The application of Rainwater harvesting technology a water resource management method, for pertinently attaining an eminence of water and ecological conservancy.

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Abstract— Due to water scarcity and demand, the provision of water of good quality is essential to utilities both for rural and urban areas of any country. Water scarcity affects 1.2 billion people on a global scale, representing nearly one fifth of the human population. In some regions, current water sources are being depleted faster than they are renewed and the majority of this depletion is being used for irrigation and agricultural purposes yet Water is a vital resource for life and for the economy. At any given time, the atmosphere contains 3400 trillion gallons of water vapor, which would be enough to cover the entire Earth in 1 inch of water but, one of the most serious challenges to solve is to manage water scarcity. As the importance of water usage optimization in monetary point of view is not that noticeable, there is a lack of the incentive to invest in implementing technologically advanced systems for putting in places sustainable supply and distribution systems of water. This study reviews water quality of Rwanda based on some elements and suggests rain Harvesting technology as a better method for water quality and for environmental conservancy.

Key Words: Rainwater Harvesting technology, Water quality, Environmental conservancy, Water scarce, Metal index, Contamination degree.

1. INTRODUCTION

Cities around the world are faced with the problem in keeping up with the growth in water demand for residential and business as a result of population growth, climate variability and climate change **[1].** Countries, water utilities, and municipalities around the world are forced to rethink and revise water policies in order to ensure sustainable use of water resources. Sustainable water use is defined as a pattern of use that ensures satisfaction of needs for the present and future generations **[2].** The avoidance of losing social welfare in the use of water and the efficient use may be seen as an instrument for the achievement of sustainability **[2].**It means that the present generations should develop strategies to manage usage of water resources in an efficient manner in order to ensure that future generations will be able to enjoy the same benefits. Measurement of the water usage forms a big part in the management of water resources. Lack of water is a devastating issue on a global scale. Only 3% of the earth's water is fresh and two-thirds of that is in frozen glaciers or unobtainable**[3].** Nearly 2.7 billion people live with limited water access at least one month out of the year as a result **[3].** current water consumption rates, is expected to raise where two-thirds of the world population might face water shortages by 2025 **[3].** Water shortages are often due to lack of humidity in the air (causing little rainfall) or human activity that disrupts the water cycle. Fig 1 depicts regions experiencing varying levels of water stress. Some regions, which are experiencing high water stress, are depleting current water sources faster than they are renewed, and the majority of this depletion is being used for agriculture. It is estimated that 70% of the world's freshwater is being used for irrigation purposes **[4, 5].** Regions in Africa, the Middle East, and Asia are affected the most severely; however, regions as close as Midwest United States experience water shortages annually**[6].** In order to help in eradicating the issue, an innovative solution must be implemented to bring a sufficient amount of water to susceptible areas. The resolution to this crisis helps address one of the eight Millennium Developmental Goals (MDG) developed by the United Nations during the Millennium Summit in 2000. The MDG was created to help improve the lives of people living in the poorest regions of the world. In particular, this project was focusing on goal 7, ensuring environmental sustainability through the integration of sustainable principles, to reverse loss of environmental resources, and to reduce the proportion of people without access to a sustainable water source **[7].**The motivation to help eradicate water scarcity around the world required a renewable sustainable resource and the answer was found in the atmosphere. Where the atmosphere contains 3400 trillion gallons of water vapor at any given time **[4].** This replenishing resource provides the sustainable and innovative solution needed to help in combating with the global crisis through the launch of rain harvesting technology [RHT] as the better combating technic.

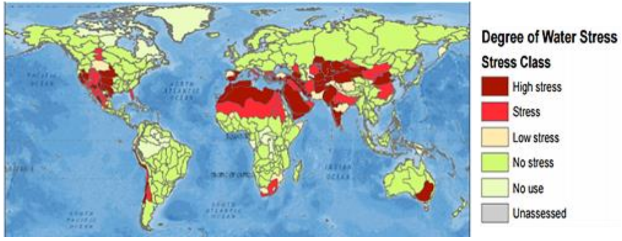


Figure 1:Map Illustrating Regions Experiencing Water Stress

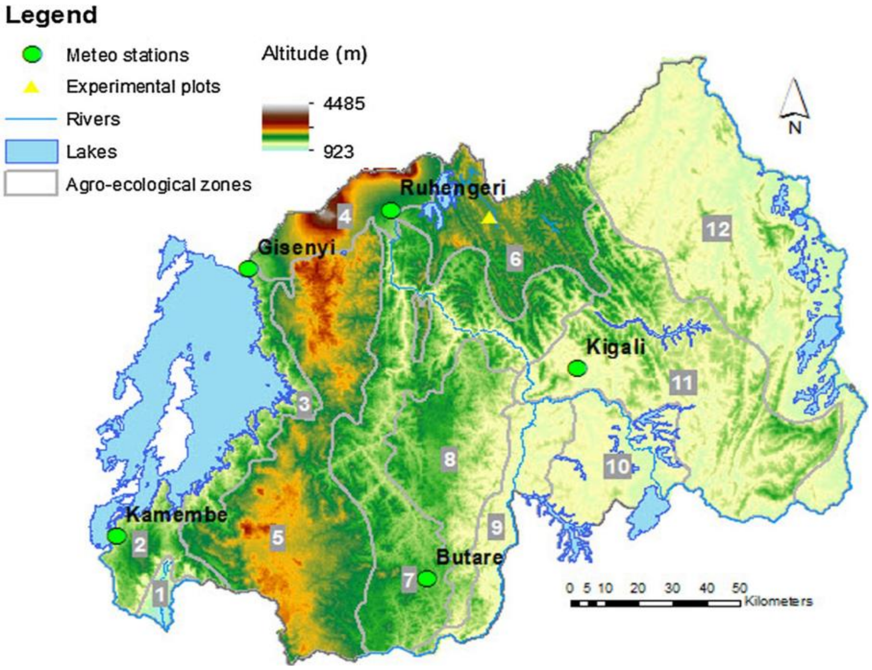
Internationally, an estimated 1.25million deaths and 75million disability adjusted life years (DALYs) are attributable annually to obtaining water from unsafe sources **[8].** Most of the deaths are from **[9]** diarrhea, especially among young children exposed to faecal contamination in drinking water**[10].** In Rwanda, un safe water is currently ranked third as a risk factor for disease **[8].** and diarrhea is

[11]. a leading cause of mortality in children under 5, accounting for an estimated 9% of overall deaths**[12].** While the UN celebrated the achievement of the Millennium Development Goal (MDG) for water in 2012, un safe drinking water is still the eighth leading risk factor for disease globally **[8].** An estimated 663 million people do not have access to an improved drinking water source (defined to include piped water to the dwelling, plot or yard, as well as public taps/standpipes, tube wells or boreholes, protected dug wells, protected springs, and rainwater collection)**[13].** However, water from improved water sources is not necessarily free of faecal contamination **[14, 15]**. with an estimated 1.8 billion people using a source that has faecal contamination, particularly in Africa**[16].** Moreover, in this hygiene challenged environments, even water that is safe at the source frequently becomes contaminated from faecal pathogens during collection, transport and storage in the homes **[17, 18]** Furthermore, safe water source coverage is not always equitable. Subnational inequalities, including urban and rural differences and differential access to types of improved water sources such as piped water is in common place **[19-23].** In Rwanda, 76% of the population has access to an improved drinking water source with 9% having access to piped water onto premises. Yet, while 85% of the urban population has access to improved drinking water sources including 28% having access to water piped onto premises access for the rural population is only 57% and 2% respectively **[24].** With the adoption of the Sustainable Development Goals and specifically Target 6.1 of achieving universal and equitable access to safe and affordable drinking water for all by 2030, there is a need to incorporate water quality testing at sources and households **[25].** In cooperation with the Rwanda Ministry of Health and DelAgua Health Rwanda, a private company distributing water filters and cookstoves financed by carbon credits **[11].** a conducted national cross-sectional study to assess the faecal contamination of drinking water at the household level was done. In addition, a testing water quality, potential risk factors for water quality were assessed at a household level and analyzed along with potential community-level determinants.

