Egypt. J. Chem. **Vol. 65**, No. 4, pp. 423 - 430 (2022)

Egyptian Journal of Chemistry
http://ejchem.journals.ekb.eg/

Biodegradation Model of Dissolved Organic Matter during River Bank Filtration, at Al-Qurain City, Sharkyia Governorate, Egypt

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Abstract
Riverbank filtration is carried out at natural conditions and may occur by lowering the groundwater stream under the surface water levels either by hydraulic boundaries such as a bank of channels or by groundwater abstraction at pumping wells. In addition, the mixing of the infiltrated river water with groundwater at the pumping outlet well and the bank filtrate's retention time have been studied and identified as one of the critical parameters that determine the efficiency of riverbank filtration and water quality. RBF water results of pH, conductivity, TDS, hardness, color, alkalinity, nitrate, nitrite, phosphate, silica, sulphate, chloride, and turbidity were complying with The Egyptian Ministry of Health and WHO guidelines. The present study showed that groundwater's iron and manganese data in the study region did not comply with Egyptian regulation (Fe more than 0.3 mg/l and Mn more than 0.4 mg/l). The river surface water quality results did not comply with Egyptian regulation in some parameters, such as microbiological parameters (total bacterial count more than 5000 CFU/ml). The examination of river surface water samples was positive in total coliform fecal coliform examination. The study has shown that the water quality results from the RBF water had high water quality, especially in values of Fe & Mn and also microbiological parameters. The correlation coefficient between DOC recorded, and DOC estimated was very strong (r was 0.94).

Keywords: River bank filtration; water quality; Dynamic model; Al-Qurain City; Sharkyia Governorate; Egypt.

1. Introduction

River-bank filtration (RBF) production is an inexpensive, sustainable, and effective treatment technique and improves the quality of surface water [1]. In the RBF process, the surface water passes through the riverbank and the aquifer; the infiltrated water expose to some processes such as sorption, physicochemical treatment, and biodegradation. The processes of sorption, biodegradation, and physicochemical filtration are efficient in removing suspended solids, viruses, bacteria, parasites, some pollutants, and organic and inorganic compounds present in surface waters, like natural organic matter and ammonium [2]. The riverbank filtration process is effective in water treatment and has been recognized in Europe, where many countries were using the RBF in their drinking water demand (~54% in France and Slovak Republic, ~46% in Finland, ~44% in Hungary, ~27% in Switzerland and ~17% in Germany [3]. Hence, RBF supply a drinking water resource, which needs to be protected and maintained, especially within some challenges like river restoration and climate change. Therefore, the management of RBF systems in a varying environment needs a good understanding of the biogeochemical and physical processes during the RBF system [4]. RBF can proceed with natural conditions and or can be induced by a groundwater aquifer under surface water levels either by hydraulic boundaries likes side channels or groundwater pumping. When the groundwater level exceeds a few decimeters below the riverbank, the hydraulic connection is lost, and river water infiltrates through an unsaturated zone, which aerates [5, 6]. RBF systems typically position in alluvial valley aquifers, predominantly consisting of gravels and sands, allowing for high abstraction rates. However, flood-plain deposits are complex geologic systems that exhibit heterogeneity on different scales and can include highly conductive “open framework gravels” forming preferential groundwater flow paths, as well as layers of silt and clay [7]. The elimination of pathogenic microorganisms was found to be practical and related to the traveling time. A breakthrough of

*Corresponding author e-mail: ms_mossad@yahoo.com
Receive Date: 18 September 2021, Revise Date: 05 October 2021, Accept Date: 10 October 2021
DOI: 10.21608/EJCHEM.2021.96710.4527

E. Coli at a pumping well site at the Rhine River was determined after a flood because of shortened groundwater traveling times [8]. Therefore, to be ensuring that the water production is high quality and safe, few traveling times are often required by local regulation and law, and the protection zones should be identified [9]. The required groundwater residence time between the river and pumping well is between 10 and 14 days in Switzerland [10] and between 50 and 60 days in Germany [11]. Infiltration Water River is subject to geochemical water properties changes related to redox reactions, dissolution/precipitation of minerals, ion exchange, and gas exchange [12, 13]. Several studies have illustrated that the most significant geochemical changes were associated with the biodegradation of natural organic matter. The degradation process proceeded dominantly in the first few meters of infiltration, where the microbial abundance and activity were highest [14, 15]. This interface between the river and alluvial groundwater, the hyporheic zone, has been identified as a distinct environment playing a crucial functional role in the biogeochemical cycling of nutrients and organic matter [16].

