagera River at Rusumo
Muvumba river at Kagitumba gauging station
Sampling sites

4.7. Relationship between the country's topography and water quality

Rwanda is known as "the land of a thousand hills". This mountainous topography is generally characterized by areas with steep slopes. The analysis of country slopes conducted by IWRM in 2013 revealed that more than 50 % of the country has slopes ranging between 15 - 40 % as shown by the Figure 22.

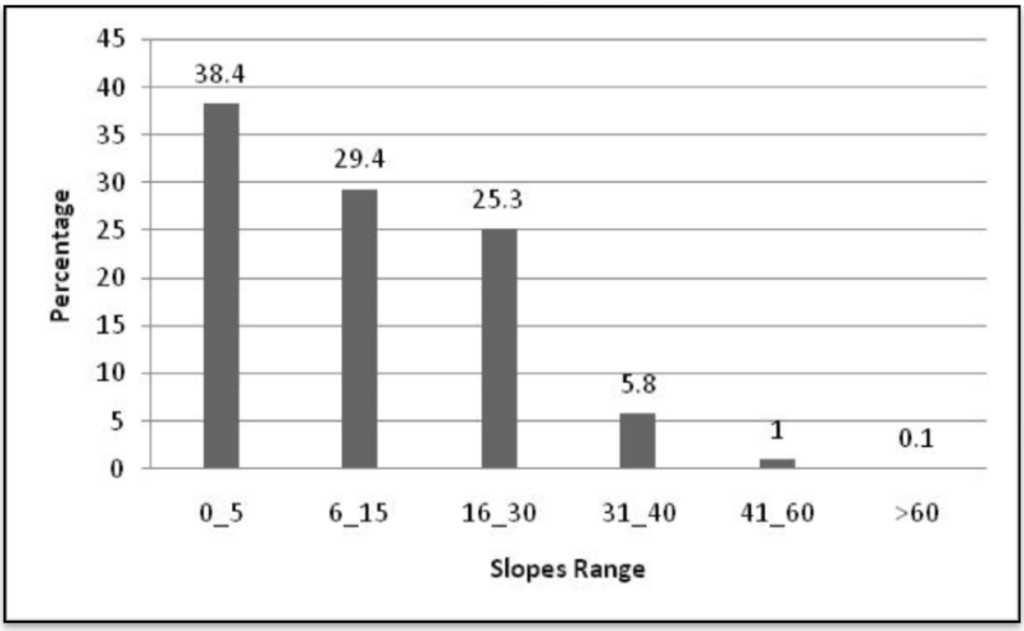


Figure 20: *Slope distribution on Rwandan territory (Source: Watershed Rehabilitation guidelines, 2013)*

This topography makes the runoff a major water quality issue across different catchments of the country. With this topography, rainwater drains into a body of water by first passing over several landmarks. This adversely affects water quality by carrying sediments, nutrients and heavy metals from uplands.

4.8. Contribution of the results to the monitoring of SDG indicator 6.3.2 "Proportion of bodies of water with good ambient water quality"

The indicator is defined as the proportion of all water bodies in the country that have good ambient water quality. Ambient water quality refers to natural, untreated water in rivers, lakes and ground water, and represents a combination of natural influences together with the impacts of anthropogenic activities. The elements that should be regularly reported include:

- Number of open water bodies, number of river water bodies,
- Number of open water bodies with good quality,

- Number of river water bodies with good quality,
- Number of open water body monitoring locations,
- Number of open water body monitoring values.

While the core physico-chemical and nutrient parameters to be monitored for open water bodies are total Oxidized Nitrogen (TON) which is a combined measure of both nitrate and nitrite and which are forms of dissolved inorganic oxidized nitrogen, Orthophosphate (OP) , pH , Electrical conductivity (EC) and Dissolved oxygen (DO).

During this study, a total of 36 monitoring sites were investigated countrywide. 30 sites were open water bodies (rivers and lakes) and 6 sites were groundwater bodies. In many cases monitoring sites were selected applying the upstream to downstream approach. These sites were located geographically in their respective level one catchment.

Furthermore, the water quality monitoring results were generated for each of the sites and all core parameters for open water bodies recommended for SDG 6.3.2 indicator were included as part of the applied water quality monitoring parameters.