2. Materials and methods

2.0 Study AREA

Rwanda is a small landlocked country located in the East Africa, lying between 1°04′ and 2°51′ S, and 28°53′ and 30°53′ E. The climate is tropical, moderated by its altitude ranging from 900 to 4507 m **[26].** Rwanda borders to Lake Kivu in the west located at 1460 m, with steep borders rising towards the mountainous Albertine branch of the Rift Valley (Congo-Nile watershed divide) that runs from North to South Rwanda at an altitude of 2000 to 2500 m. To the east of this range, the central plateau is found at an altitude of 1500 to 2000 m, which gradually lowers further in altitude into the Eastern plateau and low lands Fig.2. Rwanda experiences a bimodal rainfall pattern that is primarily driven by the progression of the Inter-Tropical Convergence Zone (ITCZ) **[27-29].** The first short rainy season (SOND) covers September to December while the second-long rainy season (MAM) lasts from March to May with peak rainfall months being November and April, respectively. Orographic effects caused by the large altitudinal variation within the country**[30].** as well as the presence of large water bodies (such as Lake Kivu) **[31].** modify the rainfall distribution pattern and thus the Rwandan rainfall has a large spatiotemporal variation. In some years, El-Niño phenomena put the country into risks of floods, landslides and drought **[32].**



1 = Imbo, 2 = Impala, 3 = Kivu lake boarders, 4 = Birunga, 5 = Congo Nile-watershed Divide, 6 = Buberuka Highlands, 7 = Central Plateau, 8 = Granitic Ridge, 9 = Mayaga, 10 = Bugesera, 11 = Eastern Plateau and 12 = Eastern Savanna.)

Figure 2: Elevation map of Rwanda showing agro-ecological zone

2.1 Water resource in Rwanda

Rwanda being a country located in the Great Lakes Region of Africa, it's topography gradually rises from the East at an average altitude of 1,250 m to the North and West where it culminates in a mountain range called "Congo-Nile Ridge" varying from 2.200 m to 3,000 m and a volcano formation, the highest volcano being 4,507 m high. This topography is characterized by a vast number of hills and mountains, a fact which results in high soil erosion and loss of water. Rwanda possesses a dense hydrographical network. Lakes occupy 128,190 ha; rivers cover an area of 7,260 ha and water in wetlands and valleys cover a total of 77,000 ha. The country is divided by a water divide line called Congo-Nile Ridge. To the West of this line lies the Congo River Basin which covers 33% of the national territory, which receives 10% of the total national waters. To the East lies the Nile River Basin, whose area covering 67% of the Rwandan territory and delivers 90% of the national waters**[33, 34].** As indicated in the paragraphs above, water quality is altered by human activities in the surrounding of water resources. The present study has the main objective to show up the quality of Rwandan water where some selected sites in the Congo and Nile basins in order to monitor the surface water quality are considered. The presence of pollutant (chemical products and microorganisms) at higher concentration in water alters its quality making it unsuitable for uses.

Thus, one of the main tasks of the environmental scientists is to monitor the water quality and to conserve them. This monitoring requires a collection of physicochemical and bacteriological data on a regular basis in order to have a base line from which an evaluation and comparison of the quality should be conducted [35]. The expected outputs of the study were to: (i) determine the physicochemical and bacteriological quality of the selected sites within the country; (ii) to discuss the results based on the quality standards of surface water and conclude whether water meet or not the standard requirements and suggesting a method for improving the water quality and environmental safeguarding as well.

2.1.0 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).

2.1.1 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 illustrates the key water bodies within the catchments of the Congo & Nile basins together with other important particular characteristics.

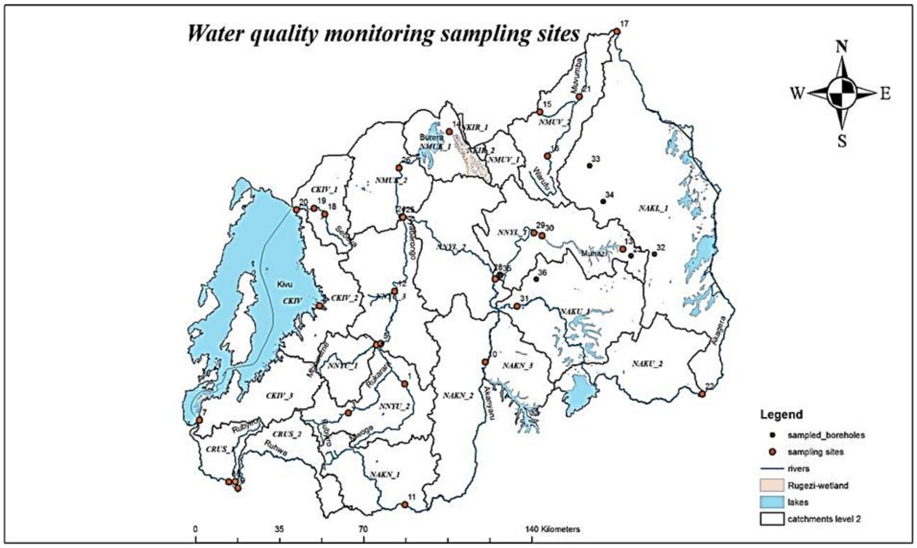


Figure 3: Water Quality monitoring sampling sites in Rwanda

Table 1: *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 X	GPS Coordinates Y	Justifications
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
RW-CRUS	Rusizi	1,005	CRUS_1_003	6	Rusizi River/Kamanyora bridge	Rusizi River	-2.70757	29.006609	Medium site
			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