NOM in river systems originates from both allochthonous (terrestrially-derived) sources and generally more biodegradable autochthonous sources (periphyton) [13]. NOM is composed of dissolved organic matter (DOM) and particulate organic matter (POM). During the infiltration of river water, DOM is transported through the riverbed as a "mobile substrate," whereas POM was retained in the riverbed sediments as a "stationary substrate" [12]. The retention and storage of POM within the riverbed was found to depend on the grain-size distribution of the riverbed sediments and the hydrologic conditions [1]. The microbially NOM degradation was mediated, and it was found that it depends on environment temperature [1]. Redox conditions at different RBF systems undergo seasonal variations with the presence of anoxic conditions in the hot season [11]. Besides temperature, the redox conditions in the infiltration zone are also affected by the availability of electron donors (NOM, ammonium) and electron acceptors (dissolved oxygen, nitrate). During the 1950s and 1960s period of industrialization, the rivers in urban areas carried high loads of organic materials and ammonium [17]. The combination of high loads of organic materials & ammonium with low oxygen levels in river water strongly was reduced conditions prevailed in the infiltration zones of several RBF systems, which causes the mobilization of Mn and Fe. Since the 1970s, river water quality has improved significantly, and oxic conditions in infiltration zones re-established [7].

This study aims to evaluate the river bank filtration water quality and try to make a modeling system to the organic matter biodegrading during passing through the river bed.

2. Experimental

Sampling: The water samples were collected from (El Saadia, Al-Muzainin RBF and groundwater well) at Al Qurain city, Sharkyia governorate, during the period of study (Jan 2017 to Dec 2019), as shown in Fig.1. The samples collection followed strictly the American Public Health Association (APHA) method 4110 B & D [18]. Representative samples were collected using suitable bottles pre-rinsed three times with the sample. The collected samples were preserved if required immediately after collection, labeled, and transferred in a cooler containing ice packs to the ISO 17025 accredited Reference Laboratory for Drinking Water, Egypt, for subsequent analysis (physical, chemical, biological and microbiological analysis). Once arrived the lab, the samples were stored at 4 °C until analyzed.

Material: The reagents utilized in this study were of analytical grade. Ultrapure water at the resistance of 18.0 MΩ (Milli-Q Advantage system, Millipore, USA) was used to prepare standards, stocks, blanks, and mobile and regenerate phase solutions. Working solutions were prepared by proper dilution of certified stock standards.

Analytical Methods: Once arrived the lab, the samples were stored at 4 °C until analyzed, according to the specific reference methods in the American Public Health Association (APHA, 2017), ASTM, EPA, …etc. SPSS 21 software was used for data analysis of dissolved organic matter investigation and biodegradation studies through river bank filtration.

