Journal of Water Resource and Protection, 2022, 14, 419-432
https://www.scirp.org/journal/jwarp
ISSN Online: 1945-3108
ISSN Print: 1945-3094

Study of the Drinkability of Groundwater on the Island of MAR in Senegal

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How to cite this paper: Ndao, S., Thioune, P.B.D. and Gassama, D. (2022) Study of the Drinkability of Groundwater on the Island of MAR in Senegal. *Journal of Water Resource and Protection*, **14**, 419-432.
https://doi.org/10.4236/jwarp.2022.146022

Received: October 29, 2021
Accepted: June 19, 2022
Published: June 22, 2022

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Abstract

For a long time, the supply of drinking water to the island of Mar was ensured by drilling and wells. The advance of the salt wedge led the populations to stop the exploitation of the drilling due to the accentuation of the salinity of the water characterized by high fluorine content. The marine environment and the rainfall deficit of recent decades as well as population growth have highlighted the sensitivity of this resource. The objective of this article is to study the drinkability of the water supplied by the drilling and the wells of the island of Mar. for this, water samples were taken in the Continental Terminal and their analysis made in situ or in the laboratory. Data processing was done by using Surfer 11 and ArcGIS software. It was emerged from this study that the drop in the piezometric level caused an entry of salt water. The mineralization of the water follows a decreasing trend from areas with marine influence inland. Groundwater in certain areas is generally of good quality with some sources of pollution linked to salinity but also to high levels of nitrate, chloride and fluorine. The island of Mar being confronted with a problem of drinkability of groundwater, the alternative would be to proceed to a transfer of better quality water from nearby areas after a hydrogeological and physico-chemical study of these waters in relation to their fitness for consumption.

Keywords

Salinity, Terminal Continental, Salt Wedge, Pollution, Solutions

1. Introduction

The management of a water resource whether surface or underground is more than necessary for the sustainable satisfaction of the water needs of a population. Indeed, a water resource is neither inexhaustible nor insensitive to environmental attacks [1].

In Senegal, apart from regions with permanent watercourses, the drinking water supply of populations relies entirely on the exploitation of groundwater reservoirs. Among these reservoirs, we find that of the sandy clay formations of the Continental Terminal of the island of Mar located on the coasts and in the estuary. It is the food source for populations and is currently facing salinization as well as a recharge deficit.

The problems linked to water management on the island of Mar prompt us to think about the ways and means to be implemented to provide solutions for the preservation of groundwater.

Indeed, the 1969-1985 drought periods, well known in the Sahel, had negative consequences in the well-watered Sudano-Guinean areas, in particular on the estuaries of the coastal areas [2]. The groundwater on the coasts and estuary of the Saloum Islands has been severely tested. This means that the decrease in rainfall and river flow as well as the increase in pumping have resulted in: the general drop in the level of water and the salinization of aquifers located near the coasts and estuaries. Thus, in the island of Mar, the drop in freshwater inflows, combined with strong evaporation and a very low slope, favored percolation of marine waters causing a considerable increase in the salinity of the coastal and estuary aquifers.

Numerous studies [3] have contributed to improving knowledge of estuaries such as Saloum and Casamance. They have shown that in addition to the saline intrusion that manifests itself on the coastal fringe of these systems, the considerable increase in the salinity of river water at the estuary level also contributes to the contamination of groundwater in this area.

In the island of Mar, a locality based in the islands of Saloum, in the region of Fatick, is more precisely in the municipality of Fimela, and there is a high chloride content of the order of 316.8 to 1134.6 mg/l whereas [4] [5] [6] [7] [8] recommend a maximum level of 250 mg/l. This high content is favored by the proximity of sea water and an overexploitation of the aquifer water which leads to the advance of the salt wedge. This is why, the populations of this locality and the surrounding areas, do not stop complaining to the state authorities because of the poor quality of the water which not only does not meet the drinking standards of the WHO but also does not allow the development of agricultural activities outside the rainy season [9]. The objective of this article is to carry out physicochemical analyzes of this water in order to decide on its drinkability.

2. Materials and Methods

2.1. Geographical Situation

Senegal covers an area of 196,722 km^2. It is bounded to the east by Mali, to the west, to the north-west and south-west by the Atlantic Ocean on a maritime frontage, to the north by Mauritania and to the south by Guinea Bissau and the Republic of Guinea (**Figure 1**). The study area covers the northern part of the Saloum estuary.

