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State of Play on the Physicochemical Quality of Waters Stored in Concrete Tank Buried Under Wet and Polluted Soil: The Case of the City of Pointe-Noire (CONGO)

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Abstract: The problem of water supply from the public distribution network is still very acute in many cities in developing countries. The intermittent supply of water is forcing some households to build underground tanks of reinforced concrete to store domestic water. This work shows the problem of sustainability of water storage tanks made of concrete, in an aggressive environment but also especially the physicochemical quality of water stored in. The methodological approach chosen is based first of all on the physicochemical analysis of the water stored in these tanks. Indeed, the reliability of tanks, which reflected in their impermeability overlooked external environment, has a direct impact on the quality of stored water and therefore the use that is made daily. In this context, the results of the physicochemical measurements carried out, the comparison of the water coming out of the treatment plant of the National Water Distribution Company (SNDE), made it possible to highlight indices of pollution in the stored waters contained in the buried tanks. Some samples of stored water, about 42.10%; which poses a public health problem. These results have clearly demonstrated the porous nature of the concrete chosen as the base material used for the construction of said tanks. Thus, anthropogenic pollution is evoked, which is confirmed by the high levels of physicochemical parameters measured in samples RE01, RE02, RE03, RE04, RE05, RE10, RE11 and RE12. In addition, 57.9% of these stored waters have low mineralization. These are acceptable as drinking water (RE06, RE07, RE08, RE09, RE13, RE14, RE15, RE16, RE17, RE18 and RE19). These waters identified as such must be subject to specific treatment and time monitoring. These results were obtained during dry season. During this period, there is drawdown of ground water. In rainy season, ground water is enhanced and exchanges are more important.

Keywords: Underground Tanks, Water Storage, Diffusion, Pollutant, Reinforced Concrete, Porosity, Contamination

1. Introduction

Drinking water is an essential element for the physiological needs of man and the whole of biodiversity. But, through it, several diseases can be transmitted to the man when no disposition is taken in order to guarantee and preserve its potability.

Hence, providing the population with a good quality of water is an effective measure of health protection [1, 2]. However, in the republic of Congo, problems of drinking water shortage encountered, and specifically in some underdeveloped or un-sanitized urban areas, remain a major concern for different households. This problem particularly arises in the city of Pointe-Noire, where the populations concerned are obliged to build underground reinforced concrete tanks for storing a large quantity of water, thus helping to reduce this shortage. The water is then pumped and distributed into the buildings via the sanitary plumbing network installed with a suppressor (motor-pump).

However, the water stored in reinforced concrete tanks, installed in wet and polluted areas is likely to be crossed by an aggressive diffusive current generated by the pollution of the surrounding environment because of anthropic activities, untreated public landfills, or other types of pollution.

Entropic activities as well as untreated garbage dumps significantly alter wet sites, thus promoting the dissolution and migration of pollutants to the groundwater in depth by gravity and through the underlying soils [3-5].

In the current context of water resources sustainable management policy, the prediction of the risk of pollution and the protection of these resources are of paramount importance [6].

However, the material used for the construction of these tanks is concrete, which is porous in nature. This weakness constitutes preferential routes for the diffusion via the capillary and porous network, of aggressive substances dissolved in the watertable which is flush with the natural ground (soil), thus altering the quality of water stored inside the tank [7]. Thus, the durability of the storage tank negatively influenced.

Similarly, the flow of untreated leachates from solid waste degradation and wastewater into channels, ravines and others generates significant contamination of soils and groundwater, which has a direct impact on groundwater quality [8] considered the vector of pollution in the case of our study.

The problem of optimizing the durability of the concretes constituting the buried tank with respect to external influences as well as the water tightness of the wall then becomes recurrent. This durability induced by the transfer properties is also evident for all structures subjected to aggressive environments, which can lead to premature degradation of the concrete material [9-10]. For these concrete tanks, this durability is not only based on their self-stability in view of the stresses due to external actions, but also, because of their ability to hinder exchanges between the surrounding environment (aggressive) and the interior of the structure thus avoiding deterioration of the quality of stored water.

Recent studies conducted by Chen current (2011) show that the permeability of concrete represents the ability of the porous material to be traversed by a fluid under a pressure gradient. It strongly depends on the porous network, its possible cracking and the water content of the material [11]. This permeability is commonly used to assess the durability of concrete structures, particularly when exposed to harmful environments [12]. Also, in the case where the concrete structure is in contact with water, according to the constitution of the cement matrix, the permeability can be understood as the ability of the porous area to be passed through by a fluid that completely fills the pores interconnected [13].

In this perspective, a study based on the physicochemical analysis of water stored in underground tanks was conducted to assess the mineral pollution of water stored under the influence of the external environment. This is to highlight the lack of reliability from the point of view of sealing, reinforced concrete walls and, ultimately, the problem of transfer of pollutants trough the walls of the buried tank.

2. Material and Methods

This study extending from June-September 2016 was conducted on a series of 19 underground tanks located in some vulnerable quarters of Pointe-Noire. These quarters are places predisposed to all kinds of contamination not only because of their geographical situation but also because of the presence in these places of untreated public landfills.

This study was conducted in two phases namely:

1. the taking of the water samples;
2. the physicochemical analysis of these samples.

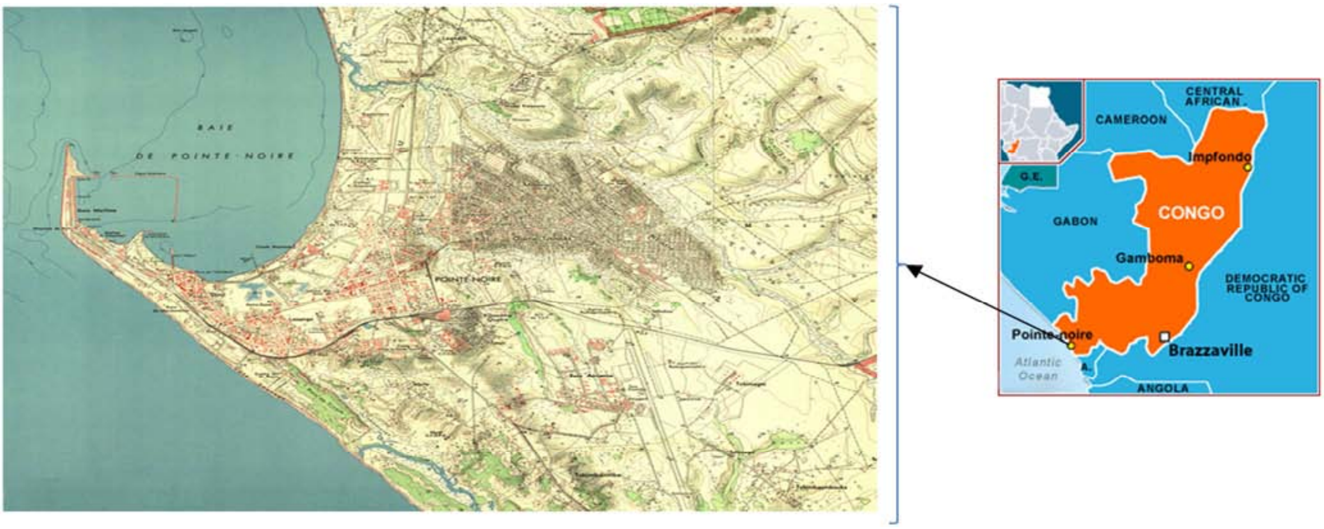

Figure 1. *Zone of survey.*

2.1. Geographic Situation

The city of Pointe-Noire is an agglomeration located to the North-East by the locality of Hinda and to the South-West by the Atlantic Ocean and Cabinda (Angola).

The geographic coordinates of the city of Pointe-Noire city are: latitude of 04°49'26,1 " South and of longitude 11°53'14,8 " is (figure 1).

Pointe-Noire is divided administratively into six (06) districts: Lumumba, Mvou-Mvou, Tié-Tié, Loandjili, Ngoyo and Mongo-Mpoukou. Its surface is of 239,953 km² square kilometres.

Geolocation of the 19 sampling sites is shown in table 1, figure 2.

***Table 1.** Geographical coordinates of the 19 sampling sites (samples).*

CODES	Altitude (Z) in m	Latitude	Longitude
RE01	236	4°47’50,7”S	11°50’37,4”E
RE02	247	4°47’49,1”S	11°50’28,0”E
RE03	31	4°47’46,3”S	11°50’21,1”E
RE04	000	4°47’50,4”S	11°50’27,8”E
RE05	44	4°47’50,9”S	11°50’27,0”E
RE06	19	4°46’18,0”S	11°52’02,8”E
RE07	21	4°46’20,7”S	11°52’07,5”E
RE08	73	4°46’38,8”S	11°52’28,9”E
RE09	62	4°46’20,9”S	11°52’07,7”E
RE10	461	4°47’45,5”S	11°53’14,2”E
RE11	16	4°48’11,0”S	11°53’45,1”E
RE12	20	4°48’03,5”S	11°53’14,0”E
RE13	541	4°47’45,5”S	11°53’14,2”E
RE14	13	4°48’11,3”S	11°53’45,0”E
RE15	60	4°46’34,9”S	11°53’05,4”E
RE16	63	4°46’33,0”S	11°53’05,8”E
RE17	110	4°46’34,4”S	11°53’07,3”E
RE18	75	4°46’36,4”S	11°53’07,1”E
RE19	56	4°46’36,5”S	11°53’17,9”E

In this figure 2, we notice the infiltration of water from the aquifer inside the tank and degradation of the walls with biofilm after construction.