Fig.1. Map of Al-Muzainin RBF and ground water well

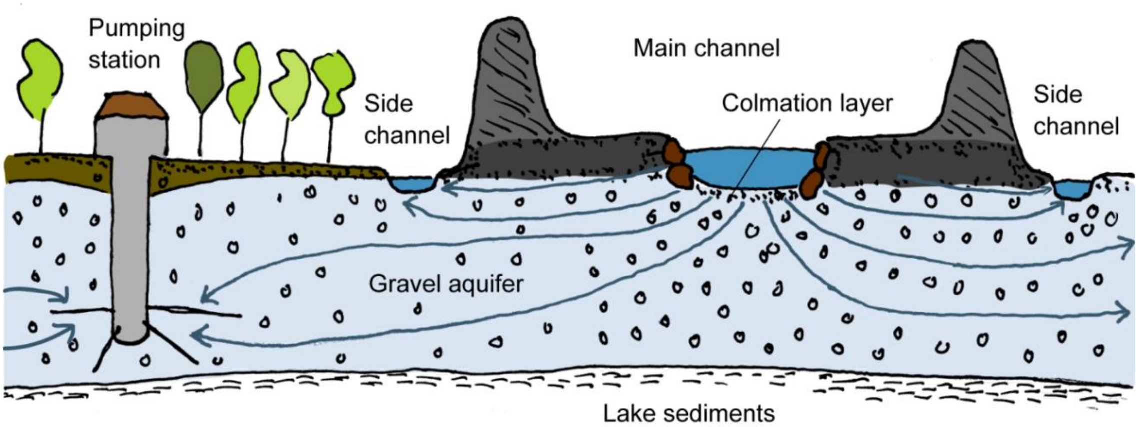

Fig.2. River bank filtration diagram

2- **Results and discussion**

The study aims to simulate the dynamics of dissolved organic matter and abstracted water flow (m3/hr) consumption during riverbank filtration across building a dynamic model as shown in Table 1 and Fig. 3, 4 and 5. The values of DOC in surface, ground and RBF were measured and recorded and also the measurements of water flow of RBF were recorded and water flow of ground and surface were estimated. The verification of the model was calculated and recorded Eq.1 as shown in Table 1 and Fig. 3, 4 and 5. The model implementation is fast and simple, and model run times are short compared to spatially explicit numerical reactive transport models. Hence, the modeling approach provides an efficient tool to estimate TOC concentrations in groundwater from those measured in the river under various climatic and hydrologic conditions. The correlation coefficient between DOC recorded, and DOC estimated was very strong 0.94, as shown in Table 1.

The study aims to evaluate the water quality collected from surface water, groundwater well, and RBF water, Al Qurain City, Sharkyia Governorate, Egypt. The results of water: pH, conductivity, TDS, hardness, color, alkalinity. nitrate, nitrite, phosphate, silica, sulphate, chloride, and turbidity were illustrated in Table 2. The results of pH, conductivity, TDS, hardness, color, alkalinity, nitrate, nitrite, phosphate, silica, sulphate, chloride, and turbidity complied with the Egypt and WHO guidelines (WHO, 2011). While the results of iron and manganese of groundwater didn't comply with Egyptian regulation (Fe more than 0.3 mg/l and Mn more than 0.4 mg/l), as indicated in Table 2. The results of surface water quality didn't comply with Egyptian regulation in microbiological parameters (total bacterial count more than 5000 CFU/ml), and also the examination of surface water samples was positive in total coliform and fecal coliform examination, as indicated in Table 2 and Fig.6.

-Turbidity Removal

Table 2 shows monthly turbidity results of El Saadia canal and water from (El Muzainin RBF, groundwater well). El Saadia canal turbidity varied during this period from 8.4 to 19.2 NTU. The turbidity of El Muzainin RBF and groundwater well remained stable and were consistently below 0.39 NTU. The results of El Muzainin RBF and groundwater well are ranged during the same period from 0.08 to 0.27 NTU and 0.13 to 0.39 NTU, respectively. The data shows that the reduction of turbidity with El Muzainin RBF and groundwater well was about 98 %. This is in accordance with [19, 20], who cited that; the highest reduction percentage of turbidity in the RBF system, also the studies of [15, 21, 22] who showed that the highest performance and stability of RBF system in reducing.

-Total dissolved salts, Iron and Manganese

The total dissolved salts result of the El Saadia canal varied from 192 to 228 mg/l, El Muzainin RBF from 259 to 295 mg/l, and groundwater well from 413 to 444 mg/l during the study period, as shown in Table 2. Many studies were conducted by [23-25] showed that the TDS was significantly reduced in the RBF system than groundwater to be under the allowable limits for potable water. Table 2 illustrated the iron and manganese results of El Saadia canal, El Muzainin RBF, and groundwater well. Fe concentration in El Saadia canal ≤ 0.016 mg/l and Mn concentration ≤ 0.007 mg/l, El Muzainin RBF results of Fe varied from 0.007 to 0.02 mg/l and Mn varied from 0.001 to 0.009 mg/l, groundwater well results of Fe varied from 0.26 to 0.49 mg/l with average 0.39 mg/l and Mn varied from 0.06 to 0.14 mg/l. Many studies were conducted by [21, 22, 25] showed that the values of Fe and Mn concentrations in the RBF system are less than groundwater.

