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Physico-chemical Characterization and Zero Valent Iron Treatment of Borehole Water of Maroua-Cameroon

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Abstract

The quality of borehole water of Maroua was evaluated using physico-chemical properties and treated using Fe/sand mixture of different composition and 100% sand in the reactive zone column filtration. While the pH, iron and chloride amounts were generally within WHO standards other measured parameters were generally above these standards. The Fe/sand system improves pH and entirely removes colour than 100% sand system. It also more performant for hardness removal in three days than 100% sand but the latter is more efficient over a longer period. There is a reduction in the flow rate of the Fe/sand mixture. The borehole water of Maroua I council area is not very potable and can be rendered more potable by using a cheap and simple filtration system based on sand and Fe.

Keywords: Borehole, Filtration, Maroua, Metallic iron, Pollution, Sand

1. Introduction

Water has been described as the most important commodity for sustaining life because it is used for drinking, agriculture, industry, sanitation, food, recreation and transportation (WHO, 2007). Despite this vital rule, its availability in quantity and quality in different parts of the world is seriously hampered by factors such as increase in human population, industrialization, and climatic change, economic and technological limitations. The most important natural sources of water are surface water which include lakes, streams, river, pond, etc. and ground water such as borehole (Prakash et al., 2006). Water from borehole (groundwater) serves as the major source of drinking water in most developing countries because a majority of the population cannot afford the treated bottled water for consumption (WHO, 2000). Unfortunately, this water from borehole is rarely treated in most developing nations thereby posing serious health risk to the consumers (Akharaiyi et al., 2007; Fovwe et al., 2014)). This is due to the fact that water can accumulate many toxic substances as most of them are soluble in it (Ikem et al., 2002). Potable or safe drinking water is thus described as water in which the microbial, chemical and physical properties meet World health organization (WHO) guidelines for drinking water Quality (WHO, 2006).

The Far North region of Cameroon (Maroua being the capital) is characterized by low annual precipitation with annual precipitation concentrated for the most part over 4 months (from July to October) (IRAD, 2013). Access to water quantity and quality is a major concern for the population, as approximately 70% of its population has no access to safe drinking water (PANGIRE), 2009**.** In addition to this water scarcity are also associated the following problems: i) lack of health and sanitation, ii) lack of sewage systems and appropriate septic tanks, iii) an almost permanent presence of stagnant water in rainy season, iv) an abundance of wastewater from various structures. These have been the principal cause of the increased cholera epidemics in Maroua between 1996 and 2010 with about 600 deaths for over 9000 cases detected (WHO, 2010; Djao et al., 2011; WHO, 2011). To overcome this situation, the Government of the Republic of Cameroon and some Non-governmental organizations (NGOs) have tried to resolve these problems by installing a few boreholes and rehabilitating existing ones that were not functioning well. But despite this initiative, the problem is far from been solved, because the maintenance of these boreholes is neglected on the one hand, and secondly, the number of existing boreholes is very small compared to the growing population. Unfortunately, no quality data exist for water from these boreholes as the local councils that are responsible for their management have no expertise in water quality assessment.

A community that lacks potable water and proper sanitation risk devastating diseases accompanied by millions of death especially children (Kravitz et al., 1999). According to World Health Organization estimate's, polluted water is directly or indirectly responsible for 80 % of all diseases (Rail, 2000). Reports say that unsafe water kills more people than any other source of death (WHO, 2011a). Due to the risks associated with the consumption of polluted water, quality assessment of borehole water for drinking and possible treatment particularly with simple and low cost technology should be integrated in the management of this underground water. Filtration has been identified as the simplest efficient technology (Lea, 2008) especially for local communities and homes with no electricity. The main research interest should be how to design a good stand-alone filter which operates for long time demanding neither electricity nor addition of chemicals. Metallic iron (Fe^o) has demonstrated significant efficiency in removing microbial and chemical contaminants from water (Noubactep, 2010). So, Fe^o filters have been suggested as low cost, efficient systems for universal safe drinking water production (Noubactep, 2008) as Fe is low cost and easy to get from industrial deposits. This study was therefore aimed at evaluating the physico-chemical characteristics of water from boreholes of Maroua-Cameroon as well as the efficiency of Fe in treating some of these physico-chemical parameters.