***Figure 2.** Buried concrete tank.*

2.2. Climate

Studies by Samba and Nganga (2011) have shown that long series of climatic data divide Congo into two types: the equatorial climate in the North and the humid tropical climate to the South.

The area of the city of Pointe-Noire belongs to the humid tropical climate. This climate is under the dominating influence of low pressures intertropical pressures from October to May and high southern subtropical pressures from June to September. The cloud cover is all the more important and almost permanent as the activity of the intertropical convergence zone (ITCZ) is reversed. It directly influences sunstroke and solar radiation. It is also characterized by an alternation of two seasons: a rainy and hot season that extends from November to April with a very strongly rainfall and a dry and cool season from June to September during which the water balance is probably deficit.

The months of October and May provide a transition period for the entry and exit of the dry season [14- 15].

2.3. Physicochemical Analysis of Samples Taken from Tanks

An observation is particularly made by comparing the raw water of the National Water Distribution Company (SNDE) taken from different boreholes, and the water from different tanks listed in the case of this study.

The assessment of the physicochemical parameters in relation to WHO normative values will also be indicated (Table 2).

***Table 2.** Guiding values for drinking water quality [1] and [2].*

PARAMETERS	UNIT	WHO standard
hydrogen Potential (pH)	-	6.5 – 8.5
Potential Redox (PR)	mV	-
Total Dissolved Solids (TDS)	mg/l	250
Temperature (t°)	°C	15-30
Conductivity (C)	$\mu s/cm$	300
Dissolved Oxygen (O_2)	mg/l	5-10
Total iron (Fe)	mg/l	0,3
Salinity (SAL)	%	0
Resistivity	Ω. cm	3000
Phosphates (PO_4^{3-})	mg/l	1
Chlorides (Cl^-)	mg/l	200
Nitrates (NO_3^-)	mg/l	50
Alkalimetric Titre (TA)	mg/l$CaCO_3$	10
Complet alkalimetric Titre (TAC)	mg/l$CaCO_3$	100
Total Hydrotimetric Titre (THT)	mg/l$CaCO_3$	150
Bicarbonates (HCO_3^-)	mg/l	200
Carbonate (CO_3^{2-})	mg/l	25
Oxydability at $KMnO_4$	mg/l	<1
Oxidation Reduction Potency Rh	-	14-25
General Mineralization (Mg)	mg/l	350

Main Physicochemical parameters measured

The assessment of the quality of the stored water is based on the measurement of the various physicochemical parameters, namely: hydrogen Potential (pH), Potential Redox (PR), temperature (T), Total Dissolved Solids (TDS), conductivity (EC), salinity (SAL), total iron (Fe_{tot}), dissolved oxygen (O_{dis}), phosphates (PO_4^{3-}), nitrates (NO_3^-), chlorides (Cl^-), Complet alkalimetric Titre (TAC), Total Hydrotimetric Titre (THT), oxydability ($KMnO_4$), bicarbonates (HCO_3^-) and general mineralization (Mg). The water stored in the underground concrete tanks comes from boreholes drawn in different areas. These waters are then integrated into the National Water Distribution Company (SNDE).

2.4. Material

The material used is composed of:

1. an Etrex-type GPS for taking geographic coordinates;
2. 0.5l plastic bottles for sampling water;
3. a multi parameter device of the CONSORT C6030 type;
4. a spectrophotometer of the Lightwave type;
5. glassware (250 ml beaker, 25 ml and 100 ml test-tube, 25 ml test cuvette.

2.5. Methodology

Withdrawal of the samples

Water samples were taken in the dry season (June-September 2016), a period that does not correspond to the recharge of the water table. The water was collected in 0.5l plastic bottles (figure 3). After sampling, the bottles were labeled in a simple way: rounding, number of passage, address, date. Once the water has been put into the bottles, they have been hermetically sealed to avoid any exchange with the surrounding environment.

Samples of water removed were kept in the refrigerator; the analyses of the different samples were carried out in 48 hours following the sampling.

Figure 3. *Water samples taken.*

Figure 4. *CONSORT C6030 multi parameter camera equipped with electrodes.*

Figure 5. *Visible UV Spectrophotometer Lightwave WPA.*

Physicochemical analyses of samples

The physicochemical analyses of 08 parameters (phosphates, nitrates, chlorides, Complet alkalimetric Titre, Total Hydrotimetric Titre, oxydability, bicarbonates and general mineralization) were carried out by three methods: the electrometric method, the spectrophotometric method and the method titrimetric.

Electrométric method

This method made it possible to determine nine (09) parameters using the CONSORT C6030 multifunction device (figure 4). The parameters thus determined are as follows: hydrogen Potential (pH), Potential Redox (PR), Total Dissolved Solids (TDS), conductivity (EC), Total iron (Fe_{tot}), dissolved oxygen (O_{dis}), temperature (T) and salinity (SAL).

Spectrophotométric method

The apparatus used was the Lightwave spectrophotometer of type (figure 5). All the physicochemical parameters to be measured will be compared with the normative values enacted by the WHO and the raw water data of the National Water Distribution Company (SNDE), summarized in [Annex, 2016].

3. Results Interpretation

3.1. Physicochemical Parameters

All results of physicochemical analyses are presented in tables 3 and 4.

Table 3. *Values of arithmetic means of physicochemical parameters.*

Code	pH	PR (mV)	TDS (mg/l)	t (°C)	Conductivity ($\mu s/cm$)	O_2 (mg/l)	Fe (10^{-6} mg/l)	Salinity	rH
RE01	7,29	31,95	156,75	20	294,5	2,38	0,95	0,1	15,68
RE02	7,40	25,98	158,25	20	298	1,25	0,95	0,13	15,69
RE03	7,21	35,13	141,4	20	266,4	2,44	0,95	0,1	15,62
RE04	7,54	19,85	149,25	20	281	2,88	0,95	0,1	15,76
RE05	7,28	33,58	151,5	20	285,75	2,81	0,95	0,1	15,72
RE06	7,06	46,2	120	20	225,25	1,31	0,95	0,1	15,70
RE07	7	48,8	109,25	20	205,5	2,44	0,95	0,1	15,68
RE08	6,57	79,3	10,33	20	19,18	1,69	0,95	0	15,87

Code	pH	PR (mV)	TDS (mg/l)	t (°C)	Conductivity ($\mu s/cm$)	O_2 (mg/l)	Fe (10^{-6} mg/l)	Salinity	rH
RE09	7,12	46,85	107,8	20	202,25	2,38	0,95	0,1	15,85
RE10	4,34	196,48	382,75	20	719	1,25	0,95	0,33	15,45
RE11	7,68	10	59,75	20	105,53	2,86	0,95	0,05	15,70
RE12	7,35	29,28	53,68	20	982,25	3,44	0,95	0,48	15,71
RE13	7,34	27,65	6,49	20	112,50	2,35	0,95	0,08	15,64
RE14	7,37	25,3	9,40	20	101,08	2,60	0,95	0,08	15,61
RE15	6,57	75,85	12,26	20	12,03	3,41	0,95	0	15,76
RE16	6,46	74,7	12,75	20	17,80	3,09	0,95	0	15,47
RE17	7,45	52,65	10,48	20	23,04	1,66	0,95	0	16,72
RE18	6,43	89,5	12,75	20	24	2 ,50	0,95	0	15,94
RE19	5,86	111,7	10,48	20	19,57	1,69	0,95	0	15,57

