Journal of Materials and
Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN
Copyright © 2023,
University of Mohammed
Premier Oujda Morocco

J. Mater. Environ. Sci., 2023, Volume 14, Issue 03, Page 348-359

http://www.jmaterenvironsci.com

Removal of iron and manganese by aeration and coagulation-flocculation in borehole water from the town of Rumonge (Burundi)

P. Ntakiyiruta[1], P-Cl. Mpawenayo[1], D. Rucakumugufi[1], P. Bigumandondera[3], T. Ndikumana[1], Jean Luc Vasel[2]

(1) Université du Burundi, Centre de recherche en sciences Naturelles et de l'environnement, B.P : 1550 Bujumbura-Burundi.
(2) Université de Liège, Département des Sciences et Gestion de l'Environnement. Unité « Assainissement et Environnement ». Avenue de Longwy, 185.B.P: 6700 Arlon- Belgique.
(3) Université du Burundi, Centre Universitaire de Recherche et de Pédagogie Appliquées aux Sciences, BP 5223 Bujumbura - Burundi

**Corresponding author, Email address: pierre.ntakiyiruta@ub.edu.bi*
***Corresponding author, Email address: pierrentakiyiruta@yahoo.fr*

Received *03 Feb 2023,*
Revised *23 Mar 2023,*
Accepted *27 Mar 2023*

Citation*: Ntakiyiruta P., Mpawenayo P.Cl., Rucakumugufi D., Bigumandondera P., Ndikumana T., Vasel J.L. (2023) Removal of iron and manganese by aeration and coagulation-flocculation in borehole water from the town of Rumonge (Burundi), J. Mater. Environ. Sci., 14(3), 348-359.*

Abstract: Groundwater often contains very high levels of iron and manganese. These two metals alter the taste and color of the water, stain clothes and sanitary appliances. In order to supply water to the population of the town of Rumonge in the southwest of Burundi, the REGIDESO (Régie de Production et de Distributioon d'eau et d'Electricité) in collaboration with the International Committee of the Red Cross (ICRC) proceeded with the drilling of underground water. Despite the great costs and means invested, the water became cloudy after a few minutes of exposure to the open air. The objective of this work is to study the water quality of this city and to compare two methods of iron and manganese removal: oxidation by air blowing and coagulation-flocculation. These two techniques were followed by the percolation of the treated water on a bed of gravel and sand. The analysis of organoleptic, physico-chemical and microbiological parameters by classical standard methods revealed that some values largely exceed the WHO guideline values for water intended for human consumption. These include an acidic pH (6.2), turbidity (68 FTU), BOD_5 (9.5mg O_2/L), NH_4^+ (6.2mg/L), PO_4^{3-} (2.85mg/L), Fe (16.5mg/L), Mn (3.60mg/L), dissolved O_2 (2mg O_2/L), Escherichia Coli (53.5UFC), mold (385) and yeasts (256). Deferrization and demanganization by air blowing resulted in Fe and Mn removal of 55.9% and 47.66%, respectively. The coagulation-flocculation method followed by filtration resulted in a much higher Fe and Mn removal of 91.7% and 90.34%, respectively.

Keywords: *Deferrisation, Demanganisation; Coagulation; Flocculation; Aeration; borehole water*

I. Introduction

Clean water is a basic necessity of human life. In the urban areas of developing countries, access to quality water is an ordeal for thousands of city dwellers (Alhassan et Kwakwa 2013; Kengmoe *et al.* 2020; Zogo *et al.* 2011). Improving access to clean water strengthens human development and protects people from water and sanitation related diseases such as cholera and dysentery (Alhassan et Kwakwa 2013; Kone *et al.* 2022). In Burundi, access to clean water in sufficient quantity and quality remains a major challenge for the government. Its hills are full of this blue gold that is so often lacking on the continent. However, many people still lack access to safe drinking water. In urban areas, only 77% of the population has access to water, while in rural areas, 43% have access (Ministère de l'Eau, de l'Environnement, de et l'Aménagement du Territoire et de l'Urbanisme 2013**)**. Water supply for the population can be provided from two sources with different characteristics: surface water and groundwater (Kangombe 2020; Kouadia *et al.* 2023). For a long time, groundwater has been synonymous with "clean water" and naturally meeting the standards of potability(Kangmoe *et al.* 2020; Godinaud *et al.* 2023).These waters are indeed less sensitive to accidental pollution. However, groundwater can also contain elements (or bodies) with concentrations far exceeding the standards of potability. This is due to the composition of the storage ground. We can mention Fe, Mn, H_2S, F... *(*Junior Ophélie *et al.* 2020).

In the town of Rumonge (Burundi), the underground water (borehole water) that is distributed by REGIDESOin collaboration with the ICRC has a pumping rate of 20L/s. This water is characterized by poor organoleptic properties: yellowish-brown coloring, salty taste, stains the laundry during washing. Analyses carried out of this water by REGIDESO have shown very high concentrations of iron and manganese (10mg/l and 2mg/l respectively). The population of Rumonge complains that this water is also the source of so-called dirty hands diseases (cholera, diarrhea) and intestinal worms (Alonso 2020). To solve the problem, the ICRC and REGIDESO have tried different solutions: (i)Change the depth of catchment, (ii) Mixing the pumping water already treated with that of the gravity springs in proportions of 10L/s and 6L/s, respectively (Alonso 2020).

Despite these alternatives, the problem has been mitigated but not solved as a whole. In addition, the borehole was located downstream from the houses and fields (mostly palm trees) where the water table is less than 2m deep (Ministère de l'Eau, de l'Environnement, de et l'Aménagement du Territoire et de l'Urbanisme 2013). In view of this situation, it has been hypothesized that the infiltration of wastewater from households and runoff water could easily pollute the borehole water and cause so-called dirty hands diseases. Geologically, this borehole is located in an amphibole-dominated zone. Amphiboles are minerals containing, among other things, the elements : Na-Ca-Mg-Fe-Al-Mn-Li (Fabriès et Rocci 1965).