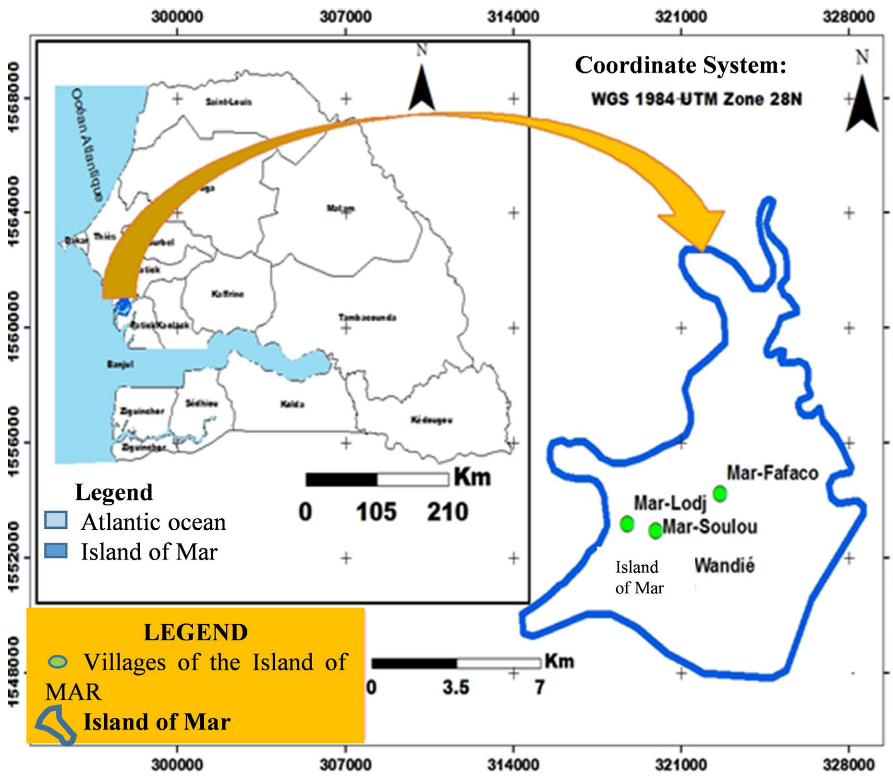

Figure 1. Geographical location map of the study area.

The island of Mar is located in the extreme southwestern part of the Municipality of Fimela, Department of Fatick, more precisely to the north of the Saloum estuary. It has more than 10,000 inhabitants [10] and brings together four (4) villages: Mar Fafaco, Mar Lodj, Mar Soulou and Mar Wandié.

The island of Mar is one of the largest islands in Senegal at 27 km long and 11 km wide. It covers an area of approximately 297 km^2.

2.2. Materials Used

Regarding the material used, these include, among others:

- An electromagnetic conductivity meter (EM31) which facilitated the acquisition of data on electrical conductivities, the variations of which reflect the heterogeneities and variations of the near-subsoil facies;
- A GPS for locating a few wells and drilling;
- A conductivity meter to measure the conductivity of the water;
- Regarding the software, we used:
- Surfing and ArcGIS which made it possible to spatialize the chemical parameters of the groundwater, the topographic data and to map the ions;
- Global Mapper has facilitated the conversion of files from Kmz format to shapefile format.

2.3. Geophysical Methods Applicable to Salinization Problems

The use of geophysical prospecting for the detection and characterization of aquifers has grown significantly in recent years. In hydrogeology, electrical resistivity can be used, for example, to identify aquifers and determine their thickness. In the environmental field, electrical methods can be used to delineate and track contaminated plumes of groundwater or soil. Indeed, these methods can also be used to monitor the quality of the water when there is a possible contamination, have followed the evolution over time using periodic surveys on the surface or in drilling by logging. In the case of salinization linked to the problems of marine intrusions, the physical parameter that allows it to be characterized is resistivity or its inverse, conductivity. Our choice, for the EM31 method which has an investigation depth of 6 m, is justified by the maximum depth of the wells in the Mar zone which is less than 6 m [11]. There are different methods of mapping soil salinity. In our study, to assess the salinity of the soil in the perimeter of the drilling, the EM31 electromagnetic conductivity meter is used.