***Table 4.** (continued): Values of arithmetic means of physicochemical parameters.*

Code	PO_4^{3-} (mg/l)	Cl^- (mg/l)	NO_3^- (mg/l)	TAC (mg/lCaCO₃)	THt (mg/lCaCO₃)	HCO_3^- (mg/l)	Oxydability at $KMnO_4$	Mg (mg/l)
RE01	0,235	31,86	0,069	134	130,88	163,48	0,32	223,86
RE02	0,273	28,08	0,013	125	132,44	152,5	0,32	226,48
RE03	0,241	28,03	0,039	126	118,39	153,72	0,32	203,22
RE04	0,28	29,57	0,041	126,5	124,88	154,33	0,36	213,56
RE05	0,305	30,07	0,031	156	126,99	190,32	0,32	217,17
RE06	0,30	23,70	0,07	87	99,88	106,14	0,32	171,19
RE07	0,37	21,62	0,013	97	91,32	118,34	0,32	156,18
RE08	0,415	1,98	0,038	8	0	9,76	0,32	26,08
RE09	0,405	21,28	0,082	92	89,88	112,24	0,32	153,71
RE10	0,28	75,68	191,37	0	319,55	0	0,44	510,49
RE11	0,33	11,10	0,033	48	46,89	58,56	0,40	100,04
RE12	0,31	103,39	0,05	132	434,33	161,04	0,64	736,69
RE13	0,36	11,83	0,032	52	49,99	63,44	0,36	106,65
RE14	0,35	10,63	0,032	46	44,91	56,12	0,32	95,82
RE15	0,36	1,26	0,08	8	0	9,76	0,32	11,60
RE16	0,39	1,86	0,08	8,5	0	10,37	0,32	24,21
RE17	0,39	2,41	0,05	10	0	12,2	0,32	31,33
RE18	0,32	2,52	0,02	12	0	14,64	0,32	32,64
RE19	0,35	2,05	0,09	10	0	12,2	0,32	26,61

Hydrogen potential (pH)

The value of the hydrogen potential pH is 4,34 minimal and 7,68 maximal; for values below 6,5 (the minimal value of the WHO standard), the water is aggressive, the case of RE10, RE19, RE18, RE16. The RE10 sample is more aggressive than the other samples, it shows that in this water, the carbonic acid (H_2CO_3) dominates on bicarbonate (HCO_3^-) which is a basic element of the calco-carbonic balance (figure 6). Aggressive samples require the treatment of equilibrium (pH correction) to achieve the calco-carbonic balance of these waters. The other samples comply with WHO standards because their pH is between 6,5 and 8,5.

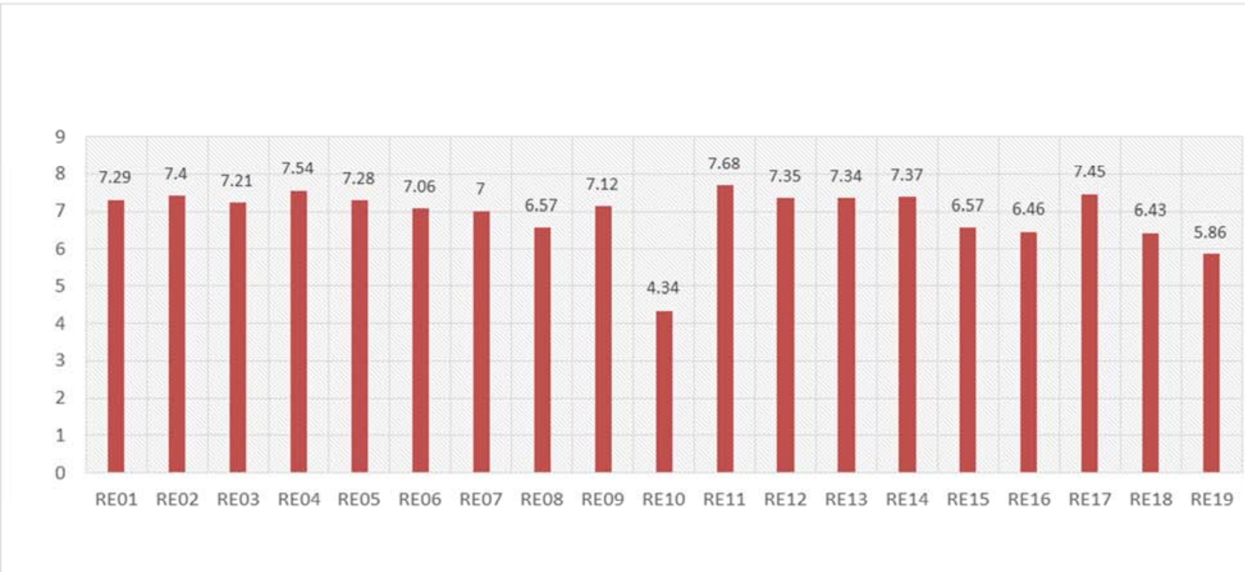

***Figure 6.** Spatial variations of hydrogen potential (pH).*

Conductivity

These results show that the conductivities are between 12,03 µs/cm and 982,25 µs/cm. The WHO standard is of 300 µs/cm, which means that.

For the conductivities lower than 100 µs/cm water is very weakly mineralized, the case of samples RE08, RE15, RE16, RE17, RE18, RE19;

For the conductivities between 100 µs/cm and 150 µs/cm, the water is weakly mineralized, the case of RE11, RE13, RE14 samples. Samples conform to the WHO standard;

For the conductivities of between 150 µs/cm and 300 µs/cm, the water is mineralized, the case of the RE01, RE02, RE03, RE04, RE05 RE06, RE07, RE09 samples (Figure 7). These samples conform to the WHO standard.

This variability of the results is certainly due to the influence of the surrounding environment relative to each sampling site, and this, compared to the raw values of the SNDE [Annex, 2016].

For the conductivities greater than 300 µs/cm, the water is highly mineralized, the case of samples RE10, RE12. The strong mineralisation is linked to the geology of these waters which is very rich in mineral salts. These conductivities do not conform to the WHO standard; these waters require the treatment of the demineralisation to bring conductivity back to normal.

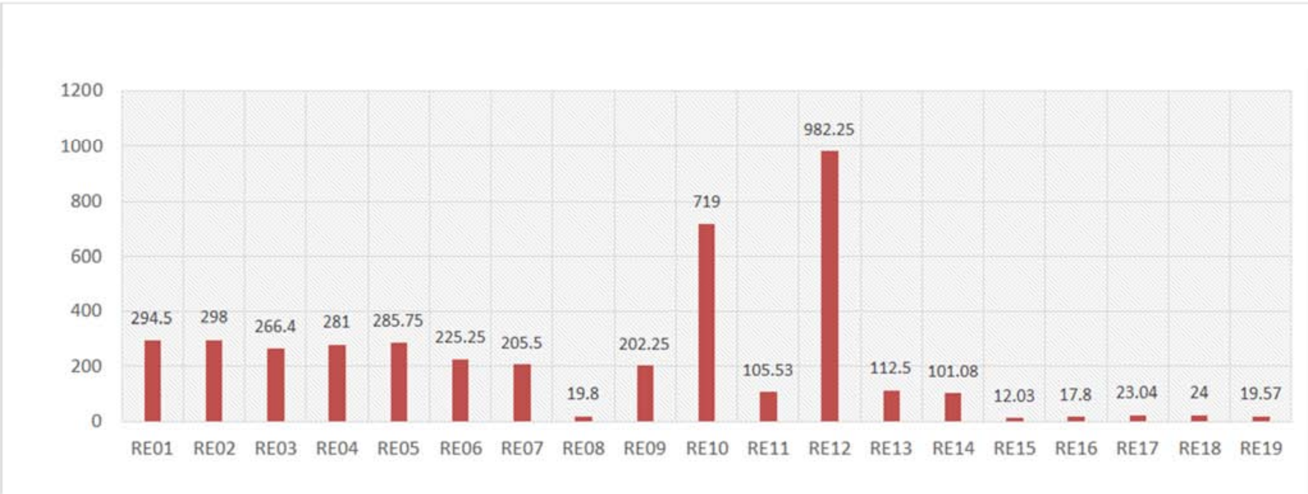

***Figure 7.** Spatial variation of conductivity.*

Salinity (SAL)

The results show that the salinities are between 0% of µs/cm and 0.48%. The WHO standard is of 0. Here, these results reveal a saline intrusion problem that is due to the proximity of the sea waters (Atlantic ocean), (figure 8), [16].

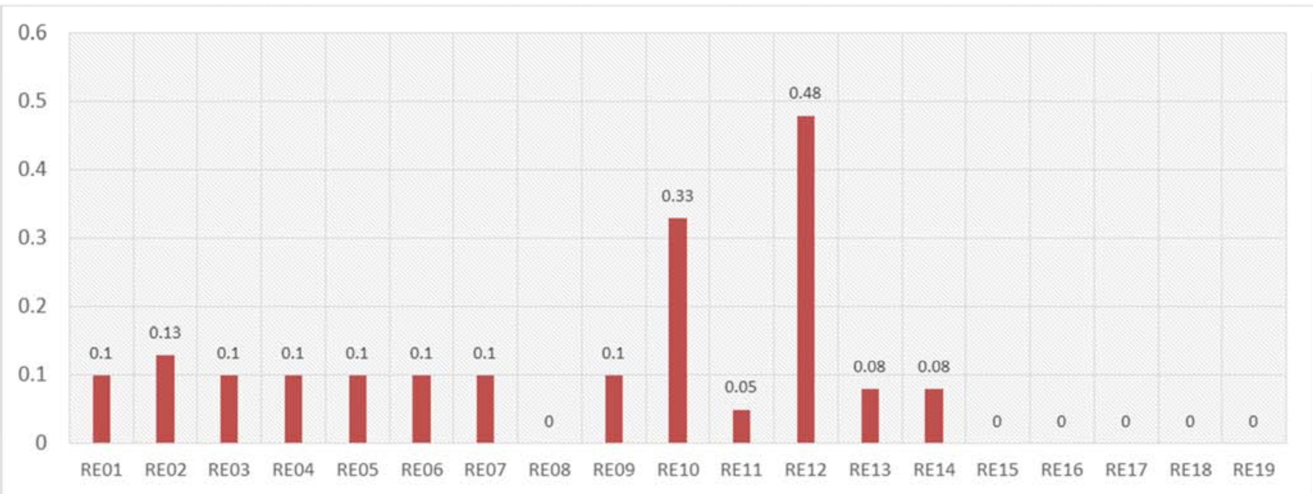

***Figure 8.** Spatial variation of salinity.*

Oxydation Reduction Potency (rH)

The results show that organic matter-related pollution is negligible, as the samples have oxidation reduction powers containing in the range of 14 to 25 which is the range of the good water (figure 9).