Table 2: Water Quality results

This table provides data on water quality 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 x 10^1	3 x 10^4	4 x 10^1	6 x 10^2
7. Kivu Lake at Kamembe Port	20.1	29.3	18.0	17.8	8.2	7.2	2 x 10^2	5 x 10^4	6 x 10^1	7 x 10^2
8. Rubyiro River at Bridge Bugarama - Ruhwa Road	6.7	12.8	15.2	28.5	16.4	13.4	3 x 10^1	8 x 10^3	1 x 10^1	3 x 10^2
9. Ruhwa River at bridge Ruhwa border	3.5	6.1	11.8	9.5	17.6	14.8	1 x 10^2	9 x 10^4	4 x 10^1	6 x 10^2
10. Akanyaru River Gihinga	2.9	7.9	17.8	25.3	3.1	4.5	2 x 10^1	5 x 10^2	1 x 10^1	2 x 10^2
11. Akanyaru River border to Burundi	8.0	13.8	14.3	15.6	15.3	2.0	7 x 10^2	7 x 10^2	3 x 10^2	5 x 10^1
12. Secoko River before discharging into Nyabarongo	4.1	7.2	9.5	11.6	15.6	14.3	7 x 10^1	7 x 10^4	1 x 10^1	4 x 10^4
13. Muhazi Upstream	78.0	83.3	12.0	18.3	9.0	6.3	3 x 10^2	8 x 10^4	1 x 10^2	8 x 10^2
14. Rugezi before discharging into Burera Lake	4.8	7.4	8.3	21.0	6.6	18.0	8 x 10^2	5 x 10^4	4 x 10^2	2 x 10^3
15. Muvumba River entering Rwanda from Uganda	12.4	17.5	17.3	21.3	9.6	6.7	2 x 10^1	3 x 10^4	1 x 10^1	3 x 10^2
16. Warufu River	11.1	12.9	16.2	18.5	10.4	7.3	1 x 10^3	5 x 10^5	4 x 10^2	7 x 10^3
17. Muvumba at Kagitumba	23.9	26.7	28.7	37.3	11.6	7.7	2 x 10^2	2 x 10^5	1 x 10^2	8 x 10^3
18. Sebeya River at Musabike	4.1	9.0	23.0	28.0	8.9	8.9	1 x 10^2	5 x 10^6	5 x 10^1	8 x 10^3
19. Sebeya River at Nyundo Station	3.5	8.8	34.2	33.0	7.5	11.3	3 x 10^2	2 x 10^3	2 x 10^2	6 x 10^2
20. Kivu Lake Gisenyi Beach	22.0	26.7	18.7	15.6	5.4	4.4	1 x 10^2	3 x 10^6	7 x 10^1	1 x 10^4
21. Muvumba after mixing with Warufu	15.6	23.9	25.3	30.0	11.2	7.8	4 x 10^0	3 x 10^5	< 1 x 10^0	1 x 10^4
22. Akagera Rusumo Border	3.5	5.6	22.0	17.2	11.6	2.0	3 x 10^2	7 x 10^5	2 x 10^2	2 x 10^4
23. Mukungwa iver Before receiving Nyabarongo	4.8	8.8	12.8	13.6	9.2	10.1	3 x 10^2	6 x 10^6	2 x 10^2	1 x 10^4
24. Nyabarongo River before receiving Mukungwa	5.4	8.0	29.7	29.0	7.2	8.4	6 x 10^2	7 x 10^6	2 x 10^2	1 x 10^4
25. Mukungwa River at Nyakinama gaugng station	4.1	8.9	11.3	13.1	6.6	5.1	4 x 10^2	3 x 10^3	2 x 10^2	1 x 10^2
26. Nyabarongo at Ruliba	30.3	26.9	36.1	33.5	7.7	9.1	9 x 10^1	5 x 10^4	5 x 10^1	5 x 10^2
27. Nyabugogo River downstream	50.0	55.0	25.9	34.5	17.0	6.0	1 x 10^3	7 x 10^3	9 x 10^2	2 x 10^2
28. Nyabugogo River Upstream	90.8	89.9	11.1	12.5	4.9	2.0	3 x 10^1	2 x 10^3	1 x 10^1	5 x 10^2
29. Muhazi Downstream	94.6	96.5	15.0	34.6	2.7	2.0	1 x 10^2	6 x 10^2	6 x 10^1	1 x 10^2
30. Akagera at Kanzenze Bridge	32.2	36.5	32.3	30.8	5.6	5.1	8 x 10^2	9 x 10^4	1 x 10^2	2 x 10^2
31. Borehole at Gatsibo-Kabarore-Simbwa-Ruhuha	10.1	16.9	21.0	29.1	2.2	2.0	8 x 10^1	1 x 10^5	2 x 10^1	6 x 10^2
32. Borehole at Kayonza-Mukarange-Agatebe	12.4	13.9	15.2	20.8	2.1	2.0	3 x 10^1	1 x 10^3	1 x 10^1	7 x 10^2
33. Artesian Well	3.5	8.3	4.2	6.8	2.0	0.0	2 x 10^2	1 x 10^3	1 x 10^2	9 x 10^2
34. Borehole at Gatsibo-Rugarama-Kanyangese-Umunini	49.4	0.0	8.2	0.0	2.2	15.8	6 x 10^2	NF	4 x 10^2	NF
35. Public Borehole at Giticyinyoni	27.1	57.5	34.0	23.2	2.0	4.4	< 1 x 10^0	<1x 10^0	< 1 x 10^0	Absence
36. Public Borehole at Nyandungu	62.1	28.3	18.4	33.6	5.6	5.1	2 x 100	<1x100	< 1 x100	Absence

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

2.1.2 Water quality results and appraisals

Water quality was evaluated by looking at a set of sixteen selected parameters and which are the major water quality issues of Rwanda. 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 3 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)**[36].**

Table 3: *Summarized table for the Standard parameters monitored*

N^o	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

2.1.3 Results Analysis

i. Electrical Conductivity [EC]

Results analyzed indicated that the Electric Conductivity (EC) is 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 Fig4. 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 fresh waters' 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.

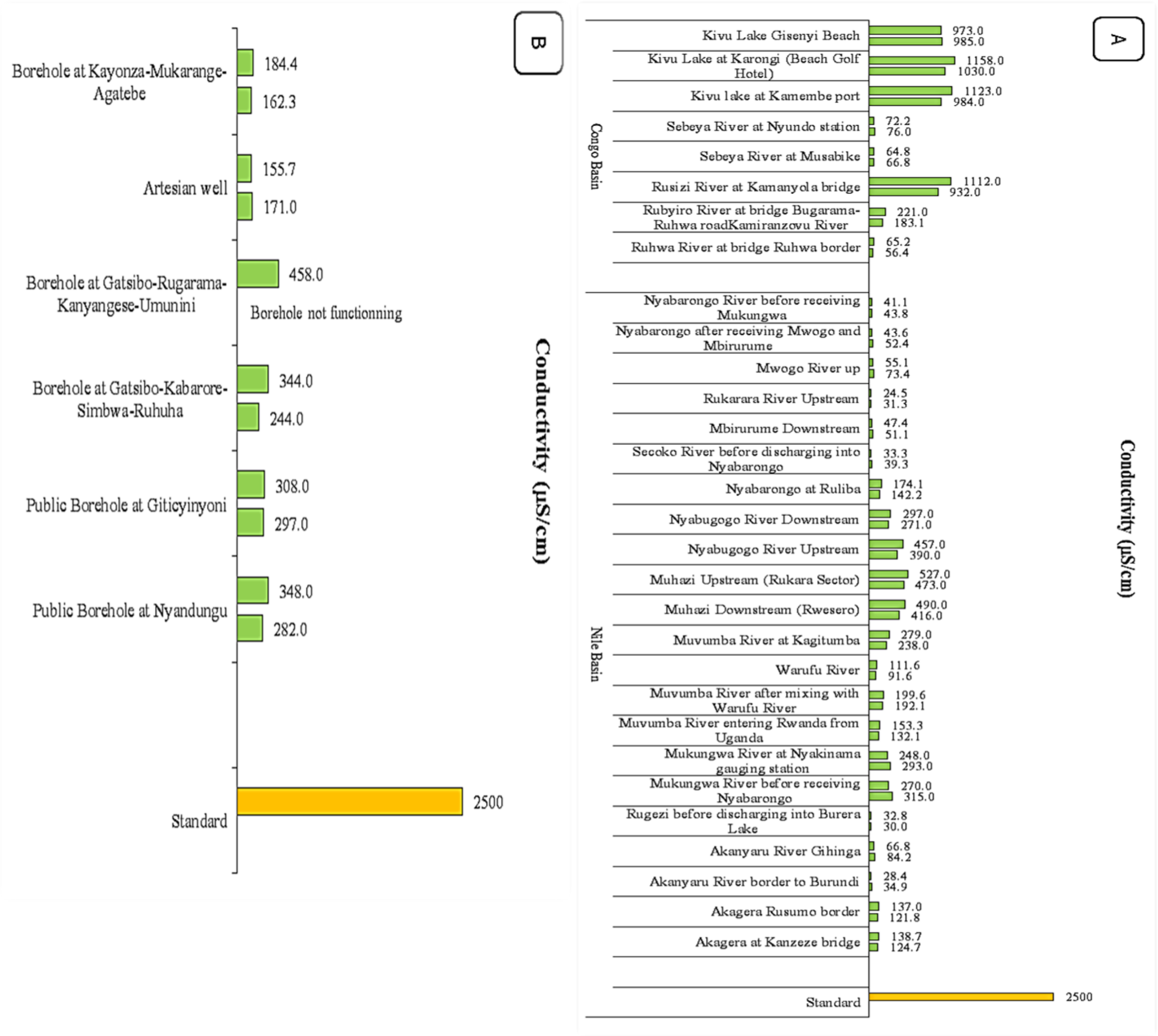


Figure 4:Variation of conductivity in all monitoring sites for period I & II, (A) for surface water & (B) for ground water. The yellow colour indicates the standard value; the green colour indicates lower conductivity values recorded when compared to the standard

ii. Dissolved Oxygen (DO)

Results obtained 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. Fig.5.