2.4. Location of Wells and Drilling Sampled

The water samples taken from the aquifer system concern 15 wells and one drilling and are tracked using Garmin-type GPS. Figure 2 locates the sites where the samples were taken.

2.5. Sampling Method Adopted

By the method of [12], 15 wells and a drilling were the subject of a campaign of piezometric readings and measurements of the physical parameters of the water

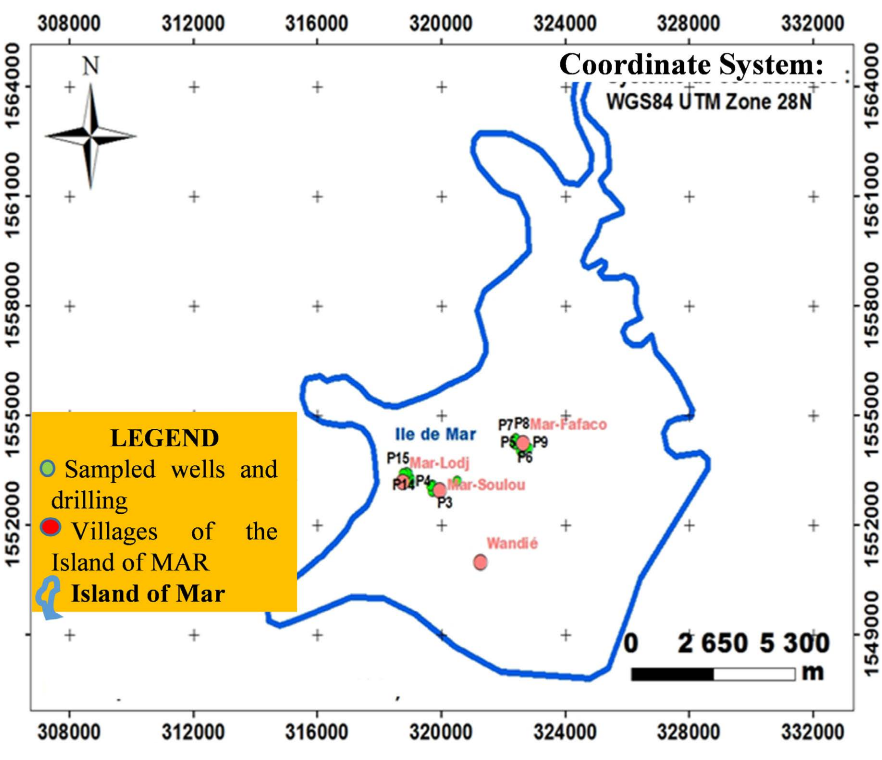

Figure 2. Location map of the sampled points.

in situ (conductivity, pH, temperature). The process consisted of taking water samples stored in 1.25 liter bottles for chemical analyzes in the laboratory. The analyzes focused only on the major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, NO_3^{-}, HCO_3^{-}). The results obtained have enabled us to draw up a number of maps.

3. Results and Discussions

3.1. Study of the Physical Parameters

In this part, as [12] [13] [14] only physical parameters such as temperature, pH and electrical conductivity are considered. The results of the analysis of the samples taken are very heterogeneous (**Table 1**).

3.1.1. Temperature

Temperature is one of the most determining factors in water chemistry. Indeed, a high temperature promotes the development of microorganisms. In addition, it can increase the taste, odor and color of water and worsen corrosion problems. These organoleptic factors, although not causing significant health risks, at a certain level, should be considered in chemical analyzes. The temperature measurements of the sampled water vary from 23˚C to 32˚C (**Table 1**). Indeed, these temperatures are close to room temperature. This highlights the open character of the aquifer, and therefore its greater or lesser vulnerability to pollution from the surface.

Table 1. Results of the physical analyzes of the waters of the island of Mar.