Table 1: Dissolved organic matter prediction through river filtration

	DOC_0 (mg/l)	DOC_g (mg/l)	Q_i (m^3/hr)	Q_g (m^3/hr)	Q_r (m^3/hr)	a	b	DOC_r (mg/l)	DOC_{actual} (mg/l)
1	5.5	0.3	86	16	102	0.26	0.13	**1.21**	1.36
2	4.8	0.2	81	22	103	0.26	0.13	**0.99**	1.1
3	3.9	0.22	77	31	108	0.26	0.13	**0.73**	0.96
4	2.8	0.12	69	43	112	0.26	0.13	**0.45**	0.58
5	3.8	0.19	82	20	102	0.26	0.13	**0.80**	0.98
6	3.6	0.13	81	23	104	0.26	0.13	**0.73**	0.88
7	4.4	0.16	86	29	115	0.26	0.13	**0.86**	0.94
8	4.9	0.15	91	12	103	0.26	0.13	**1.13**	1.28
9	5.8	0.14	74	28	102	0.26	0.13	**1.10**	1.16
10	5.4	0.1	76	25	101	0.26	0.13	**1.06**	1.18
11	5.7	0.1	75	24	99	0.26	0.13	**1.13**	1.19
12	6.5	0.12	72	32	104	0.26	0.13	**1.17**	1.22
13	6	0.15	77	28	105	0.26	0.13	**1.15**	1.26
14	6.1	0.16	74	36	110	0.26	0.13	**1.07**	1.17
15	6.2	0.19	73	35	108	0.26	0.13	**1.10**	1.2
16	3.6	0.1	72	30	102	0.26	0.13	**0.66**	0.75
17	3.9	0.12	72	34	106	0.26	0.13	**0.69**	0.77
18	3.3	0.1	73	31	104	0.26	0.13	**0.61**	0.8
19	3.4	0.1	77	29	106	0.26	0.13	**0.65**	0.8
20	4.8	0.16	79	25	104	0.26	0.13	**0.95**	0.99
21	4.5	0.15	82	20	102	0.26	0.13	**0.94**	1.1
22	4.2	0.14	83	18	101	0.26	0.13	**0.90**	1.1
23	4.1	0.13	84	19	103	0.26	0.13	**0.87**	1.02
24	4.6	0.13	79	29	108	0.26	0.13	**0.88**	1.1
25	4.2	0.12	77	31	108	0.26	0.13	**0.78**	0.95
26	5.3	0.17	74	30	104	0.26	0.13	**0.99**	0.99
27	5.2	0.18	73	33	106	0.26	0.13	**0.94**	1.21
28	5.7	0.19	72	35	107	0.26	0.13	**1.01**	1.2
29	5.5	0.18	74	28	102	0.26	0.13	**1.04**	1.14
30	5.3	0.17	75	28	103	0.26	0.13	**1.01**	1.12
31	5.2	0.16	79	26	105	0.26	0.13	**1.02**	1.14
32	5.4	0.18	82	20	102	0.26	0.13	**1.13**	1.19
33	4.9	0.15	80	26	105	0.26	0.13	**0.98**	1.1
34	4.7	0.14	77	23	100	0.26	0.13	**0.95**	1.06
35	4.4	0.12	75	26	101	0.26	0.13	**0.85**	0.97
36	3.5	0.1	72	30	102	0.26	0.13	**0.65**	0.8
Correlation Factor (r) = 0.94									