From then on, two other hypotheses emerge: (i) The yellowish-brown coloration observed would be due to the presence of iron and manganese from the alteration of amphiboles, (ii) The salty taste and the precariousness of the hygienic quality of the water can be of anthropogenic as well as natural origin. At concentrations above 0.3 mg/L, iron can not only stain laundry and plumbing fixtures, but also give an unpleasant taste to drinks (Abdennour et Ait Namane 2015; Achour *et al* 2017; Edith *et al.* 2022; Pang *et al.* 2023).

In addition to the above, iron can stimulate the multiplication of certain microorganisms that eventually form a biological film in water mains (Ayouba Mahamane et Guel 2015). Manganese can also cause irreversible neurological disorders because of its antagonism towards calcium. These disorders generally occur when iron and manganese concentrations are respectively higher than 10mg/L and 2mg/L (Kouame 2008; Ayouba Mahamane et Guel 2015). Faced with this situation more worrying in this developing country. It is therefore necessary to develop innovative, simple and effective methods to treat these wastewater. Among these methods, oxidation by air blowing and coagulation-flocculation have proven to be efficient and less expensive (Seghairi *et al.* 2017; Rakotomaria, Ratsimba, et Rakotomamonjy 2011). Thus, groundwater intended for consumption must be treated to remove all effects that interfere with its use. Once treated, it must meet the standards of potability. Thus, the objective of this work is to study and compare the quality of four types of the water consumed in the city of RUMONGE. Also, this study compare two methods of elimination of iron and manganese from borehole water: oxidation by air blowing and coagulation-flocculation.

II. Material and methods

II.1. Description of the study site

The town of Rumonge is one of the towns in Burundi where the lack of water is no longer to be demonstrated. It is located in the South of Burundi, in the province of Rumonge, 72 km from the Capital Bujumbura. Its geographical coordinates are : Latitude = 3o58'20 South (= -3.9722), Longitude =29o26'20 East (= 29.4389) and Altitude = 809 m above sea level (Ruzima *et al.* 2017). The city of RUMONGE is located on the shores of Lake Tanganyika. Its population is about 70 000 people (Ruzima *et al.* 2017). The drilling in RUMONGE is located in the KANYANKOKO district of this city. This district is geographically located in the west of this city. Moreover, this borehole is located downstream of the houses and fields, especially palm trees, and it is about 100 m from Lake Tanganyika. From the point of view of mineralogical composition, it is located in the Makara formation, a zone characterized by amphiboles. In this city, borehole water represents more than 70% of the distributed water (Alonso 2020).

II.2. Characterization of treated water samples

II.2.1. in situ measurements

For the parameters to be analyzed in situ and in the laboratory, sampling was done on four types of water: (i) raw water (i.e. water coming out of the borehole), (ii) filtered water (i.e. collected after passing through the Aquatile® filters), (iii) castle water (filtered and chlorinated borehole water), (iv) tap water (water resulting from the mixture between castle water and spring water). The parameters that may vary during transport were measured in situ. These are pH, temperature, conductivity, redox potential, dissolved oxygen, free CO_2 and alkalinity. The first five parameters were measured with a multi-probe apparatus "consort model C562" equipped with a specific electrode for each parameter and a temperature probe. The last two parameters were measured by the titrimetric method(Rodier 2009).

II.2.2. Measurements in the laboratory.

During the collection of the samples, the containers are rinsed several times with water to be analyzed. The samples are taken in brown glass bottles and in polyethylene terephthalate canisters. To ensure good preservation and avoid alteration of the samples before analysis, depending on the parameters to be determined, in some samples a few ml of concentrated acids (H_2SO_4) are added, and others are placed directly in expanded polyurethane containers (frigolites) containing ice cubes. Samples for microbiological analysis are placed in sterilized vials and placed in frigolites. Carefully labeled and well-packaged samples are transported to the laboratory.

II.2.2.1. Physico-chemical analyses.

The physico-chemical parameters: turbidity, Fe (Fe^{2+} and Fe^{3+}), NH_4^+, PO_4^{3-}, SO_4^{2-}, NO_3^-, Mn, total hardness, calcium and magnesium hardness, Chemical Oxygen Demand (COD), Biological Oxygen Demand after 5 days (BOD_5) were analyzed at the Laboratory of Chemistry and Environmental Analysis (LCAE) of the Faculty of Sciences of the University of Burundi. Turbidity, Fe (Fe^{2+} and Fe^{3+}), NH_4^+, PO_4^{3-}, SO_4^{2-}, NO_3^-, chemical oxygen demand (COD), were measured by spectrophotometric method (Rodier 2009). Cl- ions are measured by simple titration while total hardness, Ca^{2+}, Mg^{2+}, are measured by complexometric titration (Rodier 2009) . BOD_5 was measured by the manometric method using OxiTop systems. Manganese contents were determined by the spectrophotometric method using a Shimadzu UV-visible spectrophotometer, model UVmini-1240V. Manganese is oxidized to permanganate using potassium periodate (KIO4) and this permanganate is determined spectrometrically at a wavelength of 545nm(Rodier 2009).

Suspended solids (SS) and volatile suspended solids (VSS) were determined using conventional methods: The water was filtered and the weight of the solids retained by the filter was determined by differential weighing. For TSS, the calculation is made after steaming the residue at 105°C for 2h and for VSS, the calculation is made after calcining the residue at 550°C for 2h (Rezania *et al.* 2016).