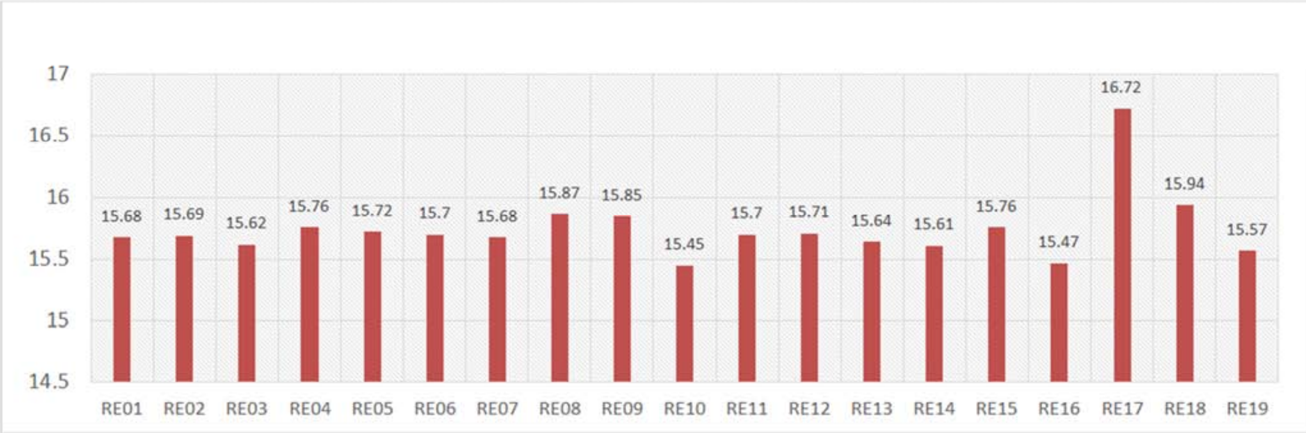

Figure 9. *Spatial variation of Oxidation Reduction Potency (rH).*

Phosphates (PO_4^{3-})

These waters have low phosphate concentrations, the maximum value is of 0.415 mg/l (RE08) below the WHO standard of 1 mg/l for the good water (figure 10). These waters require disinfection with chlorine to block the development of algaes that are related to the presence of the phosphates.

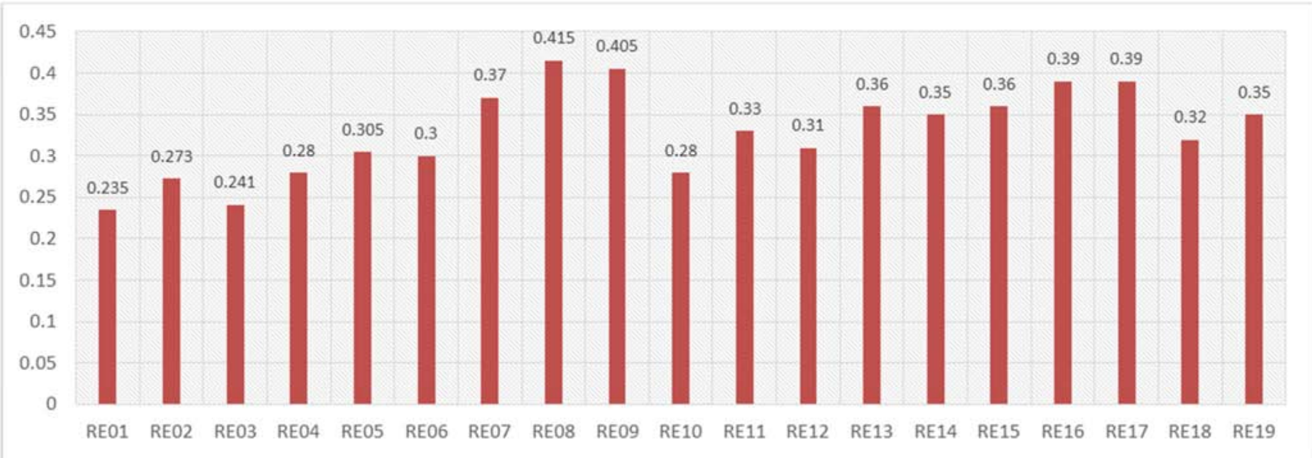

Figure 10. *Spatial variation of phosphate levels (PO_4^{3-}).*

Chlorides

The values of chloride concentrations in boreholes are all in accordance with WHO standards of 200 mg/l (figure 11).

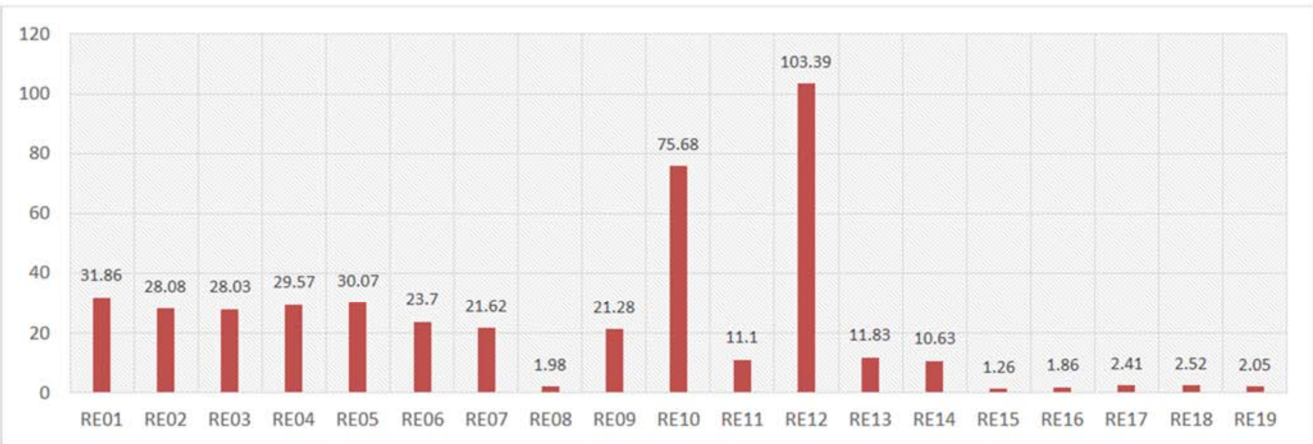

Figure 11. *Spatial variation of chloride concentration by tank.*

Nitrates (NO_3^-)

The results show that the nitrate concentrations are between 0,01 mg/l for (RE02, RE07) and 191.37 mg/l (RE10). Except for sample RE10, all others are compliant (figure 12).