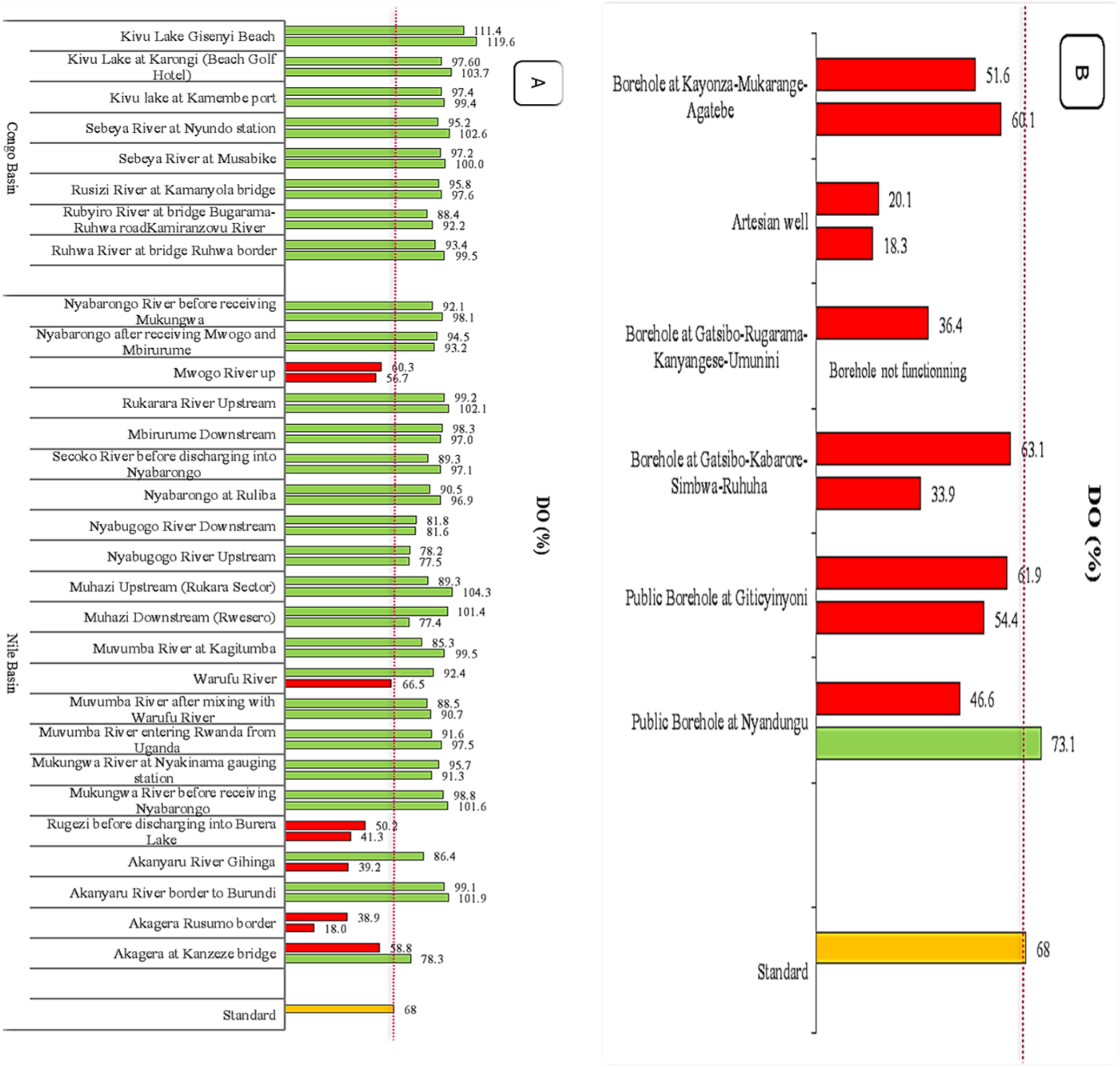


Figure 5:Variation of Dissolved Oxygen for period I & II in all monitoring sites, (A) for surface water & (B) for ground water. The yellow colour indicates the standard value; the red and green colours indicate lower and higher DO values recorded when compared to the standard limit respectively.

iii.Total Suspended Solids (TSS)

The Total Suspended Solids (TSS) recorded 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 complying with the Rwandan standards whereas the other 50 % are complying with TSS standard Fig 7. Seasonal variation shows a sharp decrease in TSS from period I to period II. This is mainly explaining the dry season and non-occurrence 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. 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

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Figure 6: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 color showing land heavy load within waters

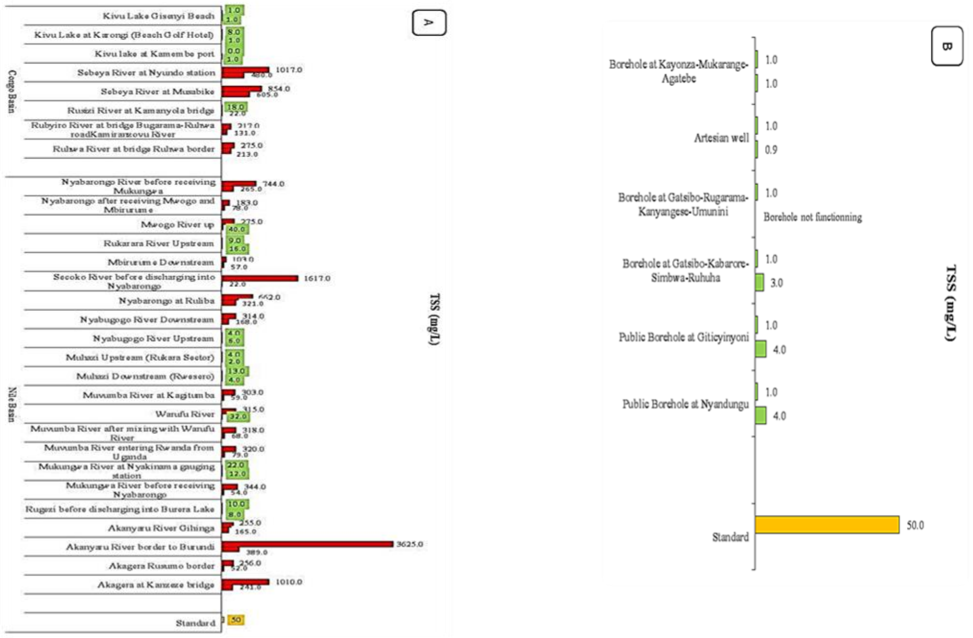
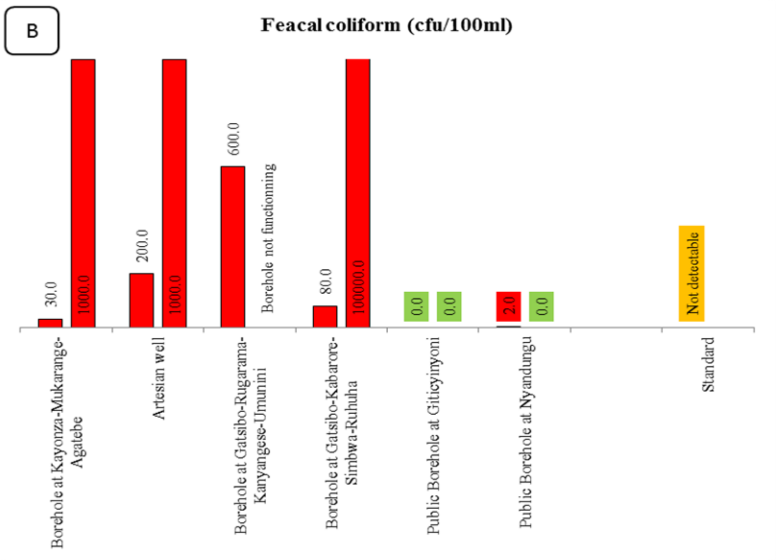