Name of samples	Aquifer captured	Group	T ˚C	pH	CE in µs/cm
P1	Continental Terminal	1	28.5	6.55	3030
P2	Continental Terminal	2	32.5	7.36	525
P3	Continental Terminal	3	24.3	6.82	2730
P4	Continental Terminal	4	26.7	6.23	315
P5	Continental Terminal	5	28.5	6.4	3038
P6	Continental Terminal	6	32	7.32	529
P7	Continental Terminal	7	28	6.56	3034
P8	Continental Terminal	8	32.3	7.38	523
P9	Continental Terminal	9	31.5	7.34	526
P10	Continental Terminal	10	25.2	6.85	2729
P11	Continental Terminal	11	27	6.25	320
P12	Continental Terminal	12	26.2	6.24	317
P13	Continental Terminal	13	23	6.8	2728
P14	Continental Terminal	14	24.7	6.83	2727
P15	Continental Terminal	15	24.4	6.81	2729
Drilling	Paleocene	16	29.9	8.26	5320

In terms of health, too high temperatures promote the proliferation of tropical germs while the strong mineralization can cause diarrhea [9].

3.1.2. The Hydrogen Potential (pH)

It is a parameter which reflects the balance between acid and base on a scale of 0 to 14 [15]; 7 being the neutral pH. It measures the concentration of H^+ ion in water. Although pH does not usually have direct consequences for the consumer, it is one of the most important operational parameters for water quality. For drinking water, WHO recommends pH values between 6.5 to 8.5. The measured pH values vary from 6.2 to 8.3 (**Figure 3**). Indeed, this range of values indicates that the groundwater is acidic to neutral. These acidic pHs may be related to the presence of sulphated soils in the area. The leaching of these soils by infiltration of rainwater can be the cause of the drop in pH. The latter may also be due to the dissociation of carbonic acid resulting from the diffusion in water of atmospheric CO_2 and that resulting from biological activity.

3.1.3. Conductivity

According to WHO, the quality limit for water intended for human consumption is EC between 200 and 1100 µS/cm. **Figure 4** shows the conductivities of the