Total Carbon (TC) and Total Nitrogen (TN) analyses were performed by the infrared detection method (Joussein, Petit, et Decarreau 2001; Ju *et al.* 2022) using a Shimadzu brand analyzer (model TOC-VCPH) at the University of Liege laboratory in Belgium. To perform this measurement, samples were first filtered on GF/C filters (Wattman 0.45µm).

II.2.2.2. Microbiological analyses

Microbiological analyses (Total aerobic mesophilic flora, Total coliforms, Escherichia coli, Yeasts, Moulds) were carried out in the microbiology laboratory of the Faculty of Agronomy and Bio-Engineering (FABI) of the University of Burundi. For this purpose, the standard methods (AFNOR) and Food and Drug Administration (FDA) were used (Afnor 1994). Thus, the sample to be analyzed was each time inoculated on the surface on agar medium and the enumeration of microorganisms was done by counting colonies. Four types of water were analyzed: raw water, filtered water, castle water and tap water.

II.3. Physical-chemical engineering processes for iron and manganese removal

After evaluating the quality of the borehole water of the town of Rumonge, we found that this water deserves an additional treatment before being distributed. Thus, in the spirit of finding a better treatment technique, four scenarios were put into play:

II.3.1. *The oxidation method by air blowing*

The aeration technique is an operation to compensate for an O_2 deficit in the raw water or to rid the water of unwanted gases (such as H_2S) in excess (Kouame 2008; Wei *et al.* 2023). During deferrisation and demanganisation by air blowing, a Tetra APS 50-400 aquarium air pump was used and the flow rate was set at 50L/h. This pump is equipped with a diffuser that can operate in a reactor with a volume varying between 10 and 60 Liters. The measurement of some parameters allowed to find the optimal duration of oxygenation which is 40s. The experimental setup for the aeration technique is shown in Figure 2.

II.3.2. The coagulation-flocculation method.

Coagulation-flocculation is a physico-chemical water purification process used for the treatment of drinking water or wastewater. Its principle is based on the difficulty that colloidal particles have to settle naturally. First, coagulation by adding metal salts removes the intercolloidal repulsions and the colloidal particles can now meet. In the second step, flocculation allows to tackle the problem of the small diameter of the colloids. With the addition of the flocculant, the colloidal particles agglomerate, forming a floc that can settle (Rakotomaria, Ratsimba, et Rakotomamonjy 2011; Lu *et al.* 2022).

In these tests of well water treatment by the coagulation-flocculation method, a device known as the Jar test (Figure3) was used. The objective was to determine the optimal dose of coagulant-flocculant and the minimum resting time. In these tests, the coagulant-flocculant used was alumina: $Al_2(SO4)_3.18H_2O$ at the concentration of 7.5g/l. The addition of alumina to each sample was preceded by an addition of 0.1N NaOH at a rate of 0.290ml/ml of alumina. The NaOH was used to adjust the pH of the samples (Wu *et al.* 2012; He et *al.* 2019). The tests were performed in beakers each containing 650 mL of borehole water sample. The reagents were first mixed rapidly at 170 rpm for 5 min and flocculation was achieved at a slower speed (i.e. 45 rpm for 15 min). Monitoring of the turbidity evolution as a function of time allowed the determination of the optimal dose of coagulant-flocculant and the optimal resting time.

Figure 2. The experimental setup for the aeration technique

II.3.3. Method of aeration and coagulation-flocculation followed by filtration on the gravel-sand bed

II.3.3.1. Preparation of the sand-gravel and the column.

a) Preparation of the sand-gravel

Filtration is a technique of separation and fractionation of substances, more specifically it separates the solid phase from the liquid phase (Holtz et *al.* 2020). The sand and gravel used were made available to us by the Regie of Production and Distribution of Water and Electricity (REGIDESO). Before use, they were first washed with water and 0.5N hydrochloric acid, then rinsed several times with distilled water, and then sun-dried. The gravel was used without sieving. In order to establish a particle size curve of the sand, 1000g of the sand sample was sieved on a series of 9 standardized sieves with different cutoff mesh sizes. The cumulative percentages of passings are used to establish the particle size curve and the average grain as well as the uniformity coefficient. The average grain or median grain of the sand used for this study is 0.29mm. This value places our sample in the good range of slow filtration sands. The grain size curve of the sand is shown in **Figure 5**.

b) Preparation of the column.

Two PVC columns with an internal diameter of 110 mm and a height of 1.20m were filled with sand passing through a 1.19mm diameter sieve. The gravel was taken without sieving. For the filling, two scenarios were considered to highlight the influence of the sand thickness: (i) In the first column, 40cm of gravel is topped by a 40cm layer of sand, (ii) In the second column, 40cm of gravel is covered by 60cm of sand. The infiltration times obtained are 189 seconds and 237 seconds respectively for the first and second column. Thus, the second scenario (40cm of gravel + 60cm of sand) was retained in the following analyses.

II.3.3.2. Implementation of aeration, coagulation-flocculation followed by filtration on a bed of gravel-sand bed.

For each technique, the column filled with 40cm of gravel topped with 60cm of sand was used. A volume of water to be analyzed of 2.5L was first treated under the optimal conditions of the technique: 40 seconds of oxygenation for aeration on the one hand, and a coagulation-flocculation after an addition of 7.5g/L of alumina on the other hand. This volume is continuously introduced in the column. In order to measure the two elements (Iron and Manganese) in the percolate, the last drops of the filtrate are collected and their contents are determined. After decantation of each water sample under analysis, the column is washed with 1500 mL of 0.5N HCl, then rinsed thoroughly with distilled water until the negative tests of the elements Fe, Mn and Cl.