DOC_0: Dissolved organic matter concentration in the canal (mg/l)
DOC_g: Dissolved organic matter concentration in the ground water (mg/l)
DOC_i: Dissolved organic matter concentration in the RBF water (mg/l)
DOC_r: Predicted (Calculated) Dissolved organic matter concentration in the RBF water (mg/l)
DOCactual: Dissolved organic matter concentration in the RBF water (mg/l)
Q_i: the water flow rate (m^3/Hr) of RBF well
Q_r: the water flow rate (m^3/Hr) from main stream (canal)
Q_g: the water flow rate (m^3/Hr) from ground water (surrounded area)
a, b and **c** constant
Empirical Model: **DOC_r (mg/l)** = $(a \times (DOC_0 \times Q_i) + b \times (Q_g \times DOC_g))/(Q_r)$ → **Eq.1.**

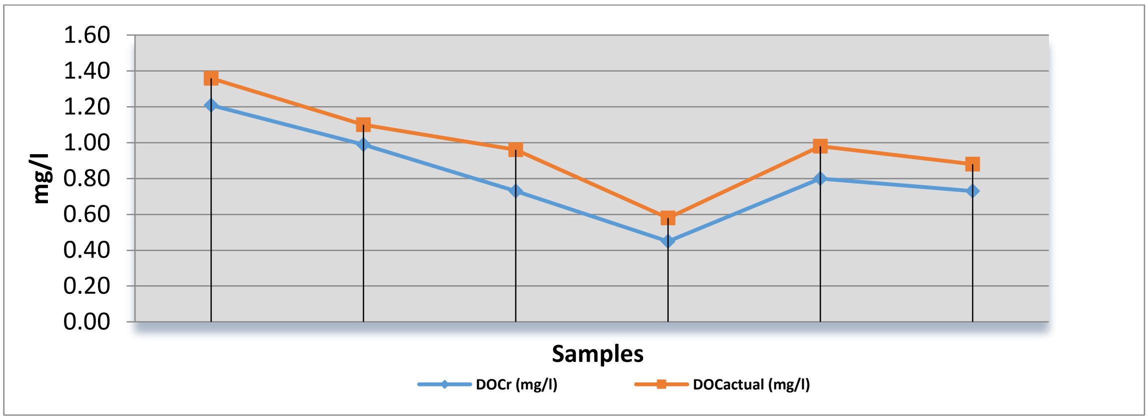

Fig.3. Dissolved organic matter prediction through river filtration

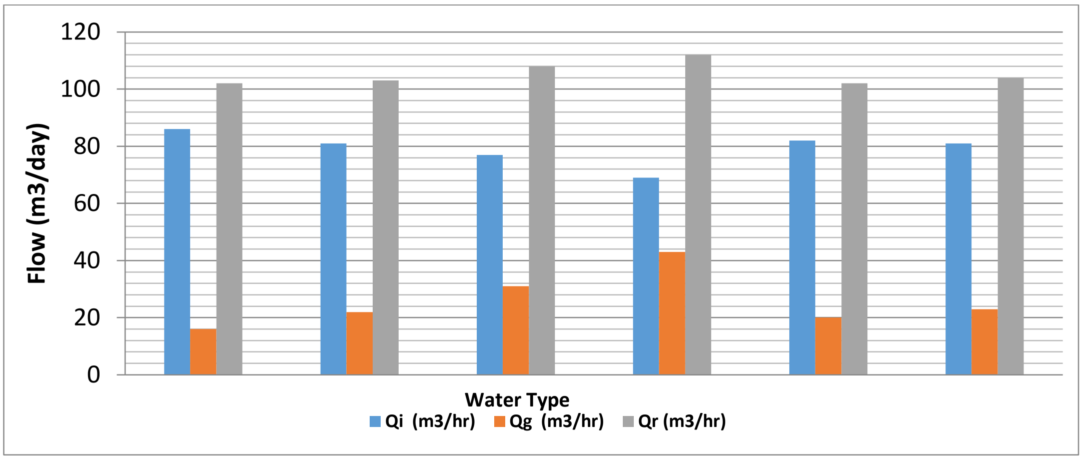

Fig.4. Water flow and water type

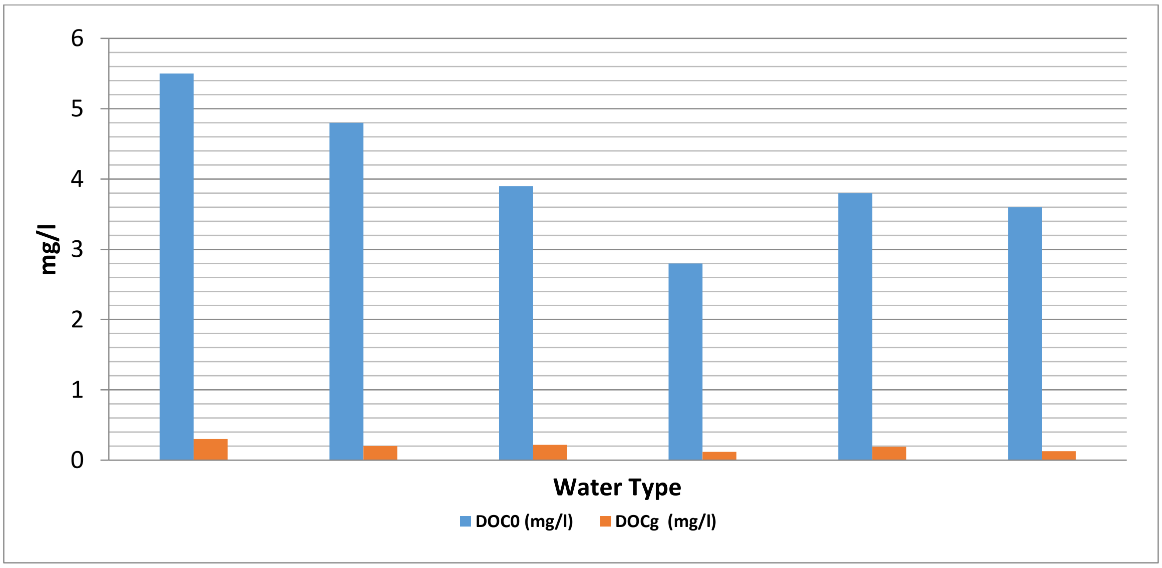

Fig.5. Dissolved organic matter and water type

Table 2: The water-quality monitoring analysis for El saadia canal, El Muzainin RBF, ground water well and EL Qurain water Planet during period study

Sample type Parameter	Unit	El Saadia canal (Surface water)	Ground water well	El Muzainin RBF
		Range (MIN-MAX)		
Temp.	^{0}C	16.6-21.5	17.5-23	17.1-22.3
pH	-	7.95-8.2	7.48-7.9	7.79-8.1