The obtained data were compared to the standards for Natural potable water (FDEAS 12:2018) which in this case represent the target values. Table 6 summarizes the percentage of compliance for each site, percentage of compliance for sampled water bodies, and the status of the water quality (good or not good according to the SDGs) for all parameters and core parameters respectively.

Method of calculating compliance with standard values of key parameters:

Considering that it is recommended to only use data for a minimum period of three consecutive years for the calculation of the indicator normally, to ensure that the results are up-to-date and globally comparable, generated data were used for illustrative reason on how to calculate the indicator.

As recommended under SDGs, as a first step, the percentage of compliance per site (C) was calculated.

$$C = \left(\frac{n_{comply}}{n_{measure}} \right) \times 100$$

Whereby:

n_{comply}: the number of monitoring values in compliance with the target values

$n_{measure}$: the total number of monitoring values.

The site with the percentage of compliance greater or equal to 80 % compliance was classified as a site with “good” quality as indicated by the SDGs. Thus, a body of water was classified as being of good quality if at least 80 % of all monitoring data from all monitoring sites within the water body are in compliance with the respective targets. In the next step, the indicator was expressed as the percentage of water bodies with “good” water quality in two ways: (a) by considering only core parameters, and (b) by considering all parameters included in this study.

By considering only core parameters recommended by SDGs, 17 water bodies out of 20 included in this study, had a degree of compliance above 80 %, and therefore the formula for calculating the value of indicator 6.3.2 indicator is:

$$\left(\frac{n_g}{n_t}\right) \times 100 = \left(\frac{17}{20}\right) \times 100 = 85\%$$

This gave a compliance degree of 85 % of all water bodies in Rwanda having good ambient water quality. However, by considering all parameters, only 8 water bodies reach a compliance factor above 80:

$$\left(\frac{n_g}{n_t}\right) \times 100 = \left(\frac{8}{20}\right) \times 100 = 40\%$$

Where:

- n_g: number of water bodies with ambient good water quality
- n_t: total number of sampled water bodies

On this basis of calculation, the proportion of water bodies with good ambient water quality of all water bodies in Rwanda reaches only 40 %.

By taking into account the five core parameters and additional three parameters (Turbidity, TSS & *E.coli)* which are alarming for the case of Rwanda the percentage of water body with ambient water quality will be 18.75% for all sixteen water bodies that had been considered during both phase of monitoring.

Table 6: Water quality results by key water body and their compliance with the target value

(Note highlighted cells in green indicate that the target is met and cells in red indicate that the target is not met)

Parameters	Kivu Lake Gisenyi Beach	Kivu Lake at Karongi (Beach Golf Hotel)	Kivu lake at Kamembe port	Sebeya River at Nyundo station	Sebeya River at Musabike	Rusizi River at Kamanyola bridge	Rubyiro River at bridge Bugarama-Ruhwa roadKamiranzovu River	Ruhwa River at bridge Ruhwa border	Nyabarongo River before receiving Mukungwa	Nyabarongo after receiving Mwogo and Mbirurume	Mwogo River up	Rukarara River Upstream	Mbirurume Downstream	Secoko River before discharging into Nyabarongo	Nyabarongo at Ruliba	Nyabugogo River Downstream	Nyabugogo River Upstream	Muhazi Upstream	Muhazi Downstream	Muvumba River at Kagitumba	Warufu River	Muvumba River after mixing with Warufu River	Muvumba River entering Rwanda from Uganda	Mukungwa River at Nyakinama gauging station	Mukungwa River before receiving Nyabarongo	Rugezi before discharging into Burera Lake	Akanyaru River Gihinga	Akanyaru River border to Burundi	Akagera Rusumo border	Akagera at Kanzeze bridge		Borehole at Kayonza-Mukarange-Agatebe	Artesian well	Borehole at Gatsibo-Rugarama-Kanyangese-Umunini	Borehole at Gatsibo-Kabarore-Simbwa-Ruhuha	Public Borehole at Giticyinyoni	Public Borehole at Nyandungu	Standards
Conductivity (µS/cm)																																						2500
DIN (mg/l)																																						30
DIP (mg/l)																																						5
DO (%)																																						68
pH (-)																																						5.5 - 9.5
Compliance to SDG 6.3.2 (%)	100	100	100	100	100	100	100	100	100	100	100	100	80	100	100	100	100	100	100	100	100	100	100	100	100	100	100	80	80	100		80	80	80	80	80	80	
Turbidity (NTU)																																						25
Total Dissolved Solids (mg/l)																																						1500
Total Suspended Solids (mg/l)																																						50
Nitrate (mg/l)																																						20
Total Nitrogen (mg/l)																																						30
Total Phosphorus (mg/l)																																						5
BOD (mg/l)																																						50
Chloride (mg/l)																																						250
Sulfate (mg/l)																																						400
Faecal Coliforms (Cfu/100ml)																																						Not detectable
E.Coli (Cfu/100ml)																																						Not detectable
Compliance to all parameters (%)	87.5	87.5	87.5	75	75	81.3	75	75	75	75	75	81.3	68.8	75	75	75	87.5	87.5	87.5	75	75	75	75	81.3	75	87.5	75	68.8	68.8	75		81.3	81.3	81.3	81.3	93.8	87.5	