III. Results and discussion.

III.1. Results of physico-chemical **and microbiological** *analyses*

The results of the physico-chemical and microbiological analyses are presented in **Tables 1** and **2** respectively. It is a synthesis of several measurements carried out on aliquots of samples from 5 different sampling campaigns.

III.1.1. Physico-chemical analyses

The results of analysis of various physico-chemical parameters allow us to emit the following observations: The average temperature (27.2°C ± 0.10) is slightly above the WHO standard **(**Masschelein 1996**)**. The average pH (6.20 ± 0.13) of the samples is acidic and the calculated value of the Langelier saturation index I (I= -1.94) shows that the water from the Rumonge borehole is an aggressive water. It can easily corrode the piping and concrete storage structures (Masschelein 1996**)**. Turbidity is an indicator of the presence of fine suspended matter. All the waters studied, up to the tap water, have a turbidity higher than the standard (68.33 MPO ± 26.44). The deposits formed in the pipes and tanks create a favourable environment for the proliferation of bacteria **(**Lu *et al. 2022***)**. The average concentrations of Fe and Mn in the tap water are respectively (1.88 mg/l ± 0.16) and (3.54 mg/l ± 0.18). These values, as well as those of other samples, are largely higher than the WHO standard which sets it at 0.3mg/l and 0.05mg/L respectively for Fe and Mn **(**Abdennour et Ait Namane 2015**)**. These waters can be classified as critical waters. Except for the tap water, the other samples contain very high concentrations of ammonium (6.2 mg/l ± 2.21). The presence of ammonium generally indicates pollution of organic origin (Ntakiyiruta *et al. 2020*). In addition, ammonium can lead to the formation of chloramines during chlorination. Phosphates are very abundant, especially in raw water, where the average is 2.85 mg/l, whereas the WHO guide value is 0.1 mg/L(Ntakiyiruta *et al. 2020*). The presence of phosphates may be due to infiltration from cesspits or manure deposits (Rodier 2009). Dissolved oxygen is very low, especially in raw water [(2.06 ± 0.87) mg/l]. The BOD_5 parameter is used to establish a qualitative classification of the water and to define the alteration of the environment by biodegradable organic matter. The comparison of the BOD_5 of the borehole water of the town of Rumonge [(9.5±0.88) mg O_2/l] with the standard value (< 3 mg O_2/l) shows that these waters are of very poor quality. Suspended solids and volatile suspended solids that should be absent are present in all categories of water analyzed. The total carbon results show that the filters used to treat the drilling water may act as an accumulator of some elements. The TC is 60.28mg/l in the raw water and 60.71mg/l in the filtered water.

Table 1. Comparison of physico-chemical analysis results from this study with standard values.

Parameters	Untreated Water	Filtered water	Castle water	Tap water	Standards WHO (Masschelein 1996)
Temperature (°C)	27.2 ± 0.10	27.5 ± 0.2	28.8 ± 0.5	27.9 ± 0.3	25
Ph	6.20 ± 0.13	6.22 ± 0.15	6.34 ± 0.12	6.40 ± 0.13	6.5-9
Turbidity (FTU)	68.33 ± 26.4	60.00 ± 36.0	26.33 ± 4.4	10.33 ± 2.4	1
Conductivity (µs/Cm)	216.33 ± 5.1	208.66 ± 6.4	205.33 ±21.7	89.3 ±14	-
Redox potential (mv)	-5.66 ± 25.7	-13.33 ± 19.7	102.00 ± 8.6	237.33 ± 27.77	-
Oxygen-dissolved (ppm)	2.06 ± 0.87	3.80 ± 1.15	4.22 ± 0.84	4.18 ± 1.20	>5
Fe (mg/L)	16.5 ± 1.00	12.15 ± 0.70	4.80 ± 2.00	1.88 ± 0.16	0.3
Mn (mg/L)	3.28 ± 0.10	2.06 ± 0.04	2.67 ± 0.81	3.54 ± 0.18	0.05
Total hardness (°TH)	10.37 ± 2.6	5.56 ± 1.42	5.63 ± 1.44	5.46 ± 1.3	15°F)
Ca (mg/L)	22.71 ± 6.2	12.3± 3.24	12.79± 5.35	13.40± 4.3	100
Mg (mg/L)	11.46 ± 2.76	7.02 ± 2.45	6.52 ± 1.05	5.96 ± 1.15	30
Alkalinity (°F)	10.90 ± 0.39	10.47 ± 0.6	7.42 ± 1.6	4.60 ± 0.48	2.5
Chlorides (mg/L)	229.07 ± 1.32	310.05 ± 1.7	298.40 ± 1.7	139.15 ± 15.45	250
Sulphates (mg/L)	18.50 ± 0.50	13.50 ± 0.60	11.50 ± 0.4	7.40 ± 0.10	250
Nitrites (mg/L)	0	0	0	0	0.1
NH$_4$ (mg/L)	6.20 ± 2.21	5.02 ± 2.02	3.10 ± 1.2	0.17 ± 0.12	0.5
Nitrates (mg/L)	0.231	0.127	-	2.417	50
Phosphates (mg /L)	2.85 ± 0.05	0	0	0.092	0.1
COD mg d'O$_2$/L	15.00 ± 1.33	15.66 ± 6.2	4.00 ± 3.0	1.50 ± 1.33	30
BOD$_5$ mg d'O$_2$/L	9.50 ± 0.88	9.33 ± 3.7	2.66± 2.4	1.22 ± 0.88	<3
CO$_2$ libre (mg/L)	52.40 ± 2.60	49.60 ± 2.4	50.70 ± 2.3	-	Non-Aggressive water
MES (mg/L)	20	7	-	2	Absent
MVS (mg/L)	15	7	-	2	Absent
C$_T$ (mg/L)	60.28	60.7	-	37.07	-