2. Materials and Methods

2.1 Study Area and Sampling of Water

This study was carried in Maroua particularly Maroua I council area. Maroua is characterized by a single rainy season from June to September, with an annual rainfall ranging from 400 to 1100 mm. A rigorous and long drought (seven months and more) prevails in Maroua with temperatures reaching 45 °C (IRAD, 2013). The population has increased from 1,394,765 inhabitants in 1976 to 3,945,168 in 2015 with a population density of 116.6 inhabitants per square kilomete, thus, bearing a heavy burden on the scare water sources of Maroua (BUCREP, 2017).

For this project, water was collected from 40 boreholes in Maroua I council area of Maroua town. These boreholes were located in the urban and rural areas of Maroua I. An example of the borehole is shown in Figure 1. The coordinates of the collection points, the altitudes and the approximate distance from the main city are presented in Table 2. The coordinated were taken using GARMIN etrex 10 GPS.

Water samples were collected in 1500 mL polyethylene bottles. These bottles were washed with detergent, then with deionized water, 2M nitric acid, then deionized water again, and finally with water from borehole. Samples were acidified with 10% HNO_3, placed in an ice bath and brought to the laboratory.

Figure 1. Example of borehole where water was sampled

2.2. Analyses of Physico-Chemical Parameters

The pH, temperature (T), total dissolve solid (TDS), electrical conductivity (EC) were measured on sampling sites using an Extech pH-conductibility EC 500 multiparameter.

Total Hardness was determined by complexometric titration using Eriochrome Black-T as an indicator by EDTA method and Chloride was estimated by Mohr's method using $AgNO_3$ solution and Potassium Chromate as an indicator (APHA, 1985).

The iron determination followed the 1, 10 orthophenanthroline method (Fortune and Mellon, 1938 using a UV-Vis spectrophotometer Spectro 23 RS, LaboMed.inc. The spectrophotometer was calibrated for iron concentrations ≤ 10 mg L^{-1}. All chemicals were of analytical grades.

The sampled water brought to the laboratory was filtered through a Whitman filter paper N° 1 and stored in a refrigerator prior to use for these analyses and for treatment.

2.3 Water Treatment

A column filtration system based on metallic iron (Fe) and sand was used in the treatment process. Each column is 44 cm in length with a 2.5 cm diameter. Each column was dived in to three portions (Figure 2). The first portion from the bottom (20 cm) for each column was packed with sand of diameter greater than 250 µm and less than 315µm. The middle portion which was the reactive zone (11 cm) was a mixture of Fe and sand, all of diameter greater than 315 µm and less than 500 µm. Three filtration systems having a different composition of the reactive zone were used. The first column contained 74.43% of Fe in the reactive zone, the rest being sand, the second contained 71.32% of Fe and the reactive zone of the third column contained 100% sand. The third portion of the column from the bottom (7cm) was packed with coarse sand while 6 cm of the column was occupied by water to be treated.

The pH, total hardness, colour removal, flow rate and iron released in to treated water (for iron containing filtration systems) were used to characterize the three systems. The flow rate was determined by evaluating the time used in obtaining 50 mL of water. The filtrations were done in triplet and reported values for flow rate, pH, total hardness, colour and iron are averages.

Colour removal was determined by measuring absorbance before and after treatment using a UV-Vis spectrophotometer Spectro 23 RS, LaboMed.inc at 538 nm (predetermined from absorption curve).

pH and total hardness were also determined before and after treatment while iron was determined in treated water (1, 10 orthophenanthroline method) for systems containing iron in the reactive zones.

Water from the site 10°57.662' N and 014°30.090' E was used for treatment because of its intense colouration and the fact that over 2000 students use it daily as their main drinking water source. This water already filtered was stored in the refrigerator and used in the filtration process for nine days.