Table 7: % main water body with ambient water quality by considering core and alarming parameters for case of Rwanda

Name of water body	DO		Conductivity		TSS		Turbidity		PH		DIP		DIN		E.Coli		Compliance with target value for all parameter 0%		
	P.I	P.II	P.I	P.II	P.I	P.II	P.I	P.II	P.I	P.II	P.I	P.II	P.I	P.II	P.I	P.II	% compliance by site	%compliance by water body	Water body classificati
National targets	68%		2500µs/sm		30mg/l		150mg/l		5.5-9.5		5mg/l		30mg/l		4cfu/100ml				
Ruhwa	93.4	99.5	65.2	56.4	275	213	557.5	399	7.29	7.14	1.33	1.4	3.37	4.85	40	600	62.5	62.5	0
Rubyiro	88.4	92.2	221	183.1	217	131	357.5	250	7.45	7.33	0.58	0.57	3.11	4.22	10	300	62.5	62.5	0
Rusizi	95.8	97.6	1112	932	18	22	27.8	61	9.11	8.95	0.37	0.38	3.14	3.63	40	600	87.5	87.5	1
Sebeya	97.2	100	64.8	66.8	854	605	1865	1390	7.04	7.03	0.44	0.48	3.35	5.47	50	8000	62.5	62.5	0
	95.2	102.6	72.2	76	1017	480	2015	1080	7.4	7.48	0.38	0.39	4.71	5.73	200	600	62.5		
Kivu	111.4	119.6	973	985	1	1	2.27	6.17	9.22	9.09	0.84	0.96	2.55	3	70	10000	87.5	88.9	1
	97.6	103.7	1158	1030	8	1	2.6	3.87	9.04	8.92	0.62	0.69	3.23	3.24	50	100	87.5		
	97.4	99.4	1123	984	<1	1	2.8	3.2	9.4	9.02	0.83	0.84	3.09	3.78	60	700	87.5		
Mwogo	60.3	56.7	55.1	73.4	275	40	416	105	6.83	6.96	0.68	0.67	3.01	3.53	50	60	56.25	71.87	0
	99.2	102.1	24.5	31.3	9	16	22.8	48.3	7.16	7.46	0.68	0.67	3.12	3.85	30	7	87.5		
Mbirururme	98.3	97	47.4	51.1	103	57	191	120	7.19	7.35	0.41	0.38	3.86	5.11	60	90	68.75	68.75	0
Nyabarongo upper	94.5	93.2	43.6	52.4	183	78	353	176	7.17	7.31	0.85	0.8	3.65	5.14	40	60	62.5	62.5	0
	92.1	98.1	41.1	43.8	744	265	1267	690	7.65	7.43	0.44	0.49	3.66	5.31	200	10000	62.5		
	89.3	97.1	33.3	39.3	1617	417	1820	920	7.2	6.75	2.69	2.17	6.8	6.13	10	40000	62.5		
Mukungwa	50.2	41.3	32.8	30	10	8	21.4	15.9	5.92	6.29	0.15	0.16	3.35	5.4	400	2000	75	77.08	0
	95.7	91.3	248	293	22	12	50.8	22.5	8.13	8.58	0.2	0.28	2.22	2.84	200	100	87.5		
	98.8	101.6	270	315	344	54	546	131	8.17	8.39	0.34	0.39	3.56	4.53	200	10000	68.75		
Nyabarongo valley	90.5	96.9	174.1	142.2	662	321	1080	921	7.93	7.86	0.59	0.62	4.15	4.2	50	500	62.5	62.5	0
Muhazi	89.3	104.3	527	473	4	2	1.93	5.9	8.57	8.65	0.44	0.45	3.34	4.52	100	800	87.5	87.5	1
	101.4	77.4	490	416	13	4	6.9	12.8	8.5	7.93	1.68	1.78	4.11	4.15	20	100	87.5		
Nyabugogo	78.2	77.5	457	390	4	6	4	28.1	7.52	7.47	1.34	1.36	3.38	3.7	10	500	87.5	75	0
	81.8	81.6	297	271	314	168	464	405	8.17	7.78	0.61	0.67	4.78	4.69	900	200	62.5		
Akagera	58.8	78.3	138.7	124.7	1010	241	2010	633	7.38	7.05	0.89	0.99	3.48	4.11	100	200	56.25	53.12	0
	38.9	18	137	121.8	256	52	424	96.8	7.72	6.54	0.75	0.67	3.17	3.08	200	20000	50		
Akanyaru upper	99.1	101.9	28.4	34.9	3625	389	11600	1055	6.77	7.5	1.47	1.48	3.59	4.4	300	5	62.5	62.5	0
Akanyaru lower	86.4	39.2	66.8	84.2	255	165	429	405	6.89	6.88	1.33	1.22	4.36	5.14	10	200	56.25	56.25	
Muvumba	91.6	97.5	153.3	132.1	320	79	544	175	7.44	7.26	0.58	0.58	4.36	4.49	10	300	62.5	60.9	0
	88.5	90.7	199.6	192.1	318	68	505	148	7.2	6.97	0.15	0.6	3.36	3.8	10	10000	62.5		
	85.3	99.5	279	238	303	59	460	120	7.83	7.37	0.59	0.63	3.35	3.73	100	8000	62.5		
	92.4	66.5	111.6	91.6	315	32	547	81	7.39	6.85	0.51	0.57	3.69	4.12	400	7000	56.25		