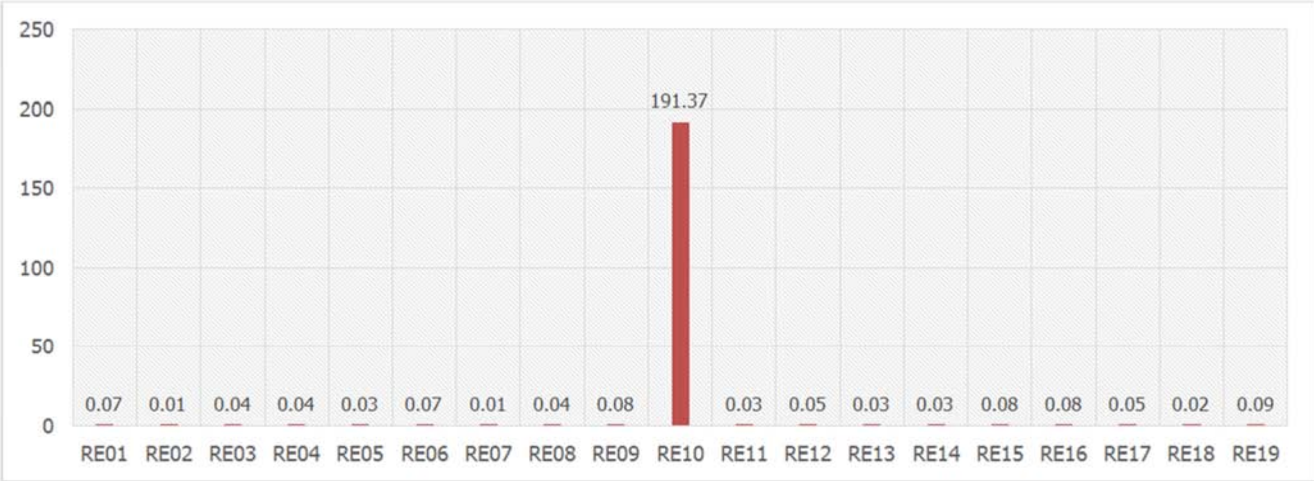

Figure 12. *Spatial variation of nitrate concentrations by tank.*

Complet Alkalimetric Titre (TAC)

TAC values range from 0 mg/l $CaCO_3$,(RE10) to 156 $CaCO_3$ mg/l (RE05).

for TAC below 40 mg/l $CaCO_3$, the water is low in bicarbonate (aggressive nature of the water); the case of the samples RE10, RE08, RE15, RE16, RE17, RE18 and RE19. The RE10 sample is more acidic than the other samples because its TAC is zero; this means that in this water, the carbonic acid dominates the bicarbonate which is null (pH is lower than the zone of turn of the orange of methyl which is 4,5);

for TAC between 40 mg/l $CaCO_3$ and 100 mg/l $CaCO_3$, the water has the calco-carbonic equilibrium character that is to say the bicarbonate dominates on carbonic acid. This is the case of samples RE14, RE13, RE11, RE09, RE07 and RE06;

for the TAC between 100 mg/l $CaCO_3$ and 150 mg/l $CaCO_3$, the water has a slightly encrusting character (formation of carbonate deposits). the relevant samples are RE01, RE02, RE03, RE04 and RE12;

for the TAC greater than 150 mg/l $CaCO_3$, the water has a strongly encrusting character, the case of sample RE05 (figure 13).

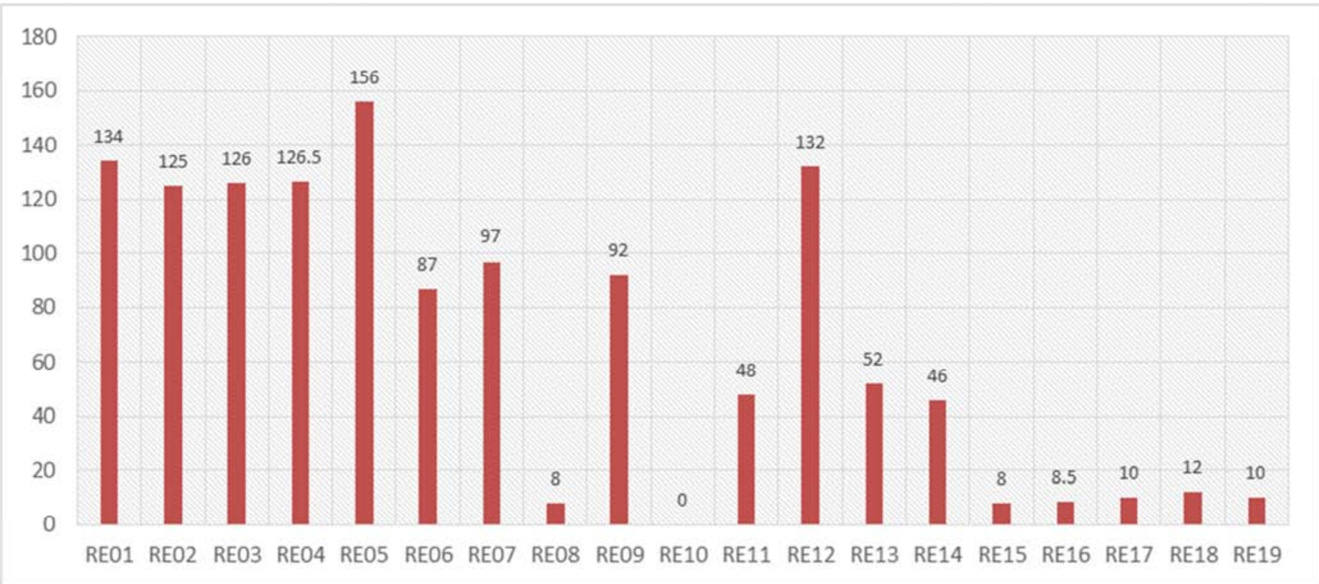

Figure 13. *Spatial variation of Complete Alcalimetric Titre (TAC).*

Total Hydrotimetric Title (THt)

The results show that the total hardness is between 0 mg/l $CaCO_3$ and 887,50 mg/l $CaCO_3$.

For a total hardness of zero, the water is very soft; these waters have negligible concentrations of calcium and magnesium. Samples with very soft water are RE08, RE15, RE16, RE17, RE18 and RE19. The sweetness of the waters influences the pH in the direction of the decay;

For total hardness less than 150 $CaCO_3$ mg/l, the water is soft; this means that the calcium and magnesium levels in these waters are in WHO standards.

The water of the RE06 sample complies with the water standard because its hardness verifies the norm.

for the hardness above 150 mg/l $CaCO_3$, the water is hard. These waters have calcium and magnesium levels that do not meet WHO standards. These waters have the character of absorption of the soap foam during the laundry and increases the phenomenon of scaling.

The waters of samples RE01, RE02, RE03, RE04, RE05, RE07, RE09, RE10, RE11, RE12, RE13 and RE14 are very hard (figure 14).

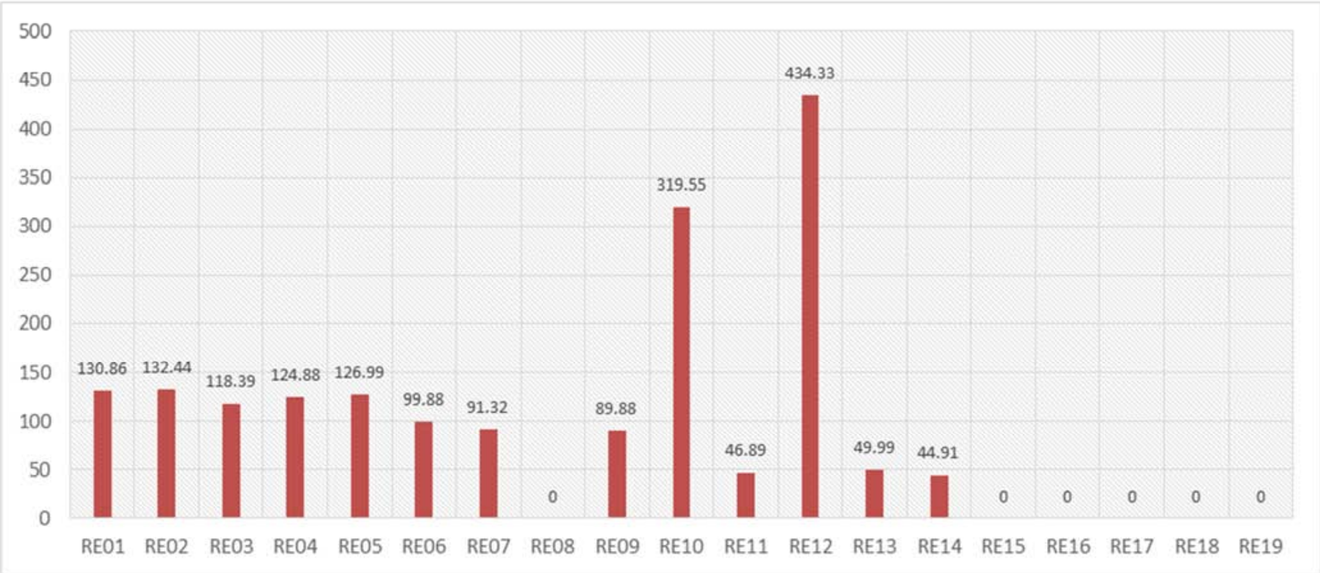

Figure 14. *Spatial variation of Total Hydrotimetric Titre (Tht).*

Bicarbonates (HCO_3^-)

The bicarbonate concentrations are between 0 and 190,32 mg/l in these results. The water is aggressive for bicarbonate concentrations below 50 mg/l, in the waters of samples RE08, RE10, RE15, RE16, RE17, RE18 and RE19 the carbonic acid is dominant on the bicarbonate then gives acid character to the water.

The waters of samples RE01, RE02, RE03, RE04, RE05, RE06, RE07, RE09, RE11, RE12, RE13 and RE14 have bicarbonate concentrations in accordance with WHO standards ranging from50 mg/l and 200 mg/l (figure 15).