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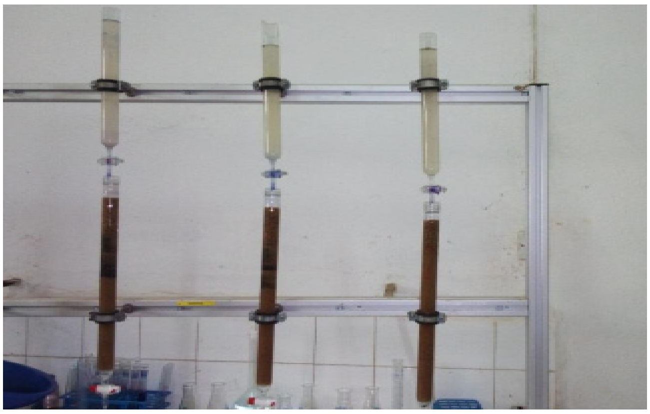

Figure 2. Filtration system used in treatment (composition of reactive zone from left to right; 74.43% of Fe, 71.32% of Fe and 100% sand respectively). Upper columns contain water to be treated

3. Results and Discussion

3.1 Physico-Chemical Characteristics

Results of temperature, pH, electrical conductivity (EC) and Total dissolve solids (TDS) for the different sites are shown in Table 1 while results of Total hardness, Total iron and chloride are shown in Table 2. The temperature for all the sites varied from 28 to 31°C. Although the pH was slightly acidic in most cases, it was generally going toward neutral with a maximum pH of 7.88 for site number 29. Thus, pH was within the WHO limits for drinking water of 6.5-8.5 but temperature was higher than the <25 °C WHO limit for drinking water (Razafitsiferana et al., 2017). Except for site 3, 39 and 40 all the other sites had TDS values higher than the 500 mg/L WHO standard with only site 25 having EC values lower than WHO standard of 250 µS/cm (WHO, 2017). The EC values were exceptionally higher for most sites with altitude less than 400 m (sites 1, 12, 16, 17 and 18) indicating the accumulation of waste material from activities like run off due to the low lying nature of these sites. Results show there was no probable relationship between the parameters studied and the distance from the main city, indicating contamination of the borehole water was not principally from urban or domestic activities but also on natural (composition of soil) as well as agricultural and atmospheric sources. Higher values of EC and TDS may be contributed by Na , K , Ca , Mg , CO , HCO , Cl , SO and NO (Umaran and Ramu, 2015). EC in water is generally due to ionization of dissolved inorganic solutes or mineralization of organic matter in the bottom water (Ramesh and Selvanayagam, 2013). High levels of TDS may produce undesirable taste. The high values obtained for temperature may be due to the fact that the average environmental temperature during the study period was 35-40 °C. Unfortunately, high water temperature favours microorganisms growth and may increase problems related to taste, odour, colour and corrosion (WHO, 2011b).

WHO drinking water standards for Total hardness, Total iron and chloride are 100 mg/L, 250 mg/L and 0.2 mg/L respectively (Razafitsiferana et al., 2017; Bharti, 2017). While iron presence was almost negligible in the borehole water studied (Table 2), the water is very hard as evident by high values of Total hardness obtained (140 -645 mg/L). Hardness is a water property which measures the salts of Ca^{2+} and Mg^{2+} (Bharti, 2017). High values of Total hardness can cause cardiovascular disease, growth retardation, reproductive failure, cancer, Cerebrovascular mortality, Malformations of central nervous system, Diabetes, Kidney stones etc. (Pallav, 2013). High values of Total hardness means the bore hole water of Maroua I is not good for domestic purposes. The chloride values were generally within the WHO standard.