Conductivity	uS/cm	320-380	688-740	432-552
Turbidity	NTU	8.4-19.2	0.13-0.39	0.08-0.27
Alkalinity	mg/l	113-139	212-240	140-156
TDS	mg/l	192-228	413-444	259-295
Total Hardness	mg/l	121-162	224-264	152-173
Sulphate	mg/l	36-46	180-186	40-44
Chloride	mg/l	20-39	45-55	22-28
Nitrate	mg/l	0.71-1.3	0.69-0.9	0.05-0.2
Nitrite	mg/l	0.05-0.16	0.01-0.02	0.01-0.02
Silica	mg/l	1.8-2.7	0.5-1	0.5-0.8
Iron	mg/l	0.01-0.016	0.26-0.49	0.007-0.02
Manganese	mg/l	0.001-0.007	0.06-0.14	0.001-0.009

Microbiological stability

The results of surface water quality in microbiological parameters (total bacterial count more than 5000 CFU/ml) and also the examination of surface water samples were positive in total coliform and fecal coliform examination. The important aspect of El Muzainin RBF performance is the microbiological water quality, as indicated in Table 3 and Fig.6. Some previous studied that executed by [26-28] the studies illustrated that many substances existing in surface water, including particles, bacteria, algae, viruses, parasites, and micropollutants, are large and in most situations perfectly reduced by RBF.

Conclusions

-The current investigation found that the water collected from Al Qurain city's groundwater did not meet local regulations and surpassed WHO criteria (Fe &Mn).