6. Conclusions and Recommendation

The aim of this study was to generate data that will contribute to monitoring and reporting on surface water quality in Rwanda. The study was conducted on 36 sampling on country main water bodies in catchment level two. These sampling sites were identified by use of their respective locations using geo-reference system (GPS). Obtained data were compared with standards values. The findings from this study reveal that some water quality parameters seem to be generally within the acceptable range countrywide like the dissolved inorganic nitrogen (DIN), Dissolved oxygen (DO), dissolved inorganic phosphorus (DIP), Electro conductivity (EC), Hydrogen potential (pH), Nitrate (NO_3^-), Total phosphorus (TP), Total nitrogen (TN), Chloride (Cl^-), Sulphate (SO_4^{2-}) and TDS.

However, other parameters like Faecal coliform (F.C), *Escherichia coli (E. coli)* a sharp increase was observed in dry season mainly explain the concentration effect of those parameters in water phase. For total Suspended Solids (TSS) and Turbidity are almost always out of the acceptable range for natural potable water. For these three parameters, sharp decreases were observed which could be explained by the non-existence of soil erosion and surface runoff water during dry season. From the above observations, it appears that lack of adequate sanitation is a very big issue in most parts of the catchments and this being the case for both urban and rural areas. Therefore, the best approach to deal with this issue in urban areas could be through improved wastewater treatment technology and management, whereas for rural areas the most appropriate approach could be through on-site sanitation systems coupled with education, sensitization and behaviour change campaigns on improved sanitation practices

The trends in turbidity of rivers were found to be always correlated to the concentration of Total Suspended Solids (TSS) whereas the concentration in total dissolved solids was always very low. The most turbid rivers were found to be the Akanyaru border to Burundi, Secoko and Sebeya Rivers. The presence of high values of the total suspended solids for Akanyaru border to Burundi, Secoko and Sebeya Rivers are attributed to the fact that these Rivers catchments are facing intensive agricultural activities and erosion this is the case of Akanyaru and Secoko Rivers. For Sebeya River, intensive unsustainable mining activities are being done from its source in

Muhanda Sector of Ngororero District and Nyabirasi Sector of Rutsiro District but also downstream in Kanama and Nyundo Sector of Rubavu District.

As fecal contamination has been shown as a serious issue in all monitored sites, we are recommending a study countrywide in order to investigate about the use of feceas as manure and on the standars of its composting as one way of controling and decreasing any microbial pollution coming that side.