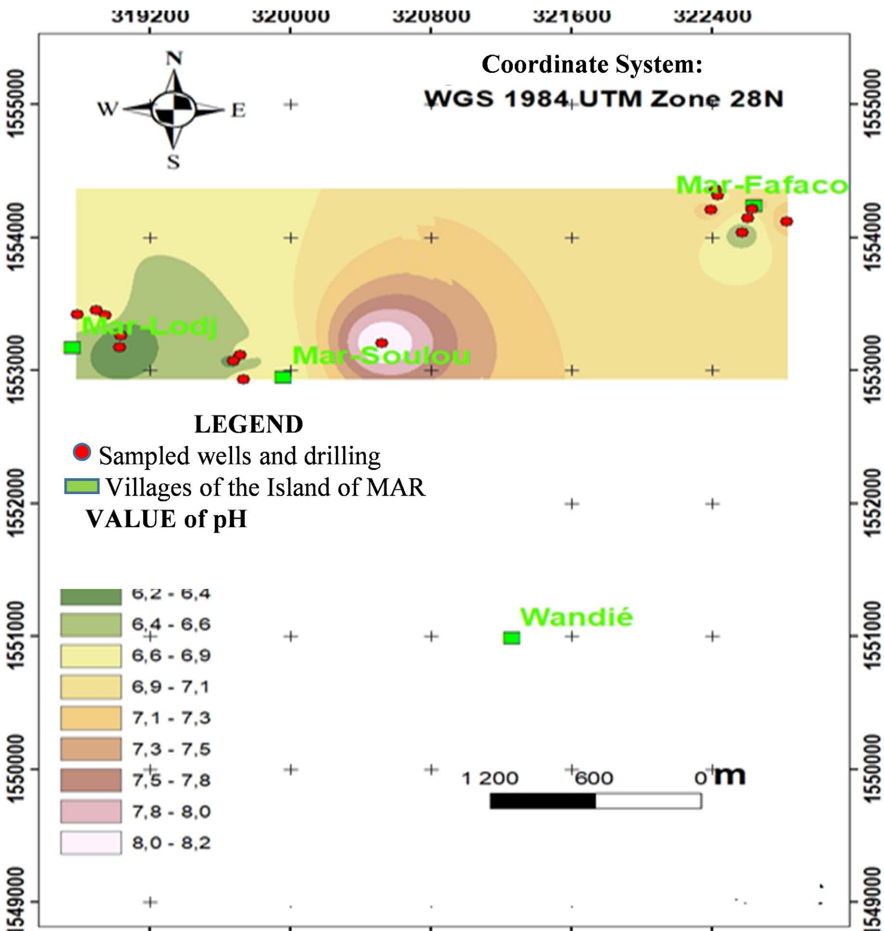

Figure 3. Variation of pH values in the water sampled from the study area

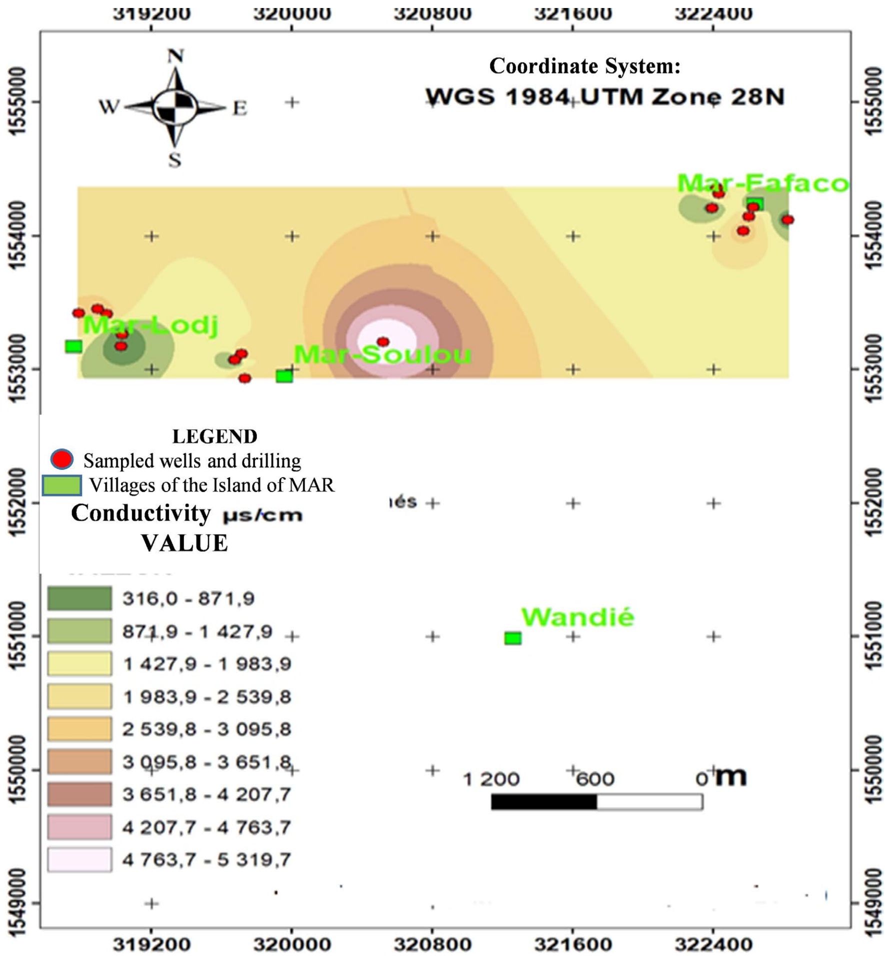

Figure 4. Conductivity map of the sampled points.

sampled points varying from 316 to 5319.7 µS/cm. Indeed, the variations of the EC are related to the modifications of the global mineralization. At Mar Lodj and Mar Fafaco, the EC values of some wells are generally low and range between 316 and 871.9 µS/cm. These low EC values may be related to dilution by infiltration of rainwater, resulting in the presence of fresh water. However, in the drilling's water and in certain sampled wells a strong high electrical conductivity is noted which exceeds the limit 1100 µS/cm. This would be due to local contamination by salt water [12].