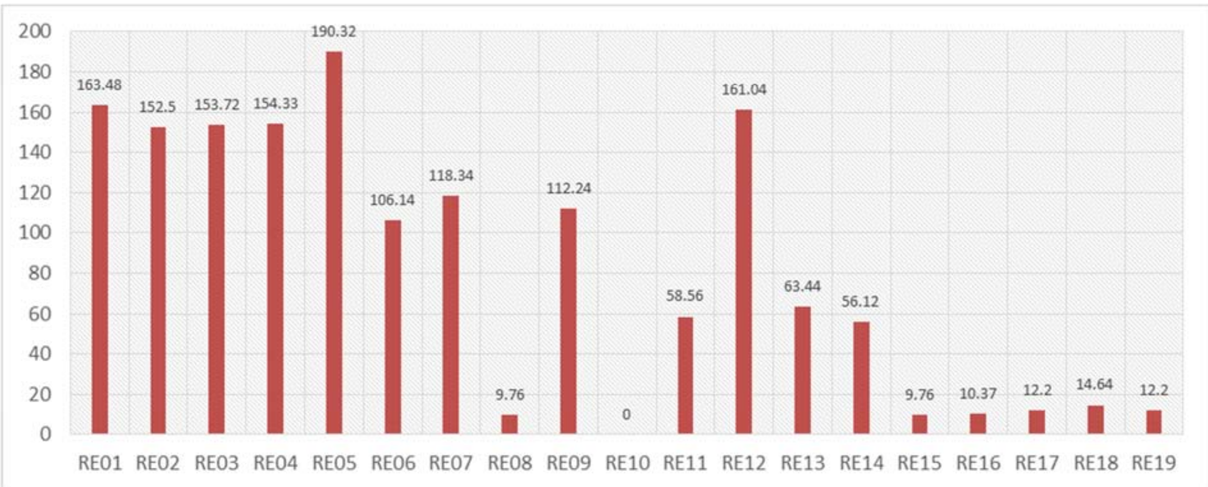

Figure 15. *Spatial variation of bicarbonates contents.*

Oxydability at $KMnO_4$

The concentrations of organic matters in the water of these samples are between 0,32 mg/l O_2 and 0,64 mg/l O_2, which means that these waters are poor in organic matter because these values are lower the WHO standards of 1 mg/l O_2 for drinking water. The presence of these organic traces in these waters requires disinfection to oxidize these organic materials (figure 16).

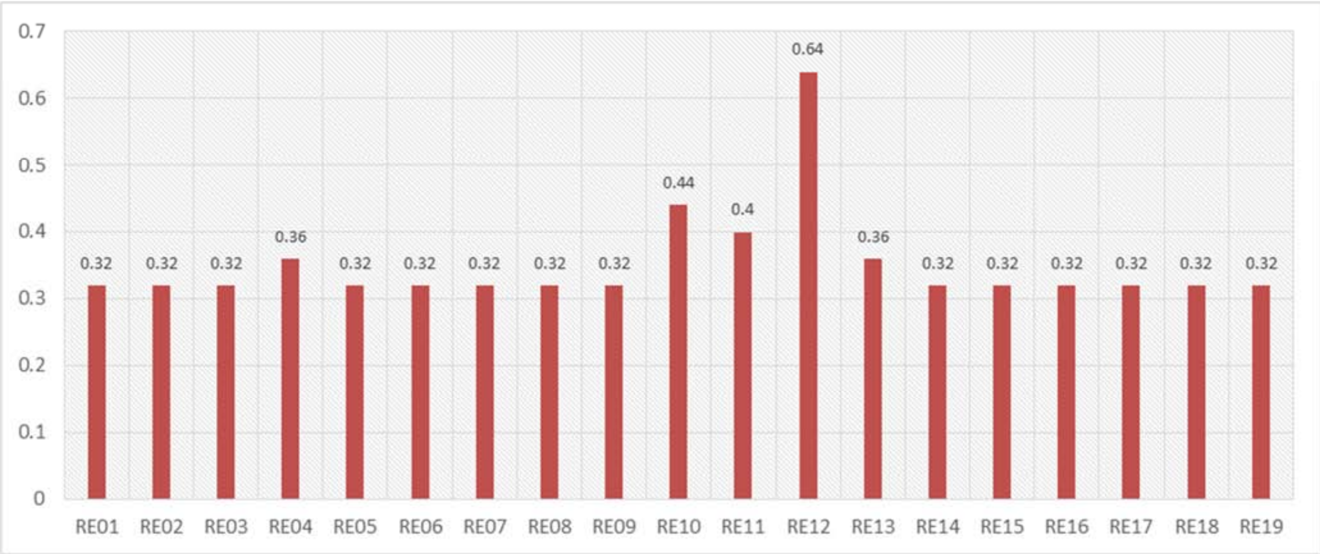

Figure 16. *Spatial variation of oxydability at $KMnO_4$.*

General Mineralization (G.M)

The results of the physicochemical analyses of the waters show that of the general mineralisations are between 11,60 mg/l (RE11, 60) and 736,69 mg/l (RE12).

For the waters whose mineralisation is lower to 350 mg/l that is the norm for the drinking water, these waters have an acceptable physicochemical composition. It is about the RE01 samples, RE02, RE03, RE04, RE05, RE06, RE07, RE08, RE09, RE11, RE13, RE14, RE14, RE15, RE16, RE17, RE18 and RE19.

The waters of samples RE10 (510,49 mg/l) and RE12 (736,69 mg/l) are highly mineralized because their general mineralisation is greater than 350 mg/l, the limit value (figure 17).

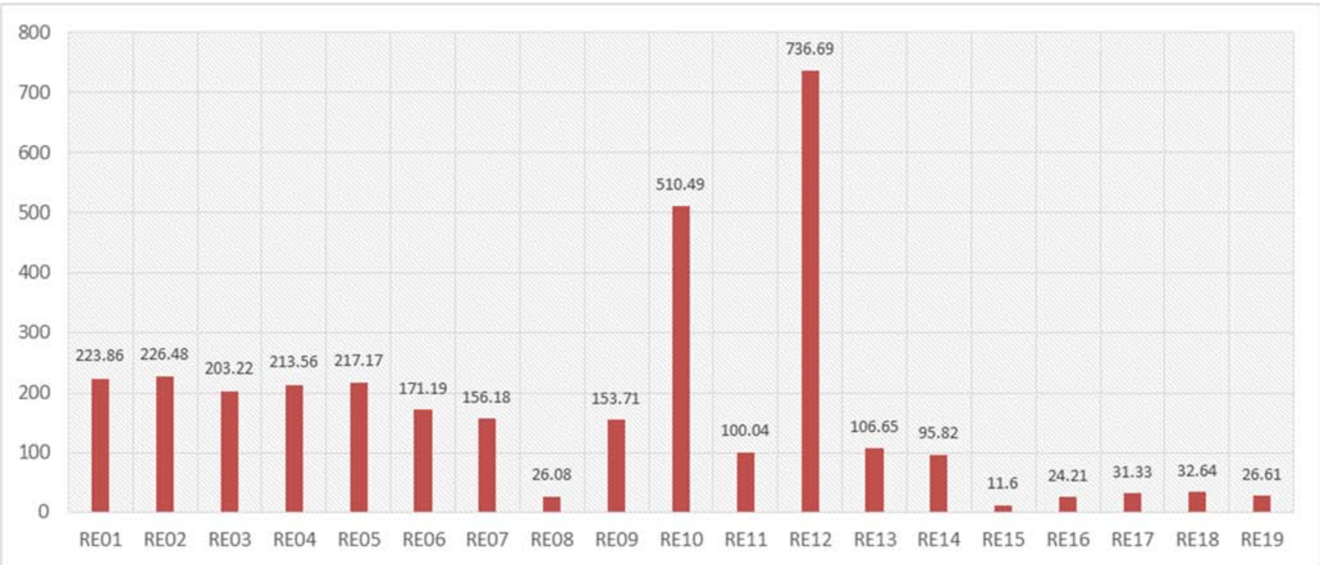

Figure 17. *Spatial variation of General Mineralisation.*

3.2. Upper Hierarchical Classification

This classification makes it possible to reduce the number of sampling sites in the case of a time tracking program. It has three groups: I, II and III. In these groups we can notice three trends and associations between tanks. This is the case of tanks RE01 - RE02 - RE03 - RE04 - RE05 - RE06 - RE07 and RE09 in the group I; RE08 - RE16 - RE18 - RE17 - RE15 - RE19 - RE11, RE13 and RE14 in the II group; RE10 and RE12 in the III group (figure 18).