As the standard we have used to discuss these results were the one for natural potable water, we are recommending to Rwanda Water and Forestry Authority (RWFA) to request to Rwanda Standard Board (RSB) to start the process of elaborating Rwandan standard for surface water which will be more appropriate to discuss this kind results.

For future monitoring campaign, it can be recommended to incorporate biological monitoring into the monitoring network because it is quick and cheap. However, a suitable expert needs to be identified in order to train WRM department staff about the use of net for biological monitoring.

The set of parameters analysed in this report were general. For future studies we recommend RWFA to extend the list to other parameters like heavy metals, pesticides, endocrines… However, this should be done at specific sites like industrial for heavy metals, pesticides for irrigated and large cultivation area, and endocrines for cities because these parameters are case specific and do not occur everywhere. Table 6 is showing sectors of activities and parameters to be monitored.

Table 8: Classification of key parameters to be monitored by sector of activity

Types of activities	Parameters to be analysed
Chemical industries	COD, organic chemicals, heavy metals, TSS, and cyanide
Food and beverage industries	Microbes (*E-coli*, coliforms)
Hospitals and pharmaceutical industry	pH, BOD, Heavy metal, endocrines
Learning institutions, Hotel and prisons	pH, BOD, oil, TN, TP, microorganisms
Mining	pH, EC, TSS, metals, acids and salts
Paper	pH, BOD, COD, solids, Chlorinated organic compounds
Roofing	Fe, Heavy metal, BOD, COD
Steel and Iron industries	BOD, COD, oil, metals, acids, phenols, and cyanide

Types of activities	Parameters to be analysed
Textile and clothes industries	BOD, solids, sulfates and chromium
Irrigated area	Pesticides, TN, TP, pH

As many water quality studies have been conducted in the past even in the future, we are recommending that an initiative can be taken by RWFA to ensure data sharing among all concern state institutions involved in such activities of water quality monitoring depending on their level of intervention.

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Annex 1. Potable water – Specification – maximum permissible limits (FDEAS 12: 2018)

Table 1 — Physico-chemical requirements for potable water

Sl. No.	Parameter	Limit		Test method
		Treated potable water	Natural potable water	
a)	Colour, TCU[a], max.	15	50	ISO 7887
b)	Turbidity, NTU, max.	5	25	ISO 7027
c)	pH	6.5 – 8.5	5.5 - 9.5	ISO 10523
d)	Conductivity, µS/cm, max.	1500	2500	ISO 7888
e)	Suspended matter, mg/l	Not detectable	Not detectable	ISO 11923
f)	Total dissolved solids, mg/l, max.	1000	1500	ASTM D 5907-13
g)	Total hardness, as $CaCO_3$, mg/l, max.	300	600	ISO 6059
h)	Aluminium, (Al), mg/l, max.	0.2	0.2	ISO 12020
i)	Chloride, (Cl), mg/l, max.	250	250	ISO 9297
j)	Total Iron (Fe), mg/l, max.	0.3	0.3	ISO 6332
k)	Sodium, (Na), mg/l, max.	200	200	ISO 9964
l)	Sulphate (SO_4), mg/l, max.	400	400	ISO 10304-1
m)	Zinc (Zn), mg/l, max.	5	5	ISO 8288
n)	Magnesium, (Mg), mg/l, max.	100	100	ISO 7980
o)	Calcium, (Ca), mg/l, max.	150	150	ISO 7980
p)	Potassium (K), mg/l, max.	50	50	ISO 9964

[a] True colour units (TCU) mean hazen units after filtration.