Table 2. Comparison of microbiological results from this study with standard values

Germs	Untreated Water	Filtered water	Castle water	Tap water	StandardsWHO (Masschelein 1996)
Mesophilic aerobic flora Total (MA FT)	(73.00 ± 6.66) $x10^3$	(45.33 ± 9.55) $x10^3$	(14.33 ± 7.88) $x10^3$	(31.00 ± 16.66) $x10^3$	<100 /mL
Total coliforms	310.00 ± 33.33	240.00 ± 10.00	2.66 ± 1.11	39.33 ± 2.17	0 /100mL
Escherichia *coli*	53.33 ± 12.88	192.00 ± 16.00	2.00 ± 1.33	12.33 ± 2.44	Absent
Yeasts	256.00 ± 18.66	222.00 ± 24.00	131.33 ± 13.55	118.00 ± 11.33	-
Moulds	385.00 ± 24.66	443.33 ± 6.22	493.33 ± 29.77	268.00 ± 29.33	-

III.2. Results ofmicrobiological analyses

The results of the microbiological analyses reveal a massive presence of germs, notably *Escherichia coli*. The Rumonge well water is constantly contaminated by fecal pollution germs. Most of this permanent contamination comes from household discharges because the piezometric level of the water table is less than 2m from the surface of the ground, not to mention the effects of open defecation (Han et Morrison 2022).

III.3. Results of the physical-chemical engineering processes of iron and manganese removal

III.3.1. Aeration

By measuring some parameters, we were able to determine the aeration time and the results of these measurements are presented in **Table 3**.

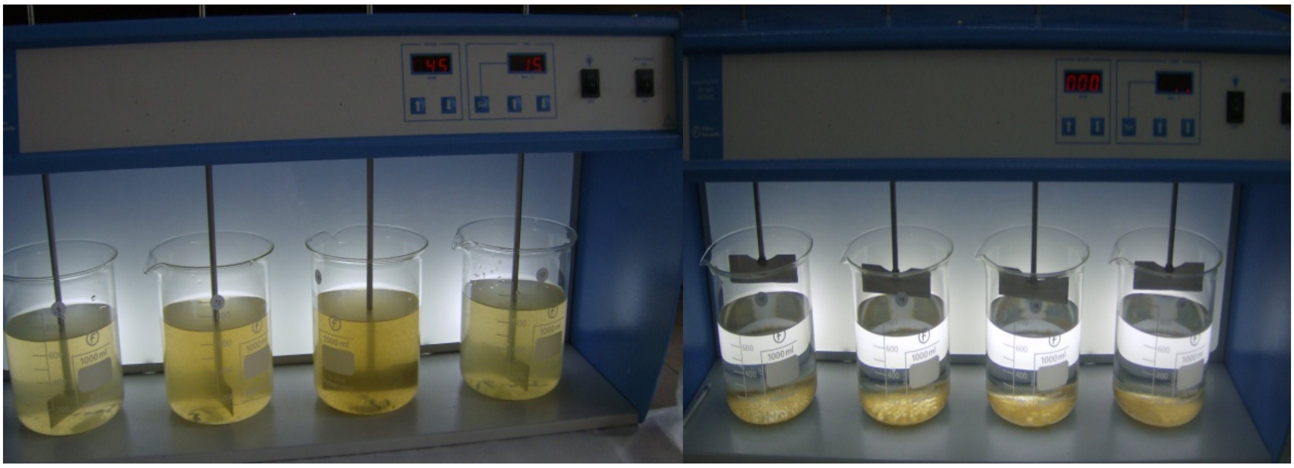
Table 3. Monitoring of the evolution of some parameters after aeration

	Contact time (in seconds)						
Parameters	0	10	20	30	40	50	60
Temperature (°C)	24.7	24.7	24.7	24.6	24.5	24.5	25
O_2 dissolved mg/l	2.35	2.75	3.58	4.3	4.69	4.26	4.2
pH	6.21	6.42	6.85	6.94	7.12	7.08	7
Cond (µs/cm)	204	204	204	205	205	205	204
Redox potentiel (mv)	143	143	139	98.8	86.92	79.2	55
Turbidity (FTU)	58	58	50	16	16	16	16
Fer (mg/l)	15.5	15.2	14.6	13.2	11.6	11.6	12
Manganese (mg/l)	3.34	3.34	3.1	2.58	2.22	2.22	2.2

The aeration results show that the optimal aeration time is 40s, after which the pH and dissolved oxygen pass through a maximum (7.12 and 4.69 respectively). The observed deferrisation and demanganisation rates were 25.16% and 33.53% for iron and manganese respectively. In view of these results, the problem of high concentrations of these two elements is not resolved. Therefore, the air blowing method is not appropriate for the removal of the two elements Fe and Mn, in order to respect the standards. This difficulty in removing Fe and Mn could be explained by the presence of other ionic species in the water, such as bicarbonates, sulphates, silicates or the presence of organic matter that can contribute to the stabilization of iron and manganese in the form of complexes and increase the difficulty of their oxidation (Achour *et al*, 2017).

III.3.2. Coagulation-Flocculation

Figure 3 shows the appearance of the water after treatment by the coagulation-flocculation process. It shows a clear decrease of turbidity. The minimum turbidity is obtained with 4 ml of a 7.5g/l solution, i.e. 30mg of alumina, and after 45 minutes of rest. It should be noted that the increase in turbidity beyond the optimal dose is due to a re-solution of the precipitated colloids following the charge inversion (Fatombi *et al.* 2013). **Figure 4** shows the evolution of turbidity as a function of coagulant-flocculant dose and rest time.