Figure 7:Variation of total suspended solid for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow color indicates the standard value; the red and green colors indicate higher and lower TSS values recorded when compared to the standard limit respectively

iv. *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. 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 **[37].**



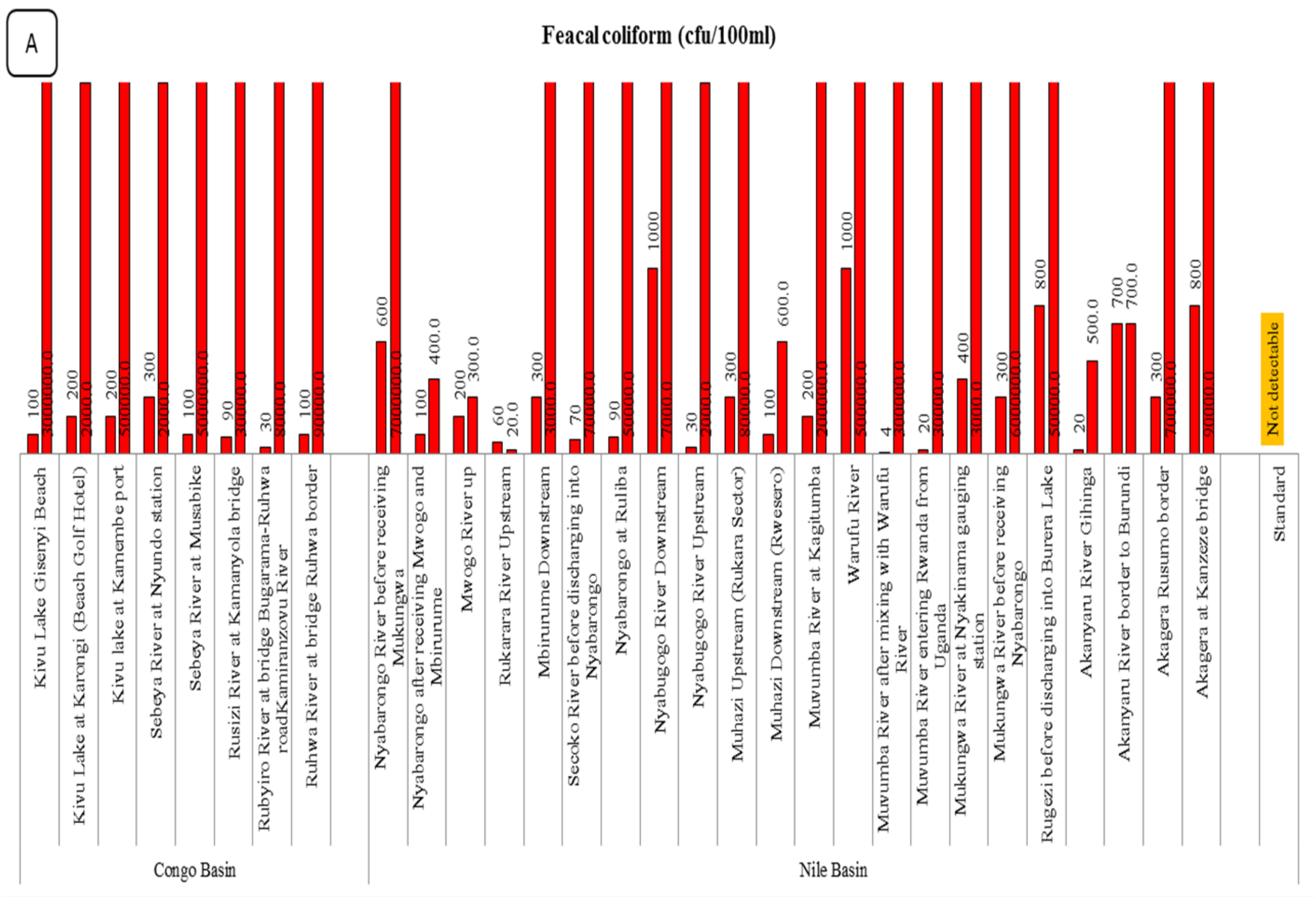


Figure 8:Variation of faecal coliform for period I & II in all monitoring sites (A) for surface water & (B) for ground water. The yellow color indicates the standard value; the red and green colors indicate the higher and lower faecal coliform values recorded when compared to the standard limit respectively.

General observatory Analytics for the monitored parameters

From all documented data on this water quality study 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 and these are: Biochemical oxygen demand (BOD), Chloride (Cl-), dissolved inorganic phosphorus (DIP), dissolved inorganic nitrogen (DIN), electro conductivity (EC), nitrate (NO3-), hydrogen potential (pH), total nitrogen (TN), total phosphorus (TP), total dissolve solids (TDS) and sulphate (SO42-). while the remaining five (5) parameters representing 31.25 % were out of the recommended standard limits for few or many of selected monitoring sites and 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 means that the turbidity of the monitored rivers largely depends on the accumulation of suspended solids. and 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.

2.1.3 Surface water availability in Rwanda

In Rwanda, surface water is currently polluted by anthropogenic activities resulted in the use of fertilizers and pesticides in agriculture. Rwandan people utilize industrial fertilizers (NPK, urea) and pesticides to improve the yield productivity as the soil is becoming more and more degraded. These chemicals highly soluble reach the surface water by runoff. Furthermore, in Rwanda many farming activities are located in valleys near Rivers and streams where they release manure containing nitrogen. Hence, all these agricultural and farming activities may pollute water and lead to eutrophication process and extinction of ecosystem. Domestic and industrial effluents contribute much to the pollution of surface water by dumping solids waste and releasing liquid wastes containing pollutants in general like heavy metals (cadmium, chromium, lead, zinc,) and other chemicals resulting from industrial processing. The other factor affecting also much the surface water quality is the erosion contributing to water pollution by sediments transport and suspended matters. As most of Rwandan hills and mountains have a steep slope, hence the soil moves to the valleys and reach the surface water Fig.9