Table 1. Sampling sites and their physico-chemical parameters

Site N°	**Approximate Distance from Main City (metres)**	**Latitude**	**Longitude**	**Altitude**	**T (°C)**	**pH**	**EC (µS/cm)**	**TDS (mg/L)**
1	5	1058218	01428027	398±2m	31.4	6.76	6.84mS/cm	866
2	10	1057784	01427640	407±3m	31.9	6.9	629	437
3	15	1059622	01428586	403±3m	31.4	7.2	312	212
4	10	1059692	01428379	408±3m	31.1	6.4	5.7mS/cm	543
5	5	1060336	01429852	403±3m	31.2	7.4	836	584
6	0	1058981	01429006	406±3m	30.6	7.4	821	571
7	8	1059153	01429770	404±3m	30.8	6.85	1156	805
8	10	10592113	01429883	405±3m	31.3	6.94	1116	781
9	3	1058526	01429661	405±3m	30.5	6.22	882	615
10	4	10585220	01429318	391±2m	29.9	6.91	752	525
11	4	1058359	01430549	405±2m	30.3	6.94	722	505
12	2	1058816	01431820	401±2m	30	6.52	5.77mS/cm	4030
13	4	1059002	01432013	404±3m	30	6.71	850	595
14	10	1059313	01431978	398±3m	29.5	6.47	7.05mS/cm	4930
15	7	1059212	01432893	397±2m	30	6.8	854	600
16	10	1058786	01432296	393±3m	29.9	6.58	7.18mS/cm	5200
17	4	1059294	01433077	397±3m	29.9	6.6	6.84mS/cm	4780
18	5	1059430	01433378	397±2m	29.7	6.83	6.01mS/cm	4180
19	7	1056845	01427481	411±2m	29.9	7.35	2.01mS/cm	1040
20	10	1056888	01427531	416±3m	29.7	7.2	1409	987
21	5	1056354	01427114	423±3m	29.7	7.23	1365	953
22	5	1055755	01426364	417±3m	29.7	5.85	19.74	13.6
23	7	1055823	01426326	420±2m	29.5	7.45	1605	1120
24	10	1055709	01426181	418±2m	29.5	7.65	2.45mS/cm	1720
25	8	1055617	01425504	422±2m	29.7	6.85	14	979
26	4	10555500	01425418	426±2m	28.5	7.18	3.91mS/cm	2730
27	3	1055306	01425375	422±2m	28.1	7.65	4.3mS/cm	2960
28	5	1055397	01425256	422±2m	28.2	7.53	1184	528
29	15	1054752	01424409	423±2m	28.7	7.88	3.37mS/cm	2370
30	3	1055700	01426105	426±2m	28.4	7.61	3.20mS/cm	2240
31	7	1057703	01429124	408±2m	28.2	7.01	1418	992
32	8	1057662	01430090	407±3m	28	6.27	2.70mS/cm	1890

33	15	1056812	01431120	400±2m	28.3	6.91	2.64mS/cm	1840
34	10	1056685	01431090	400±3m	28.4	7.17	1355	950
35	5	1058040	01426752	415±2m	28.4	7.73	3.39mS/cm	2340
36	10	1057827	01426426	416±2m	28.1	7.06	2.65mS/cm	1870
37	8	1057413	01426178	415±3m	28.1	7.08	2.36mS/cm	1680
38	12	1058450	01426192	417±3m	28.1	7.18	7.70mS/cm	3960
39	7	1058218	01428027	398±2m	31.8	7.23	485	338
40	4	1057784	01427640	407±3m	31.8	6.9	503	352

Table 2. Total hardness, total iron and chloride content of some Maroua I borehole water

Latitude	Longitude	Total Hardness (mg/L)	Fe (mg/L)	Chloride (mg/L)
1058786	01432296	645	0.069	283.6
1059313	01431978	570	0.069	283.6
1057662	01430090	165	1.527	35.45
10° 58.218' N	014°28.027' E	535	0.022	195.98
1059622N	01428586E	165	0.038	35.45
1058450	01426192	455	0.000	88.625
1058040	01426752	365	0.000	17.725
1058816	01431820	170	0.000	53.175
1057703	01429124	125	0.000	35.45
1059294	01433077	252.5	0.000	194.975
1059692N	01428379E	140	0.241	35.45
1055617	01425504	325	0.000	70.9
1055306	01425375	335	0.000	106.35
1055700	01426105	170	0.000	17.725

3.2 Assessment of Treatability of Bore Hole Water by Fe^o/Sand Filtration

Metallic iron and sand were used in the reactive zone because studies have shown enhanced contaminant removal in an iron/sand/water relative to an iron/water system due to the avoidance/delay of particle cementation by virtue of the inert nature of sand. 100 % Fe systems will 'clog' rapidly and iron corrosion and the corresponding contaminant removal will be minimal (Noubactep, 2013). This clogging phenomenon is evident in Figure. 3a presenting results of the flow rate of the filtration process (nine days) with different composition of the reactive zone, where it is observed that the flow rate decreases in the order 74.43 % Fe > 71.32 % Fe > 100 % sand.