(a) Before the Jar-test experiment (b) After the Jar-test experiment

Figure 3. Experimetal setup for the Jar-test.

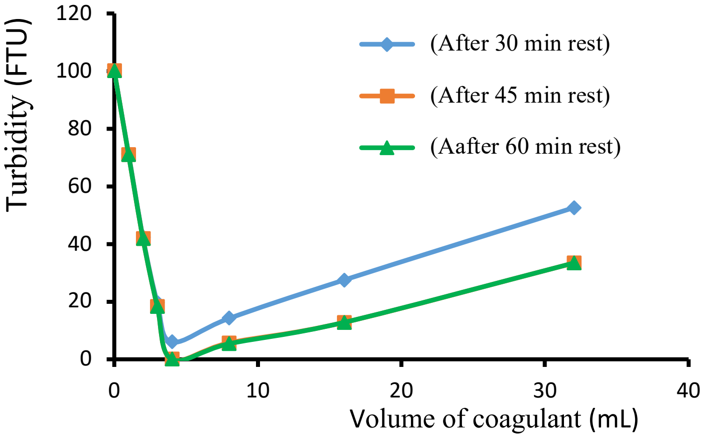


Figure 4. Time evolution of turbidity as a function of the coagulant-flocculant dose

III.3.3. Aeration, coagulation-flocculation followed by filtration on a gravel-sand bed

The aeration and coagulation-flocculation was followed by filtration on a gravel-sand bed. We first established the particle size curve and it is shown in **Figure 5.** The average grain size of the sand used is 0.29mm. The results, expressed as % removal rate after aeration, coagulation-flocculation followed by gravel and sand bed filtration are reported in **Table 4.**

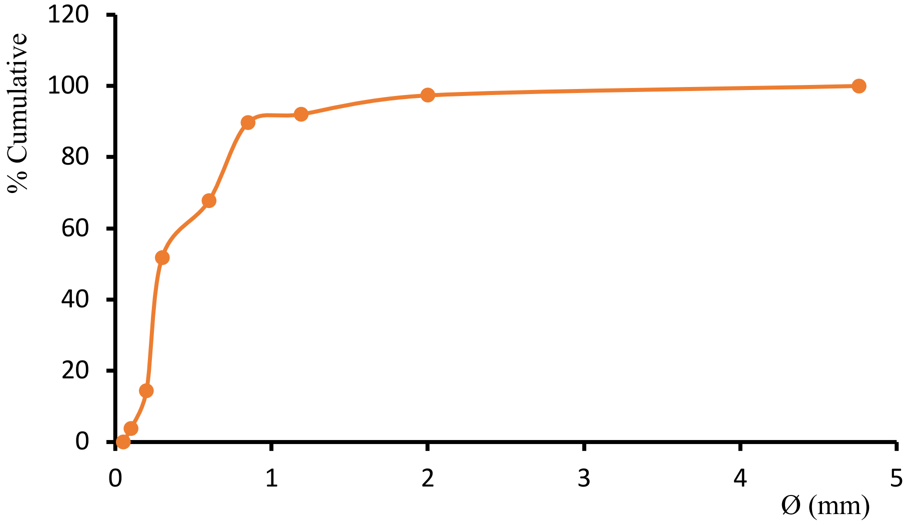


Figure 5. Sand grading curve

Table 4. Fe and Mn removal rate after aeration, jar-test followed by filtration on gravel and sand bed. and sand filtration.

Element	% removal after aeration	% removal after Jar-test	% removal after aeration + filtration	% removal after Jar-Test +filtration
Fe	25.16	86.70	55.90	91.70
Mn	33.53	80.40	47.60	90.34

After the aeration technique followed by filtration, the removal rates are 55.90 and 47.60 respectively for Fe and Mn and after the Jar-test technique followed by filtration on a gravel and sand bed, the removal rates reach 91.7% and 90.34% for Fe and Mn respectively. Thus, there is a clear advantage of the Jar-test coagulation-flocculation water treatment technique over the airblast oxidation method. These results are in agreement with those found by Fatombi et al. 2013 (Seghairi *et al.* 2017) (94% Fe and 90% Mn removal) when treating surface water using Moringa oleifera seeds. These results also show that the removal rate of Mn is lower than Fe. This could be explained by the fact that Mn has a higher oxidation potential than Fe, which makes it difficult to remove (Achour *et al.*2017).

Conclusion

This work is of great interest especially for the population that resides or frequents the town of Rumonge and that consumes the water distributed by REGIDESO. The results of the physico-chemical and microbiological analyses carried out on this water confirm the concerns of this population about its potability. From the beginning to the final stage of treatment, this water always contains undesirable elements making it unfit for human consumption. This water contains high levels of NH_4^+(6,2mg/l ± 2,21), Fe^{2+}(16,5mg/l ±1,00), Mn^{2+}(3,28mg/l ± 0,1), Phosphates (PO_4^{3-}, 2,85mg/l ± 0,05). The water table being barely at 2m, ammonium ions and phosphates percolate almost directly and stain this well water. These results justify the unpleasant metallic taste of this water as well as its brown appearance and color. Bacteriological analyses reveal the massive presence of germs, in particular Escherichia coli (53.5 CFU ± 12.88), whose dangerousness cannot be demonstrated. The elimination of iron and manganese by the method of oxidation by air blowing followed by filtration on a bed of gravel and sand showed a low elimination rate, 55.9% and 47.66%, respectively for iron and manganese. The process of coagulation-flocculation followed by filtration on a gravel and sand bed led to a satisfactory result, i.e. 91.7% and 90.34% respectively for Fe and Mn. The drilling water treatment process including coagulation-flocculation followed by filtration on a bed of gravel and sand was more efficient than the oxidation process by air insufflation followed by filtration on a bed of gravel and sand.