Figure 9: A hill affected by landslide

2.1.4 Land use practices

Water resources in Rwanda are mainly threatened by reclamation and degradation, especially those outside national parks. Human activities threatening water in Rwanda include settlements and road construction, drainage, unplanned conversion to agriculture of some wetlands, industrial pollution sewage and excessive harvest of products. Land use practices such as trampling of stocks, human disturbances, burning of vegetation, soil excavation processes have devastated vegetation cover to such an extent that the soil surface of areas has become susceptible to erosion. Increased housing developments associated with urbanization, directly affects the soils' physical characteristics thus lowering water infiltration and increasing runoff and soil erosion with increased potential for floods. This has happened in Kigali and to a lesser extent in other provincial towns across the country. Roofing of housing complexes and paving of roads and other access routes has reduced the surface area available for soil infiltration. During the rainy season much of the run-off flows to the valleys below with minimal infiltration which is one of the main ground water recharge pathways. In cases of the existence of open sewers and exposed drainage canals, the rain water carries along with it the domestic waste directly into the marshlands below as is the case for the Gikondo and Nyabugogo wetlands for Kigali. The direct impact of reduced soil infiltration is increased run-off, soil erosion on bare soils and siltation of water ways in the lower slopes or marshlands. Also associated with urbanization is watershed destruction and increasing incidences of dumping of untreated effluent in rivers and marshlands. In urban areas wetlands are most likely to be used as dumping sites for wastes or wetlands may be converted to other forms of land use, such as residential and industrial development, road construction. The Gikondo industrial area located in Gikondo-Nyabugogo wetland greatly affects the ability of the wetland to clean wastewater and control siltation of streams **[35, 38].**Urban settlement without adequate sanitation has increased the surface water or ground water pollution because so far, no sewer and treatment network has been set up since the creation of Kigali and other country major cities. The current techniques for human waste or wastewater management are the digging of ground septic tanks or direct dumping of wastewater into rivers or wetlands These habits lead in general to surface and groundwater contamination water. Fig10.

Figure 10:The photo showing the human wastewater from the Urban settlement

2.2 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. 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 **[39, 40].**

The analysis steered in some rivers of the country showed a strong correlation between the rainfall distribution and certain physical parameters of water quality **[41].**

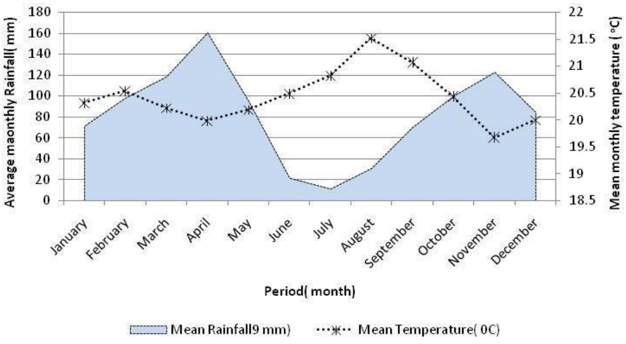


Figure 11:*Annual distribution of rainfall*

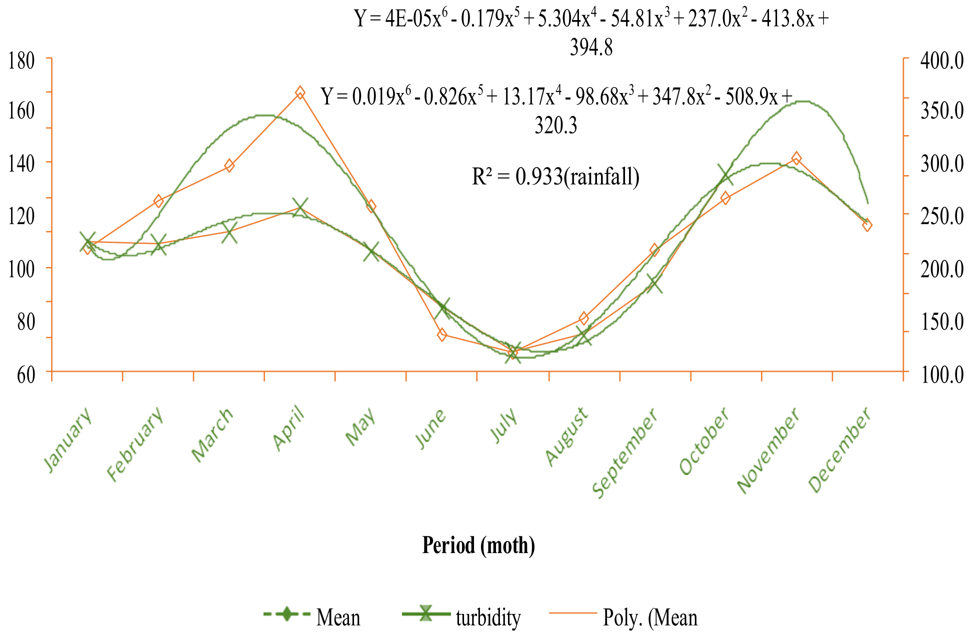
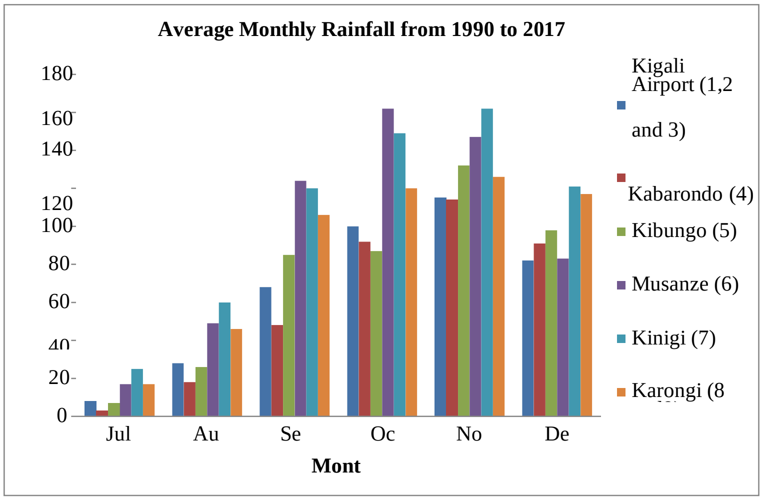


Figure 12: Relationship between Rainfall and turbidity of Yanze river

Figure 13:Average monthly rainfall recorded at meteorological stations neighboring the water sampling sites



2.3 Rwandan quality of drinking Water

To ensure that water undergoes prior treatment and to increase access to safe drinking water, about sixteen water treatment plants are operating countrywide. These initiatives have increased the percentage of people accessing safe drinking water from 23% in 1990 to 82% in 2016 **[42, 43].** Therefore, the water samples were collected from springs in different areas in country to ensure that the water quality of selected springs is healthy according to the standards set by the World Health Organization for metals in water Table 4

Table 4 Names and location of the sampling sites

No	Sampling sites	Location (province)
1.	Kinyinya	Urban, Kigali city
2.	Mburabuturo	Urban, Kigali city
3.	Runda	Semi-Urban, Southern Province
4.	Kabarondo	Semi-Urban, Eastern Province
5.	Kibungo	Rural Eastern Province
6.	Musanze	Semi-urban, Northern Province
7.	Kinigi	Rural, Northern Province
8.	Karongi	Semi-urban, Western Province
9.	Nyamishaba	Rural Western Province

2.3.1 Field sample collection and investigational approaches

The water samples were collected from nine drinking water sources located in urban, semi-urban, and rural areas of Rwanda, during the dry season (July–September) and rainy season (October–December), respectively. Only three categorically water samples were collected monthly from each sampling site from the surface water. the samples were preserved in washed- acid 100ml in a polypropylene container for the avoidance of characteristic changes and were digested, concentrated, and prepared for analysis by atomic absorption spectrophotometry (AAS) using an AA Spectrometer M Series. The extensively monthly water quality monitoring conducted and the measured elements were calcium (Ca), iron (Fe), manganese (Mn), copper (Cu), aluminum (Al), and zinc (Zn). The drinking water samples of dry and rainy seasons were compared, the monthly maximum rainfall (mm) records at each meteorological station neighboring the water sampling site were obtained Fig. 13 for July, August, and September for the dry season, and October, November, and December for the rainy season of 2017. During the analysis, the rainfall variability was referred to in order for better understanding how changes in rainfall stimuluses the drinking water quality.