Table 2 — Limits for inorganic substances in natural and treated potable water

Sl. No.	Contaminant	Maximum limit mg/l		Test method
		Treated potable water	Natural potable water	
a)	Arsenic (As)	0.01	0.01	ISO 11969
b)	Cadmium (Cd)	0.003	0.003	ISO 5961
c)	Lead (Pb)	0.01	0.01	ISO 8288
d)	Copper (Cu)	1.000	1.000	ISO 8288
e)	Mercury (Hg)	0.001	0.001	ISO 12846
f)	Manganese (Mn)	0.1	0.1	ISO 6333
g)	Selenium (Se)	0.01	0.01	ISO 9965
h)	Ammonia (NH_3)	0.5	0.5	ISO 11732
i)	Total Chromium (Cr)	0.05	0.05	ISO 9174
j)	Nickel (Ni)	0.02	0.02	ISO 8288
k)	Cyanide (CN)	0.01	0.01	ISO 6703
l)	Barium (Ba)	0.7	0.7	ISO 14911
m)	Nitrate (NO_3^-)	45	45	ISO 7890
n)	Boron (Boric acid)	2.4	2.4	ISO 9390
o)	Fluoride (F)	1.5	1.5	ISO 10359
p)	Bromate (BrO_3)	0.01	0.01	ISO 15061
q)	Nitrite (NO^-_2-N)	0.9	0.9	ISO 6777
r)	Molybdenum (Mo)	0.07	0.07	ISO 11885
s)	Phosphates (PO_4^{3-})	2.2	2.2	ISO 15681
t)	Free residual Chlorine	0.2 - 0.5 [a]	Absent	ISO 7393
u)	Uranium	0.03	0.03	ASTM D 6239-9

[a] Under conditions of epidemic diseases, it may be necessary to increase the residual chlorine temporarily.

Annex 2. Discharged standards for industrial effluents into water bodies- maximum permissible limits (EAS, 2012)

	Parameter	Permissible limits
1	Temperature increase (°C)	<3
2	Total suspended solids (mg/l)	50.0
3	Total Dissolved Solids (mg/l)	2000.0
4	Oil and grease (mg/l)	10.0
5	BOD_5 (mg/l) (20°C)	50.0
6	COD (mg/l)	250.0
7	Faecal Coliforms (MPN/100ml)	400
8	Ammonia (as N) (mg/l)	20.0
9	Arsenic (mg/l)	0.01
10	Benzine (mg/l)	0.1
11	Cadmium (mg/l)	0.01
12	Hexavalent Chromium (mg/l)	0.05
13	Copper (mg/l)	3.0
14	Cyanide (mg/l)	0.1
15	Iron (mg/l)	3.5
16	Lead (mg/l)	0.1
17	Mercury (mg/l)	0.0002
18	Nickel (mg/l)	3.0
19	Phenol (mg/l)	0.2
20	Sulphide (mg/l)	1.0
21	Zinc (mg/l)	5.0
22	pH	5-9

The total amount of heavy metals shall not exceed 10.0 mg/l

Annex 3. Tolerance limits for discharged domestic wastewater (RS, 2017)

Table 1 — Physical requirements for discharged industrial wastewater

S/N	Parameter	Requirements	Test methods
1.	Temperature increase °C	< 3	Thermometer [1]
Note [1]The thermometer used should be calibrated according to National Measurement Law			

Table 2 — Chemical requirements for discharged industrial wastewater

S/N	Parameter	Permissible limits (max.)	Test methods
1.	pH	5-9	RS ISO 10523
2.	Total suspended solids mg/l	50	RS ISO 11923
3.	Total Dissolved Solids mg/l	2000	RS ISO 7888
4.	Oil and grease mg/l	10	ISO 9377
5.	BOD5 mg/l (20°C)	50	RS ISO 5815
6.	COD mg/l	250	RS ISO 6060
7.	Ammonia (as N) mg/l	20	RS ISO 6778
8.	Phosphates mg/L	10	Analytical tests (capillary electrophoresis)
9.	Free chlorine mg/L	1.0	ASTM D1253-14
10.	Arsenic mg/l	0.01	ISO 11969
11.	Benzine mg/l	0.1	ISO 11423
12.	Cadmium mg/l	0.1	ISO 5961
13.	Hexavalent Chromium mg/l	0.05	ISO 23913
14.	Copper mg/l	3	ISO 8288
15.	Cyanide mg/l	0.1	ISO 6703
16.	Iron mg/l	3.5	RS ISO 6332
17.	Lead mg/l	0.1	ISO 8288
18.	Mercury mg/l	0.002	ISO 5666
19.	Nickel mg/l	3	ISO 8288
20.	Phenol mg/l	0.2	ISO 8165
21.	Sulphide mg/l	1.0	ISO 13358
22.	Zinc mg/l	5	ISO 8288
23.	Selenium mg/L	0.02	ASTM D3859-15
24.	Pesticides mg/L	Not detectable	ASTM D8025-16

Table 3 — Microbiological requirements for discharged industrial wastewater

S/N	Parameter	Permissible limits	Test methods

1.	Faecal Coliforms cfu /100ml	400	RS ISO 4831