However, the role of the corrosion products in contaminant removal is demonstrated in Figure 3b. The reactive zones with 74.43 and 71.32 % Fe showed a 100 % colour removal for the nine days of study. These findings are closer to those of (Btatkeu-K et al., 2014), with optimal Fe/sand volumetric ratio of 25/75. Contrarily, the 100 % sand system showed the residual colour increasing from 0.05 on day 1 of the treatment to above 0.10 on the 9th day of the treatment. Though sand is an inert material, it removes contaminants by forming weak hydrogen bonds through its hydroxyl group with aqueous contaminants (Fangwen et al., 2009) which quickly get saturated. Thus, sand and other non-expansive additives should not be regarded as material slowing the mass transport of reactants to the Fe^0 surface, but rather as a dispersant sustaining the system's efficiency (more Fe^0 is consumed, more adsorbing agents are produced). Contaminant removal in iron/sand system occurs on the surface of different iron corrosion products produced in a cycle of aqueous iron corrosion involving (i) oxidative dissolution ($Fe \Rightarrow Fe^{2+}$), (ii) solvatation ($Fe(H_2O)_6^{2+}$), (iii) volumetric expansion (formation of $Fe(OH)_n$ colloids), (iv) volumetric contraction (Fe hydroxides/oxides) processes (Noubactep et al, 2013).

While colour removal with Fe^o/sand systems was very efficient, the flow rates decreased considerably from 1.6 mL/s for 71.32% Fe^o and 1. 3 mL/s for 74.43 % Fe for day 1 of treatment, to about 0. 44 mL/s and 0.42 mL/s respectively on the 6th day and remaining constant up till the 9th day. This indicates generation of more iron corrosion products with increase contaminant removal performance.

The corrosion of iron is evident from its detection in the treated water sample (Table 3). Nonetheless from the values obtained it is difficult to define any corrosion pattern. For the 74.43 % Fe, the concentration of iron that went in to solution increased from 0.00 mg/L in day one to 0.45 mg/L on the 9th day while for 71.32% Fe in the reactive zone, 0.19 mg/L was obtained on day 1 but the rest of the days showed fluctuations (increasing and decreasing).

From the results of pH and hardness presented in Table 3, it is observed that treatment in the presence of iron significantly improves the pH of the water especially for drinking purposes. The increase in pH is the result of the corrosion products mainly the hydroxides which have a basic character. However, there is little improvement in the pH of water treated with 100% sand as sand is not transforming. The removal of the hardness by the iron and sand systems showed high efficiency on the first day of treatment; 165 to 67.5 mg/L for 74.43% Fe in the reactive zone, 165 to 70 mg/L for 71.32% Fe and 165 to 80 mg/L for 100% sand system. The highest removal in the 74.43% Fe in the reactive zone demonstrate the presence of more decontamination sites resulting from more corrosion products. But after three days of treatment this system efficiency for hardness removal was reduced compared to the systems with 71.32% Fe and that with 100% sand in the reactive zone. This is probably due to clogging or agglomeration of sites originating from large amounts of corrosion products. This possibly explain why the system with 71.32% Fe in the reactive zone was more efficient over the treatment period as the large amount of sand present avoided or limited agglomeration. The fact that sand also effectively removed hardness over the nine days may be due to weak electrostatic interactions between the negative sand surface and the cations responsible for hardness.