Acknowledgements

The acknowledgements go to the Academy of Research and Higher Education (ARHE) of Belgium for having contributed to the financing of this research.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Compliance with Ethical Standards

This article does not contain any studies involving human or animal subjects.

References

Abdennour, Nadia, et Theresa Ait Namane,(2015), Etude comparative de la qualité physico-chimique et bactériologique des eaux mises en distribution de la ville de Tizi-Ouzou (Barrage de Taksebt et forages de Boukhalfa), *Thesis, Université Mouloud Mammeri.* https://www.ummto.dz/dspace/handle/ummto/9467.

Achour, S, A.A. TIBERMACINE, et F. CHABBI (2017), Le fer et le manganèse dans les eaux naturelles et procédés d'oxydation chimique : cas des eaux algériennes ». *Larhyss Journal* 6 (32): 139-54.

Afnor. 1994. Essais des eaux . Qualité de l'eau , *Association Française de Normalisation*.

Alhassan, Hamdiyah, et Paul Adjei Kwakwa, (2013), When water is scarce: the perception of water quality and effects on the vulnerable ». *Journal of Water, Sanitation and Hygiene for Development* 4 (1): 43-50. https://doi.org/10.2166/washdev.2013.140.

Alonso A., (2020). « Réflexion pour une Stratégie Eau de la Coopération belge: Consultation des acteurs au Burundi », 36.

Ayouba Mahamane A., et Guel B.,(2015),Caractérisations physico-chimiques des eaux souterraines de la localité de Yamtenga (Burkina Faso) ». *International Journal of Biological and Chemical Sciences* 9 (1): 517-33. doi: 10.4314/ijbcs.v9i1.44

Edith K., Alhabib I.M., Léontine T., Djimako B., et Jean-Claude D.M. (2022). « Evaluation of quality of water from wells and boreholes located in some irrigated perimeters of N'Djamena city: Case of sites of Digangali, Moursal, Sabangali and Walia ». *Journal of Materials and Environmental Science* 13 (12), 1446-55.

Fabriès J., et Georges R., (1965), Le massif granitique du Tarraouadji, République du Niger. Étude et signification pétrogénétique des principaux minéraux. *Bulletin de Minéralogie* 88 (2): 319-40. https://doi.org/10.3406/bulmi.1965.5851

Fatombi, J. K., G. Avocznh, N. Topanou, Aminou T., et Josse R. G., (2013), Elimination Du Fer et Du Manganèse d'une Eau de Surface Par Les Graines de Moringa Oleifera . *International Journal of Biological and Chemical Sciences* 7 (3): 1379-91. https://doi.org/10.4314/ijbcs.v7i3.43.

Godinaud J., Klepikova M., Larroque F., Guihéneuf N., Dupuy A., et Bour O. (2023). « Clogging Detection and Productive Layers Identification along Boreholes Using Active Distributed Temperature Sensing ». *Journal of Hydrology* 617 (février): 129113. https://doi.org/10.1016/j.jhydrol.2023.129113.

Han, Heechan, et Morrison R. R. (2022). « Data-Driven Approaches for Runoff Prediction Using Distributed Data ». *Stochastic Environmental Research and Risk Assessment* 36 (8): 2153-71. https://doi.org/10.1007/s00477-021-01993-3.

He Weipeng, Zhoulong Xie, Wenjing Lu, Maolin Huang, et Jingwei Ma. (2019), Comparative Analysis on Floc Growth Behaviors during Ballasted Flocculation by Using Aluminum Sulphate (AS) and Polyaluminum Chloride (PACl) as Coagulants. *Separation and Purification Technology* 213 (avril): 176-85. https://doi.org/10.1016/j.seppur.2018.12.043.

Holtz A., Weidener D., Leitner W., Klose H., Grande P. M., et Jupke A. (2020), Process Development for Separation of Lignin from OrganoCat Lignocellulose Fractionation Using Antisolvent Precipitation. *Separation and Purification Technology* 236, 116295. https://doi.org/10.1016/j.seppur.2019.116295

Joussein Emmanuel, Sabine Petit, et Alain Decarreau (2001), Une nouvelle méthode de dosage des minéraux argileux en mélange par spectroscopie IR. *Comptes Rendus de l'Académie des Sciences - Series IIA - Earth and Planetary Science* 332(2), 83-89. https://doi.org/10.1016/S1251-8050(01)01511-7.

Ju Jinrong, Yali Feng, Haoran Li, Ruifeng Wu, et Ben Wang (2022), An Approach towards Utilization of Water-Quenched Blast Furnace Slag for Recovery of Titanium, Magnesium, and Aluminum ». *Journal of Environmental Chemical Engineering* 10 (4): 108153. https://doi.org/10.1016/j.jece.2022.108153.

Junior Ophélie, Djadé, Traoré Abou, Koffi KOFFI, Keiba Noel Keumean, Gbombele Soro, et Nagnin Soro. (2020), Evaluation du niveau de contamination des eaux souterraines par les éléments traces métalliques dans le département de Zouan-Hounien (Ouest de la Côte d'Ivoire). *Journal of Applied Biosciences* 150 (juin): 15457-68. https://doi.org/10.35759/JABs.150.6.

Kangombe, Thomas Kayobola. (2020), Approvisionnement en eau potable en milieu rural en République Démocratique du Congo face à l'Objectif 6 de Développement Durable, Exemple de la province du Maniema », 1-162.