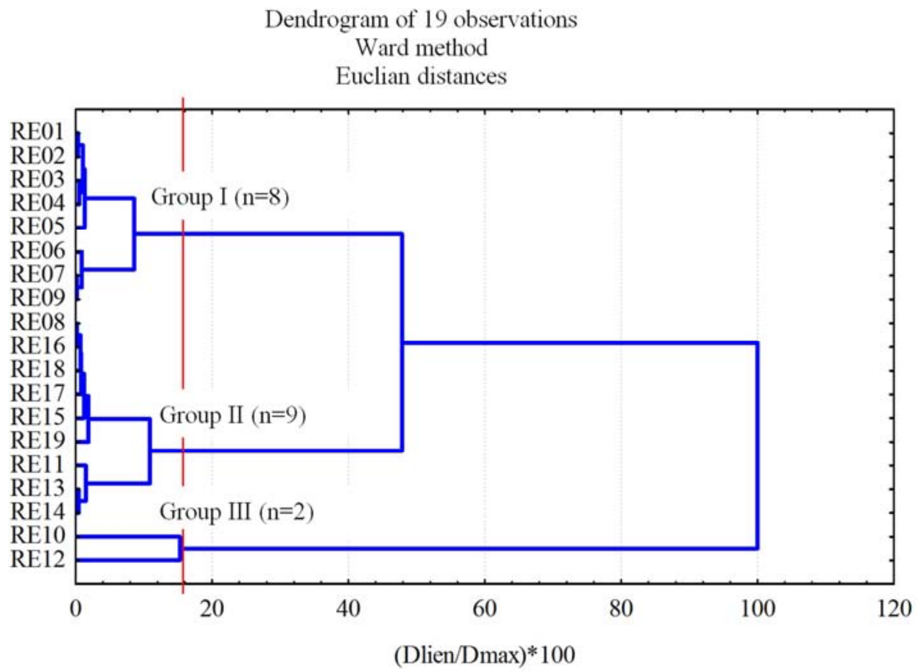

Figure 18. *Dendrogram of burried tanks.*

Similarly, the results on the statistical analysis application are shown in figures 19 and 20.

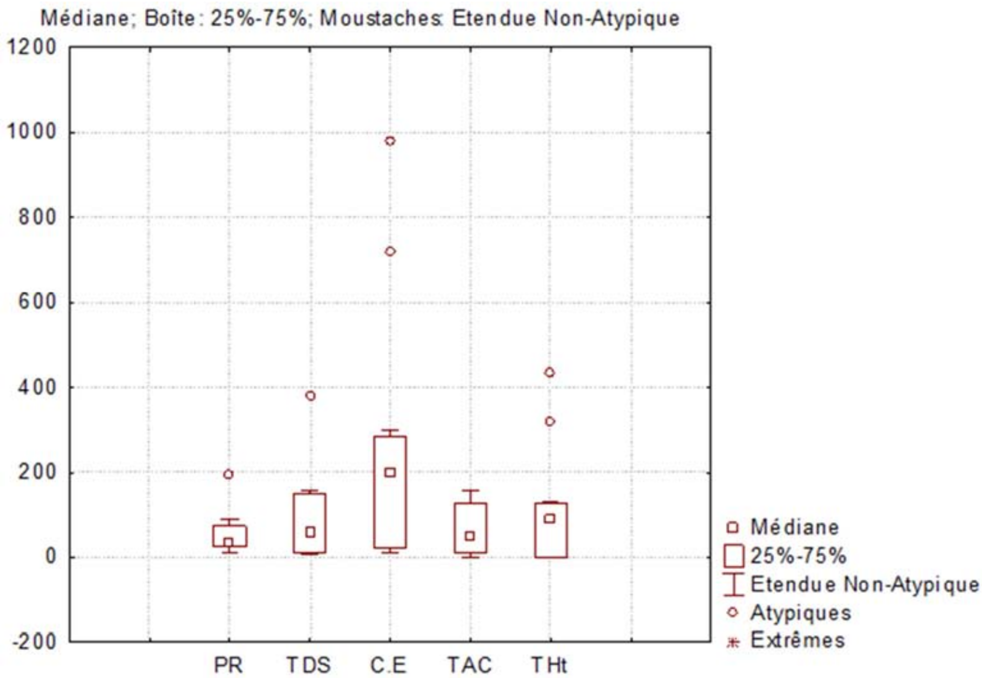

Figure 19. *Variability of redox Potental (RP), Total Dissolved Solids (TDS), Electrical Conductivity (EC), Complete Alcalimetric Title (CAT) and Total Hydrotimetric title (THt).*

These is a low variability of the Redox Potential (PR) compared to the mean (50,57).

The Total Dissolved Solids (TDS), the Total Hydrotimetric title (THt), and the Complete Alcalimetric Title (CAT) show remarkable variability relative to their mean (88,17; 95,28 and 67,26), respectively with extreme values: 523 mg/l (RE12), 434,33 mg/l $CaCO_3$ (RE12) and 156 mg/l $CaCO_3$ (RE05).

The Electrical Conductivity (EC) meanwhile, has a significant variability compared to the average (220,77). We also note an extreme value 982,25 µs/cm for RE12.

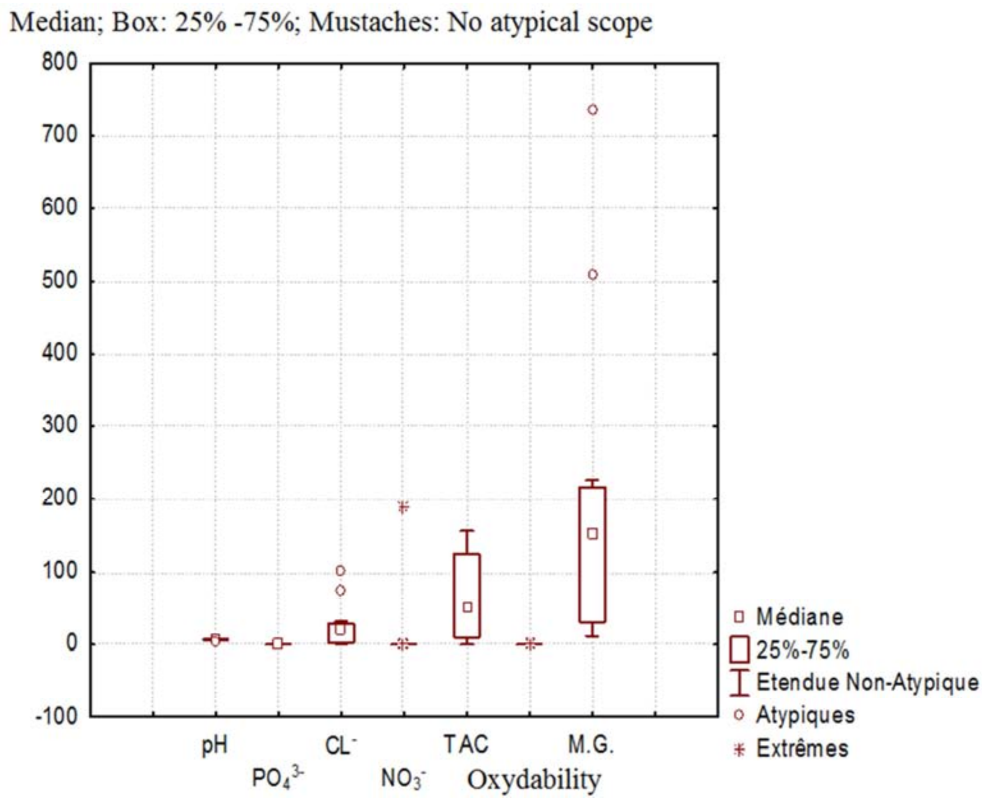

Figure 20. *Hydrogen potential (pH), variability, phosphate (PO43-), chloride (Cl-), nitrate (NO3-), Complet Alkalimetric Titre (TAC), oxydability (KMnO4) and General Mineralisation (G.M).*

In this figure, there are three trends:

1. a constant variation of the dissolved oxygen and of the Complet alkalimetric Titre;
2. a low variability of the hydrogen potential;
3. average variability of phosphate, nitrate, Total Hydrotimetric Titre, bicarbonate, oxydability and the chloride;
4. a very big variability of the general mineralisation.

Overall, this dispersion is explained by the spatial and temporal variation of these measurements [17-19]. The matrix of this table allows us to analyze the data and to assess the possible correlations between the different parameters of the water quality considered. These results are very significant for each physicochemical parameter studied. This matrix shows on the one hand a remarkable dispersion of rather important parameters as the total dissolved solids (TDS), the electrical conductivity (CE), the resistivity, the Total Hydrotimetric Titre (THt) and the general mineralization. This large dispersion is explained by the spatial variation of these measurements. On the other hand, the matrix shows a weak dispersion of parameters such as temperature, total iron, dissolved oxygen and alkalimetric titre.