3.2. Chemical Parameters

The results obtained after chemical analysis [14] of the major ions are as follows:

3.2.1. Sodium (Na^+)

The sodium content ranges from 40.4 to 1683.9 mg/l (**Figure 5**). In fact, most of the water sampled has sodium content higher than the standard accepted by the WHO (200 mg/l). The most excessive concentrations are observed in the drilling with a maximum value of 1683.9 mg/l. This high content could be explained by the fact that it is located near the arm of the sea where there is a high salinity

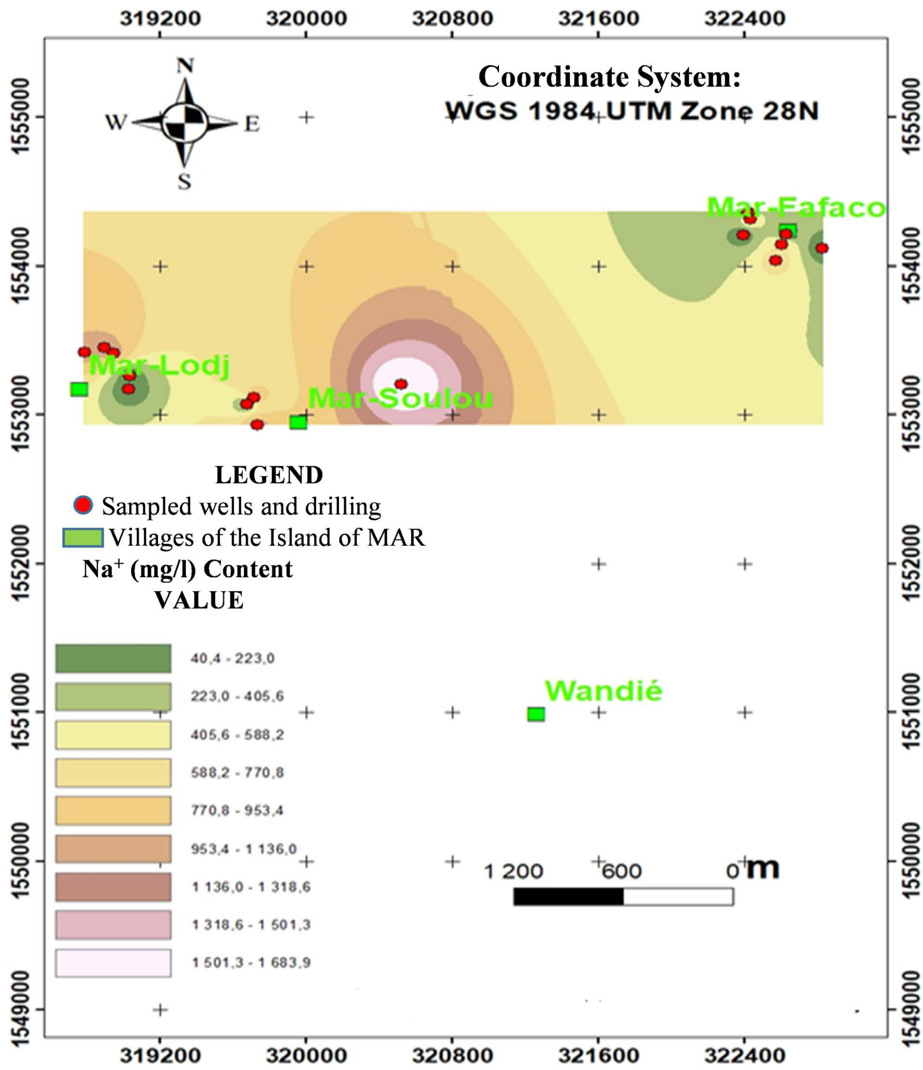

Figure 5. Map of sodium content (mg/l).

as confirmed by the electromagnetic conductivity map. A lack of Na^+ can lead to dehydration, muscle paralysis, reduced growth and general numbness [4].

3.2.2. Potassium (K^+)

Throughout the entire study area, the potassium content varying from 9.0 to 45.8 mg/l (Figure 6) exceeds the WHO standard (12 mg/l) with the exception of a few wells (P2, P4, P11, P12) where their potassium contents are lower than this WHO required value. This high content could be explained by agricultural effluents.