Kengmoe E., Tchouongsi B., Tagne C. T., Touoyem F. M., et Bonganjum N. S. (2020), Approvisionnement en eau et risques sanitaires dans le bassin versant amont de l'Abiergué à Yaoundé (Cameroun) . *European Scientific Journal* 16 (8): 102-23. https://doi.org/10.19044/esj.2020.v16n8p102.

Kone T., M. Kamagate K.R. Effebi B.P. Essis P.J.M. Ouattara et Coulibaly L. (2022). « Assessment of water resources vulnerability to climate change in a tropical region: A case study of the Gbêkê region (Côte d'Ivoire) ». *Journal of Materials and Environmental Science* 13 (11), 1290-1303.

Kouadio L.M., Tillous K.E.N., Coulibaly V., Sei J., Martinez H., et Pannier F. (2023). « Assessment of metallic pollution of water and soil from illegal gold mining sites in Kong 2, Hiré and Degbézéré (Ivory Coast) ». *Journal of Materials and Environmental Science* 14 (01), 41-61.

Kouame, Fernand. (2008), Elimination Du Fer et Du Manganèse Par Aération – Filtration Des Eaux de Forage En Zone Rurale Dans Les Pays En Développement: Cas de La Région de Tiassalé (Sud de La Côte d'Ivoire) ». *European Journal of Scientific Research* 19 (3), 558-67.

Lu, Jinsuo, Xiaojiang Huang, Zhiqiang Zhang, Heliang Pang, Kunyu Chen, Haozhe Xia, Yiyu Sui, Rongwen Chen, et Ziang Zhao. (2022), Co-Coagulation of Micro-Nano Bubbles (MNBs) for Enhanced Drinking Water Treatment: A Study on the Efficiency and Mechanism of a Novel Cleaning Process. *Water Research* 226 (novembre), 119245. https://doi.org/10.1016/j.watres.2022.119245.

Masschelein W.J. (1996). Processus unitaire du traitement de l'eau potable. *Editions* CEBEDOC. 37851070. *Liège.* https://www.worldcat.org/fr/title/processus-unitaire-du-traitement-de-leau-potable/oclc/37851070.

Ministère de l'Eau, de l'Environnement, de et l'Aménagement du Territoire et de l'Urbanisme. (2013), Burundi – Politique Nationale d'Assainissement et Stratégie Opérationnelle.

Ntakiyiruta, Pierre, Bi Gouessé Henri Briton, Gaston Nsavyimana, Kopoin Adouby, David Nahimana, Gaspard Ntakimazi, et Laurence Reinert. (2020), Optimization of the phytoremediation conditions of wastewater in post-treatment by Eichhornia crassipes and Pistia stratiotes: kinetic model for pollutants removal ». *Environmental Technology* 14 (2), 1-14. https://doi.org/10.1080/09593330.2020.1852445.

Pang, Yumao, Bingbing Shi, Xingwei Guo, Xunhua Zhang, Yonghang Wen, Guoxin Yang, Xudong Sun. (2023). « Machine Learning Algorithm Optimization for Intelligent Prediction of Rock Thermal Conductivity: A Case Study from a Whole-Cored Scientific Drilling Borehole ». *Geothermics* 111 (juin), 102711. https://doi.org/10.1016/j.geothermics.2023.102711

Rakotomaria, Etienne, Marie Ratsimba, et Pierre Rakotomamonjy. 2011. « Valorisation chimique du kaolin dans le traitement des eaux : préparation de nouveaux coagulants minéraux ». *Revue des sciences de l'eau / Journal of Water Science* 24 (4), 437-48. https://doi.org/10.7202/1007629ar.

Rezania, Shahabaldin, Mohd Fadhil Md Din, Siti Fatimah Kamaruddin, Shazwin Mat Taib, Lakhveer Singh, Ee Ling Yong, et Farrah Aini Dahalan (2016), Evaluation of Water Hyacinth (Eichhornia Crassipes) as a Potential Raw Material Source for Briquette Production. *Energy* 111 (septembre): 768-73. https://doi.org/10.1016/j.energy.2016.06.026.

Rodier, J. (2009), L'analyse de l'eau. *9ème Edition, Dunod, Paris, 1579 p.*

Ruzima, Adelphi, Gitec, et H. Karen (2017), Plan de contingence de la commune de Rumonge 69p.

Seghairi, Nora, Leila Mimeche, Adel Bouzid, et Yassir Ayachi (2017), Traitement des eaux usées par coagulation -flocurationn en utlisant le sulfate d'alumium comme coagulant. *Journal of Water and Environmental Sciences* 1 (4), 230-34.

Wei, Xutao, Meng Zhang, Jinhua Wang, et Zuohua Huang. (2023), Investigation on Lean Blow-off Characteristics and Stabilization Mechanism of Premixed Hydrogen Enhanced Ammonia/Air Swirl Flames in a Gas Turbine Combustor. *Combustion and Flame* 249, 112-130. https://doi.org/10.1016/j.combustflame.2022.112600.

Wu, Caihong, Yan Wang, Baoyu Gao, Yanxia Zhao, et Qinyan Yue. (2012), Coagulation Performance and Floc Characteristics of Aluminum Sulfate Using Sodium Alginate as Coagulant Aid for Synthetic Dying Wastewater Treatment. *Separation and Purification Technology* 95, 180-187. https://doi.org/10.1016/j.seppur.2012.05.009.

Zogo, D, LM Bawa, HH Soclo, G Djanéyé-Boundjou, et D Atchekpe. 2011. « Effect of pre-chlorination on the efficiency of iron and manganese removal from surface water by coagulation-flocculation using aluminium sulphate: case of the Okpara dam in the Republic of Benin ». *International Journal of Biological and Chemical Sciences* 4 (mars). https://doi.org/10.4314/ijbcs.v4i6.64983

(2023) ; http://www.jmaterenvironsci.com