Table 5. *Correlation matrix of the different parameters studied.*

Parameter	pH	PR	TDS	C.E	O_2	Salinity	Resistivity	rH
pH	1,00							
PR	-0,83	1,00						
TDS	-0,42	0,50	1,00					
C.E	-0,16	0,23	0,60	1,00				
O_2	0,36	-0,29	-0,37	0,05	1,00			
Salinity	-0,15	0,22	0,53	0,99	0,07	1,00		
Resistivity	-0,61	0,64	0,55	0,82	-0,07	0,83	1,00	
rH	0,33	-0,08	-0,33	-0,27	-0,15	-0,28	-0,23	1,00
PO_4^{3-}	-0,03	0,05	-0,61	-0,49	0,08	-0,40	-0,21	0,33
CL_-	-0,17	0,23	0,60	1,00	0,07	0,99	0,82	-0,27
NO_3^-	-0,80	0,84	0,76	0,48	-0,38	0,47	0,80	-0,27
TAC	0,58	-0,51	0,33	0,45	0,19	0,40	-0,12	-0,16
THt	-0,15	0,22	0,61	1,00	0,06	0,99	0,81	-0,28
HCO_3^{2-}	0,58	-0,51	0,33	0,45	0,19	0,40	-0,12	-0,16
Oxydability	-0,08	0,11	0,14	0,83	0,27	0,87	0,78	-0,15
MG	-0,13	0,20	0,57	1,00	0,07	0,99	0,81	-0,27

Table 5. *Continued.*

Parameter	PO_4^{3-}	Cl-	NO_3^-	TAC	THt	HCO_3^{2-}	Oxydability	M.G
pH								
PR								
TDS								
C.E								
O_2								
Salinity								
Resistivity								
rH								
PO_4^{3-}	1,00							
CL.	-0,48	1,00						
NO_3^-	-0,22	0,48	1,00					
TAC	-0,58	0,45	-0,30	1,00				
THt	-0,50	1,00	0,48	0,47	1,00			
HCO_3^{2-}	-0,58	0,45	-0,30	1,00	0,47	1,00		
Oxydability	-0,15	0,83	0,28	0,14	0,82	0,14	1,00	
MG	-0,48	1,00	0,45	0,46	1,00	0,46	0,84	1,00

Significant correlation in fat and color at $p < 0.05$.

This matrix makes it possible to analyze the data and to evaluate the possible correlations between the various water quality parameters considered in this study. The matrix groups together the correlations of several variables with each other, the coefficients indicate the influence that the variables have on each other [20- 21]. The coefficients are calculated on several variables taken 2 to 2. It is a symmetric matrix and its diagonal is made up of 1 since the correlation of a variable with itself is perfect. They can thus detect certain associations between the various physicochemical parameters measured. Values shown in bold are significant at a level of significance $p < 0.05$. This means that the risk of being wrong in rejecting the null hypothesis that the correlations are not different from 0 is less than 5%.

4. Discussion

Several studies have been carried out on the vulnerability of surface water and groundwater [16, 22], but few studies have been carried out on the characterization of water stored in buried concrete tanks.

The different physico-chemical parameters of the samples taken from the water used in this work highlight the vulnerability to pollution of water stored in the underground tanks, this, considering not only the variability of the results but also of the values which are far from the normal for some samples.

Except for the salinity parameter added and justified by the ocean waters, these results obtained in the city of Pointe-Noire are qualitatively better than those obtained in the city of Brazzaville [23- 25].

But, marks of pollution are supported by the aggressiveness of surrounding environments where concrete tanks are located are highlighted. But, these indices of pollution are especially favored by the weakness of concrete that is its permeability [11, 1, 2 and Annex, 2016].

The studies conducted by Demestre (2011) and Malanda (2015) show that an aggressive ion transport within the concrete by diffusion (Fick's law) takes place for structures exposed to a severe environment (chlorides ions, sulphate, etc.), for which the concentration of the aggressive ion is greater outside than inside the medium considered. The capillarity effect can thus constitute preferential pathways for the migration of the pollutants into the tank [23, 25, 26].

It is worth emphasizing that the porous structure of concrete makes possible, over time, the penetration of polluting species; which leads to a gradual degradation of the characteristics of the concrete material [27].

Thus, the results of measurements of the physico-chemical parameters carried out during this study revealed the existence of a spatio-temporal variation of the concentrations of different physico-chemical parameters. The uneven distribution of ion concentrations by site explains relatively the possible influence of the immediate environment, of population density with untreated landfills in some areas.

Similarly, the differences in reactivity observed in the different sites could be attributed not only to the aggressiveness of the surrounding environment, Guergazi and Achou (2015), but especially to a large extent to the quality of the walls of the tank that is, sealing.

The analysis revealed for the RE10 sample, the presence of the nitrate content is very strong thus constituting an effective pollution posing in the short or medium term a public health problem may arise [28, 30]. At the end of this work, studies carried out reveal that waters stored in the various points are not all inappropriate. The pollution indices are noticed at different degrees: namely highly polluted water, moderately polluted water and unpolluted water.

Current data do not explain the formulation of concretes used to make these storage tanks. The observed alteration of stored water, which over time can lead to very high pollution, is attributed to an exogenous origin [29, 21].

5. Conclusion

This study made it possible to assess globally the physicochemical quality of the water stored in underground tanks. The results obtained revealed quite remarkable pollution indices in the samples (RE01, RE02, RE03, RE04, RE05, RE10, RE11 and RE12), that is 42.10%. In addition, 57.9% of the samples analyzed (RE06, RE07, RE08, RE09, RE13, RE14, RE15, RE16, RE17, RE18 and RE19) have a fairly contrasting potability.

The variability of the results obtained according to all the different physicochemical parameters, in space and time is remarkable, which leads us to believe that these pollution indices are likely to evolve over time. This can pose a public health problem.

This evolutionary pollution could be justified by external contaminations due to groundwater, and by the problem of durability of the concrete walls of buried tanks. To avoid possible health risks, preventive measures (chlorination) are of paramount importance and must be advised to consumers of this water.

The results obtained open up interesting prospects. They allow to consider in the near future, the development of a more sealed concrete with almost zero porosity in order to preserve the drinkability of the stored water.

Although it is difficult to obtain an absolute watertightness of the concrete with respect to water, it is however possible to minimize the risk of pollution of the stored water by approaching a very low porosity of the concrete.

In the rainy season when the water table is raised, the values of the physicochemical parameters measured may be higher.

Acknowledgements

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Appendix

Results of physicochemical parameters of Pointe-Noire raw water (Source SNDE, 2016).

Table 6. *Physical and Chemical Analysis Bulletin.*

Parameters	Results	Unit	WHO standard
pH at 20 °C	7,75	-	6,5 – 8,5
Residual Chlorine	0,35	mg/l	0,2 – 0,5
Turbidity	0,18	NTU	< 5
Color	0,0	mg/l Pt-Co	< 1
Odor	without	-	without
Flavor	without		without
Appearance	Homogenous	-	Homogenous
Total Dissolved Solids (TDS)	58,05	mg/l	200
Conductivity at 20 °C	113,20	µs/cm	< 350
Alkalimetric Titre (T.A)	0,0	mg/L$CaCO_3$	5
Complet Alkalimetric Titre (T.A.C)	43,56	mg/l $CaCO_3$	< 100
Total Hydrotimetric Titre (THT)	50,30	mg/l $CaCO_3$	< 150
Suspended Matter (M.E.S)	0,0	mg/l O_2	< 1
Calcium Ca^{2+}	16,98	mg/l O_2	70
Magnesium Mg^{2+}	3,40	mg/l O_2	50
Nitrates NO_3^-	1,03	mg/l O_2	< 50
Nitrites NO_2^-	0,00	mg/l O_2	< 0,1
Phosphates PO_4^{3-}	0,42	mg/l O_2	< 1
Ammonium NH_4^+	0,00	mg/l O_2	< 0,5
Sulfates SO_4^{2-}	1,58	mg/l O_2	< 250
Sulfides S^{2-}	0,00	mg/l O_2	0,1
Fluoride F^-	0,04	mg/l O_2	< 1,5
Chloride Cl^-	14,60	mg/l O_2	< 200
Potassium K^+	1,02	mg/l O_2	12
Sodium Na^+	9,48	mg/l O_2	< 150
Total iron	0,06	mg/l O_2	0,3
Manganese Mn^{2+}	0,00	mg/l O_2	0,1
Copper CU^{2+}	0,04	mg/l O_2	1
Aluminium Al^{3+}	0,08	mg/l O_2	0,3
Bicarbonates HCO_3^-	53,14	mg/l O_2	200
Silicon SiO_2	8,03	mg/l O_2	12

Parameters	Results	Unit	WHO standard
Oxydability with $KMnO_4$ in an acid middle	0,13	mg/l O_2	< 1
Oxidation Reduction Potency - (rH)	21,64	-	20 - 27
General Mineralization	101,88	mg/l O_2	350

Name of the shipper: SNDE (Pointe-Noire)
Type of sample: Tap water
Sampling site: /Date and time of sampling: 17/02/2016 at 11 h 26
Date and time of arrival at the laboratory: 19 /02/16 at 9h30
Start date and time of analysis: 19 /02/16 at 11h25

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