2.3.2 Indexing approach

2.3.2.1 Metal Index

This study used the metal index (MI); it is generally used for metals in drinking water quality**[44].** The metal index takes into account possible additive effect of metal elements on the human health that help to quickly evaluate the overall quality of drinking waters. Metal index is given by the expression proposed by **[45].** and is calculated as shown below:

$$\mathbf{MI} = \sum_{i=1}^{n} \frac{\mathbf{CI}}{[\mathbf{MAC}]\mathbf{i}},$$

where MAC is the maximum allowable concentration and CI is the mean concentration of each element. The higher concentration of metal was compared with its respective MAC value that shows the worse quality of water. MI value > 1 is a threshold of warning **[46].** Water quality and its suitability for drinking purpose can be examined by determining its metal pollution index **[47, 48].** This study applied the above metal index for the estimate value of six metal elements, namely, aluminum, calcium, manganese, copper, iron, and zinc.

Table 5 Concentration and mean value of metal elements during the dry season

Sites	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean/element**
Ca	43.6	54	61.4	31	91.8	63.2	84	21	26	52.88
Fe	0.38	1.14	0.2	0.39	0.33	0.09	0.2	0.2	0.09	0.33
Mn	0.4	0.21	0.02	0.17	0.32	0.01	0.4	0.003	0.11	0.18
Cu	0.51	0.28	0.13	1.31	1.1	0.18	0.03	0.41	0.12	0.45
Al	0.03	0.11	0.03	0.16	0.03	0.12	0.11	0.08	0.09	0.08
Zn	0.38	0.38	0.4	0.54	0.37	0.10	1.01	0.11	1	0.47
Mean/site	7.55	9.35	10.36	5.59	15.65	10.61	14.29	3.63	4.56	

Table 6 Concentration and mean value of metal elements during rainy season

Sites	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Mean/element**
Ca	75.2	92	82	72.8	102.7	77.1	127.1	37.8	32.1	77.46
Fe	0.71	1.24	0.61	0.43	0.65	0.07	0.08	0.18	0.13	0.45
Mn	0.16	0.26	0.14	0.32	0.44	0.2	0.15	0.04	0.14	0.2
Cu	0.65	1.46	0.8	1.78	1.9	0.2	1.06	0.84	1.17	1.09
Al	0.09	0.32	0.06	0.28	1.01	0.15	0.86	0.14	0.19	0.34
Zn	0.8	0.83	0.9	0.76	0.58	1.13	1.08	0.14	1.04	0.79
Mean/site	12.93	16.01	14.08	12.72	17.88	13.14	21.72	6.52	5.79	

2.3.2.2 Contamination degree (Cd)

The contamination degree is defined as the sum of all concentration factors**[49].** The water samples are classified by calculating the degree of contamination in water samples. Contamination degree, by added various parameters assuming water quality, investigates the convenience of drinking water samples for municipal consuming **[50].** The contamination degree has to be calculated and split up for all samples based on the surpassed parameters from standard values. The degree is calculated as follows:

$$\mathbf{Cd} = \sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{cf_i}$$

, where $\mathbf{cf_i} = \left\{\frac{\mathbf{CA_i}}{\mathbf{CN_i}} - \mathbf{1}\right\}$

where by Cf_i is the contamination factor for the *ith* parameter CA_i is the measured value for the *ith* parameter CN_i is the standard allowed value for the *ith* parameter. The results confirmed in Tables 5 and 6 indicated gradual increase of the values of metal elements, particularly during the dry season (July–September2017) compared with the values noted during the rainy season (October– December 2017). The mean concentrations of the analyzed metals were used to calculate the metal index (MI) and contamination degree (Cd) during both seasons and the mean concentration of elements on sites were used to calculate the metal index and contamination degree of each sampling site. Table 10 exemplifies the metal index and the contamination degree of measured metal elements in drinking water sources. The Table 8 below represents the metal index for each drinking water sampled during both seasons and it also indicates the sites which are on a threshold level of warning according to their recorded metal index value Table 5. According to**[45, 51],** the classification of metal index to the drinking water quality classifies into six different classes and their characteristics as exemplified in Tables 9 and 10. The contamination degree classifies drinking water quality into three different classes as exemplified in the Table 10; it revealed that all sampled sites were classified in class 1 which is characterized by low contamination where the Cd < 1 Table 9.

Table 7 The metal index and contamination degree of measured elements during the dry season (ds) and rainy season(rs)

Metal elements	Ci or CAi in ds (mg/L)	(MAC)i or (CNi)/mg/L	Ci or CAi in rs	MI (ds)	MI (rs)	Cd (ds)	Cd (rs)
Ca	52.88	80.0	77.46	0.66	0.92	− 0.34	− 0.08
Fe	0.33	0.3	0.45	1.1 (threshold of warning)	1.49 (threshold of warning)	0.1	0.49
Mn	0.18	0.1	0.2	1.8 (threshold of warning)	2.00 (threshold of warning)	0.8	1.00
Cu	0.45	1.0	1.09	0.45	1.09 (threshold of warning	− 0.55 -0.60 -0.85	0.09
AL	0.08	0.2	0.34	0.40	1.70(threshold of warning)		0.70
Zn	0.47	3.0	0.79	0.15	0.26		-0.74

Table 8 Metal index and contamination degree of each sampling site

Sampling sites	Cd Dry season	Cd Rainy season	MI Dry season	MI Rainy season
1	− 0.46	− 0.08	0.53	0.91
2	− 0.33	0.13	0.66	1.13 (threshold of warning)
3	− 0.26	0.001	0.73	0.99
4	− 0.6	− 0.09	0.39	0.90
5	0.1	0.27	1.10 (threshold of warning)	1.26 (threshold of warning)
6	− 0.24	− 0.06	0.75	0.93
7	0.01	0.54	1.01 (threshold of warning)	1.54 (threshold of warning)
8	− 0.74	− 0.53	0.25	0.46
9	− 0.67	− 0.58	0.32	0.41

Table 9 Classification of metal index

MI	Characteristics	Class	Site no. in dry season	Site no. in rainy season
< 0.3	Very pure	1	8	–
0.3–1.0	Pure	2	1, 2, 3, 4, 6, 7, and 9	1, 3, 4, 6, 8, and 9
1.0–2.0	Slightly affected	3	5	2, 5, and 7
2.0–4.0	Moderately affected	4	–	-
4.0–6.0	Strongly affected	5	–	-
> 6.0	Seriously affected	6	–	-

Table 10 Water quality classification using contamination degree (Cd

Cd	Characteristics	Class	Sampling site
Cd < 1	Low contamination	1	All sampling site
1 < Cd	Moderate contamination	2	
Cd > 3	High contamination	3	