-According to the findings of this investigation, the water collected from surface water in Al Qurain city did not meet local regulations and surpassed WHO criteria (total bacterial count and faecal coliform).

-The water samples collected from surface water may be contaminated as a result of faulty wastewater treatment discharged into the mainstream, making them unfit for human consumption.

-A new semi-analytical model for simulating the dynamics of dissolved organic matter and abstracted water flow (m^3/hr) consumption during riverbank filtration was given in the study. When compared to spatially explicit numerical reactive transport models, the model implementation is quick and easy, and model run times are short. As a result, the modelling approach provides a useful tool for estimating TOC concentrations in groundwater from river measurements under a variety of meteorological and hydrologic conditions.

-The study found that while the amount of water extracted from RBF was greater than that extracted from groundwater, the RBF water produced had high water quality, particularly in terms of Fe and Mn values, as well as microbiological characteristics.

-The correlation coefficient between the DOC measured and the DOC calculated was extremely high (0.94)

Table 3: Average water quality parameters at period of El saadia canal, El Muzainin RBF and ground water well

Sample type Parameter	Unit	Raw surface water	Ground water well	RBF water
Total algal count	U/ml	112000	12	5
Total bacterial count	CFU/ml	43000	32	4
Total coliform	CFU/100ml	411	Nil	Nil
Fecal coliform	CFU/100ml	156	Nil	Nil

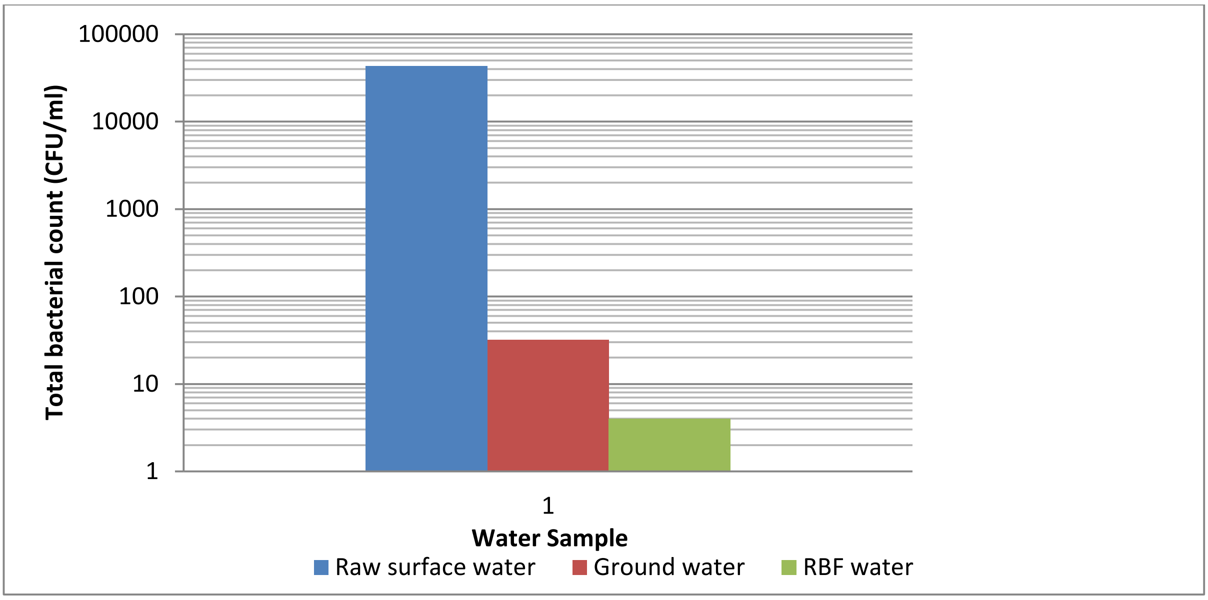

Fig.6: Total bacterial count (CFU/ml) of raw surface, ground and RBF waters

3. Conflicts of interest

"There are no conflicts to declare".

4. Acknowledgments

I am deeply thankful to all Members of the Reference Laboratory for Drinking Water.

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