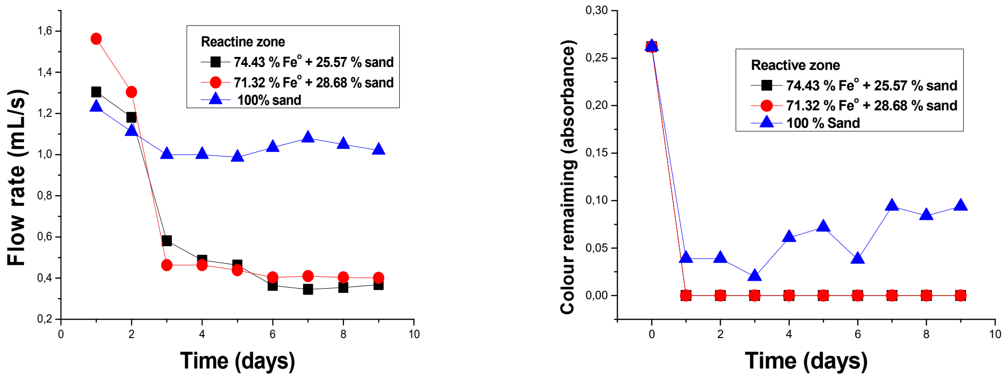

Figure 3. a) Flow rate of the filtration process b) Residual colour after the filtration process

Table 3. pH, Total hardness and released solution iron before and after Fe/sand Fitration.

Time/days	**Reactive zone: Fe°/Sand (74.43 % Fe°)**					**Reactive zone: Fe°/Sand (71.32 % Fe°)**					**Reactive zone: 100 % Sand**			
	pH		**Hardness**			**pH**		**Hardness**			**pH**		**Hardness**	
	Before	After	Before	After	[Fe] mg/L	Before	After	Before	After	[Fe] mg/L	Before	After	Before	After
1	6.49	7.19	165	67.5	0.00	6.49	6.70	165	70.0	0.19	6.49	6.60	165	85.0
2	6.49	7.15	165	85.0	0.08	6.49	7.00	165	80.0	0.58	6.49	7.09	165	92.5
3	6.27	7.40	165	70.0	0.16	6.27	7.35	165	80.0	0.10	6.27	7.01	165	82.5
4	6.27	7.48	165	105.0	0.15	6.27	7.39	165	70.0	0.35	6.27	6.81	165	97.5
5	6.27	7.43	165	95.0	0.15	6.27	7.30	165	80.0	0.19	6.27	6.80	165	82.5
6	6.27	7.33	165	75.0	0.15	6.27	7.30	165	80.0	0.23	6.27	6.96	165	87.5
7	6.27	7.38	165	90.0	0.32	6.27	7.40	165	85.0	0.21	6.27	6.85	165	77.5
8	6.27	7.31	165	90.0	0.24	6.27	7.32	165	85.0	0.08	6.27	6.89	165	77.5
9	6.27	7.31	165	90.0	0.45	6.27	7.27	165	87.5	0.10	6.27	6.88	165	77.5

Before = before treatment, After = after treatment.

4. Conclusions

The following conclusions are drawn based on results obtained from evaluating the physico-chemical characteristics of water from boreholes of Maroua-Cameroon as well as the efficiency of Fe/sand in treating some of these physico-chemical parameters. The majority of boreholes water has temperature, electrical conductivity, total dissolve solids and total hardness values that exceed WHO standards. Equally, the majority of boreholes water contain no iron and has chloride within the WHO standards. Fe/sand filtration system is very efficient for removal of colour from Maroua borehole water than 100% sand. The presence of high amount of Fe in Fe/sand mixture of the reactive zone of the filtration system reduces its permeability over time compared to 100% sand .The use of Fe/sand in the reactive zone of the filtration system improves the pH of the treated water than 100% sand. Also, the use of Fe°/sand and 100% sand in the reactive zones of the filtration systems show high efficiency towards hardness removal. However, the Fe/sand is more efficient than 100% sand for a short term (3 days in this study) while 100% sand is more efficient over a long time (9 days for this study). Fe use in the filtration system releases iron on to the treated water. Although this may be a problem, for the case of Maroua borehole water it is an advantage as this water had almost no iron, a very vital chemical for the human body in trace amounts. Owing to the dependence of over 70% of the population on this water source, results obtained in this study should permit the government and the donating NGOs to equip these boreholes with treatment systems so as to render the borehole water potable and limit water quality related epidemics very recurrent in Maroua. Simple filtration systems employing sand and zero valent iron, all of them locally available can significantly render this water potable as evident from results of this study.

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