3.Discussions

As shown in Table 8 and Fig. 13, the sampling sites located in areas with high rainfall similarly recorded higher metal pollution index and higher contamination degree. This impact of rainfall patterns on water quality is marked by the results of the study, the rainfall acted effortlessly as a driver to water pollution, where high MI was recorded during the rainy season than MI during the dry season. The metal index and contamination degree per each sampling site indicated the high value of index during the rainy season at the sampling sites of Mburabuturo, Kibungo, and Kinigi compared with the metal index and contamination degree during the dry season, but also higher at the sampling site of Kibungo and Kinigi at large extent than other sampling sites .The maximum metal index was assessed at Kinigi site(1.54) during the rainy season and at Kibungo site(1.1) during the dry season(Table5). Contingent on classification of metal index for drinking water quality, the average index for samples of dry and rainy seasons was 0.63and 0.94. According to metal index's classification on water quality, during the dry season, most of the sites are classified in class 2 which is characterized as pure, while site8 is classified in class1(very pure). Besides, site5 is classified as slightly affected (class 3). The sites of 1, 3, 4,6,8, and 9 are classified in class 2(pure), whereas the sites 2,5, and 7 are classified as slightly affected in class 3 Table 9. The maximum degree of contamination was recorded for the site of Kinigi (0.54) during the rainy season, while during the dry season, the maximum contamination degree was 0.1 for Musanze site; the minimum degree of contamination has been fixed for the Karongi site (− 0.74) in the dry season and (− 0.58) in the rainy season at Nyamishaba site Table 8. The contamination degree average for all the sites during the dry and rainy seasons are − 0.35 and − 0.04 respectively, which are classified in class 1 as low degree of contamination. In this study, drinking water sources located in urban areas, such as site of Kinyinya and Mburabuturo are polluted compared with the sampling sites located in rural areas. This agrees with the reports**[52-54].** on water quality monitoring, which highlighted how urban waters are predominantly becoming polluted at high extent compared with that located in rural areas due to wastes generated by households, industries, slaughtering houses, directly thrown into waters, and other urban activities located nearby water bodies. Although the proportion of people accessing on safe drinking water increased in the past years in Rwanda, the results of this study presented that some people still consume polluted water, mostly during the rainy season than in the dry season. The iron and manganese are the key pollutants in the drinking water sources considered in this study Table 8. Consequently, it was observed that the consumers of polluted water sources might be subjected to toxicity of the nervous system and cancer, liver, heart, and pancreatic damage as a result of excess manganese and iron the highly noticed pollutants among other measured elements. Hence, this expresses how rainfall undermines water quality as it facilitates easy pollutants runoff downwards water bodies. From these perceptions calling for urgent rainfall management is a vital for both environmental conservancy and the upgrading of water quality, among the ways that could be using are the reinventing rainfall harvesting techniques within the country.

3.1 Conclusions

Clean water is still a scarce resource in Rwanda. Some people get it once or twice a week or even a month without accessing to water, and there are residents in some areas which do not access it and resort to consuming untreated water from lakes and other water bodies. Lack of clean water is a challenge to hygienic practices such as to wash clothes and the body which may bring up with health impacts especially for young children with the inclusiveness of old ones too, Failing to access on water residents pay Rwf200 [$ 0.206787] per a jelly can (20 litres) to people who brings it to them as it is fetched from farther places and the fetched water they brought seemingly to be un clean. 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 % 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 which adversely affects water quality by carrying sediments, nutrients and heavy metals from uplands. 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 and 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 in Table 11 and 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. 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 %, This gives 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%, which came up with water bodies with good ambient water quality of all water bodies in Rwanda to be at only 40 %. Again, the study examined the quality of drinking water in different categorically indexes **[2]** for both seasons **[3],** where 9 sampling sites were introduced for studying analysis. it was observed that during rainy season water gets more polluted, and the results obtained indicated that the mean value of iron and manganese exceeded the drinking water guidelines of the World Health Organization than other elements measured, and these elements also were highly indexed than other monitored elements. Under all the insights stated in this paper that threatens Rwandan water quality we are suggesting the following measures:

1. Since Rwanda is rich in precipitation throughout the year it is better to launch rainwater harvesting technology as the better technic for suitably attaining the quality of potable water and for environmental conservancy as well. This will upsurge underground storages, and enables local communities to supply drinking water to their infrastructure hence eradicating the scarce of water and reduces sediments carried into source water which are the sources of metals in water.
2. Even though, environmental management is a cross cutting issue at every decision-making level, monitoring and evaluation of its execution and success basing on community's reality and national development plans are highly suggested.

Table 11: 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)

Compliance to all parameters (%)	**E.Coli (Cfu/100ml)**	**Faecal Coliforms**	**Sulfate (mg/l)**	**Chloride (mg/l)**	**BOD (mg/l)**	**Total Phosphorus**	**Total Nitrogen (mg/l)**	**Nitrate (mg/l)**	**Total Suspended**	**Total Dissolved Solids (mg/l)**	**Turbidity (NTU)**	**Compliance to SDG 6.3.2 (%)**	**pH (-)**	**DO (%)**	**DIP (mg/l)**	**DIN (mg/l)**	**Conductivity (µS/cm)**	**Parameters**
87.5	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	100	🟩	🟩	🟩	🟩	🟩	Kivu Lake Gisenyi Beach
87.5	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	100	🟩	🟩	🟩	🟩	🟩	Kivu Lake at Karongi (Beach Golf Hotel)
87.5	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	100	🟩	🟩	🟩	🟩	🟩	Kivu lake at Kamembe port
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Sebeya River at Nyundo station
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Sebeya River at Musabike
81.3	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Rusizi River at Kamanyola bridge
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Rubyiro River at bridge Bugarama-Ruhwa roadKamiranzovu River
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Ruhwa River at bridge Ruhwa border
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Nyabarongo River before receiving Mukungwa
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Nyabarongo after receiving Mwogo and Mbirurume
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Mwogo River up
81.3	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Rukarara River Upstream
68.8	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	80	🟩	🟥	🟩	🟩	🟩	Mbirurume Downstream

75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Secoko River before discharging into Nyabarongo
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Nyabarongo at Ruliba
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Nyabugogo River Downstream
87.5	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	100	🟩	🟩	🟩	🟩	🟩	Nyabugogo River Upstream
87.5	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	100	🟩	🟩	🟩	🟩	🟩	Muhazi Upstream
87.5	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	100	🟩	🟩	🟩	🟩	🟩	Muhazi Downstream
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Muvumba River at Kagitumba
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Warufu River
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Muvumba River after mixing with Warufu River
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Muvumba River entering Rwanda from Uganda
81.3	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Mukungwa River at Nyakinama gauging station
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Mukungwa River before receiving Nyabarongo
87.5	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	100	🟩	🟩	🟩	🟩	🟩	Rugezi before discharging into Burera Lake
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Akanyaru River Gihinga
68.8	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	80	🟩	🟥	🟩	🟩	🟩	Akanyaru River border to Burundi
68.8	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	80	🟩	🟥	🟩	🟩	🟩	Akagera Rusumo border
75	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	100	🟩	🟩	🟩	🟩	🟩	Akagera at Kanzeze bridge
81.3	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	80	🟩	🟥	🟩	🟩	🟩	Borehole at Kayonza-Mukarange-Agatebe
81.3	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	80	🟩	🟥	🟩	🟩	🟩	Artesian well
81.3	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	80	🟩	🟥	🟩	🟩	🟩	Borehole at Gatsibo-Rugarama- Kanyangese-Umunini
81.3	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	80	🟩	🟥	🟩	🟩	🟩	Borehole at Gatsibo-Kabarore-Simbwa- Ruhuha
93.8	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	80	🟩	🟥	🟩	🟩	🟩	Public Borehole at Giticyinyoni
87.5	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	80	🟩	🟥	🟩	🟩	🟩	Public Borehole at Nyandungu
	Not detectable	Not detectable	400	250	50	5	30	20	50	1500	25		5.5 - 9.5	68	5	30	2500	Standards

CRediT author statement

James NTAYOMBA: Original Draft, Conceptualization, Formal analysis, Visualization, Investigation **Li Xiao Ying, Etienne Gasasira:** Resources, Supervision, Project administration, Review & Editing **BWIMBA MUGANGA Godfrey:** Writing - Review & Editing.

Declaration of competing interests

The authors declare no conflicts of interests

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