3.2.3. Chlorides (Cl^-)

The chloride distribution map (Figure 7) shows that the wells (P2, P4, P6, P8, P9, P11, P12) have chloride contents ranging from 45.6 to 209.9 mg/l, less than the WHO standard (250 mg/l) unlike the other remaining wells where the concentrations are well above 250 mg/l. The highest concentrations of Cl^- are observed in the drilling, which reaches 1524.4 mg/l. This high content could be

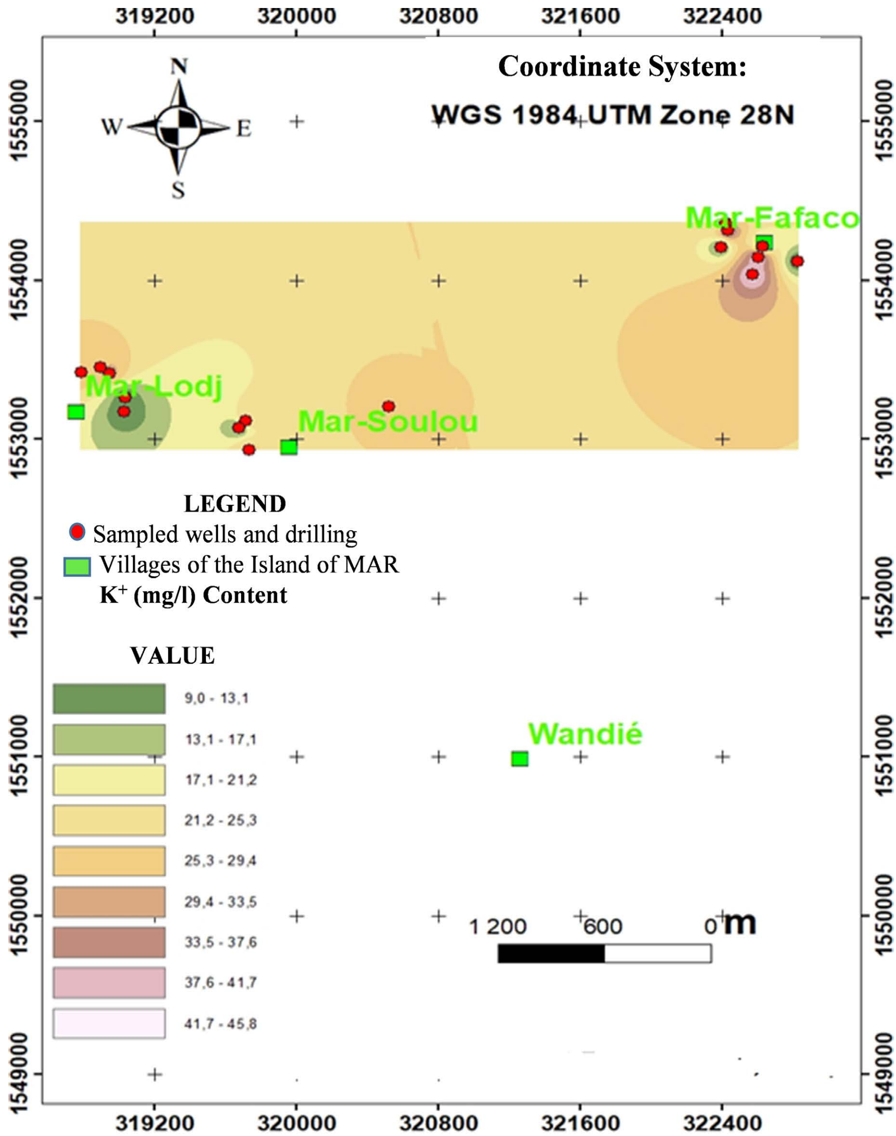

Figure 6. Map of potassium content (mg/l).

explained by a saline intrusion due to the proximity of the inlet. A concentration more than 200 mg/l can be dangerous for patients with cardiovascular or renal diseases [4] [6] [16].

3.2.4. Fluorine (F^-)

Fluorine concentrations are generally low in all the wells at Mar Fafaco, Mar Soulou and Mar Lodji varying from 0.05 to 1.4 mg/l and much lower than the value accepted by the WHO which is equal to 1.5 mg/l. However, the fluorine concentration in the drilling (at Mar Soulou) is much higher than the accepted standard with a maximum value of 3.2 mg/l (**Figure 8**). Indeed, excess fluorine in groundwater (concentration between 0.7 and 1.7 mg/l) causes dental fluorosis due to hypermineralization of dental enamel induced by fluorine during the secretory phase and maturation of phenomena leading to the formation of enamel. This phenomenon occurs in an age group between 0 to 7 years old [4] [17].

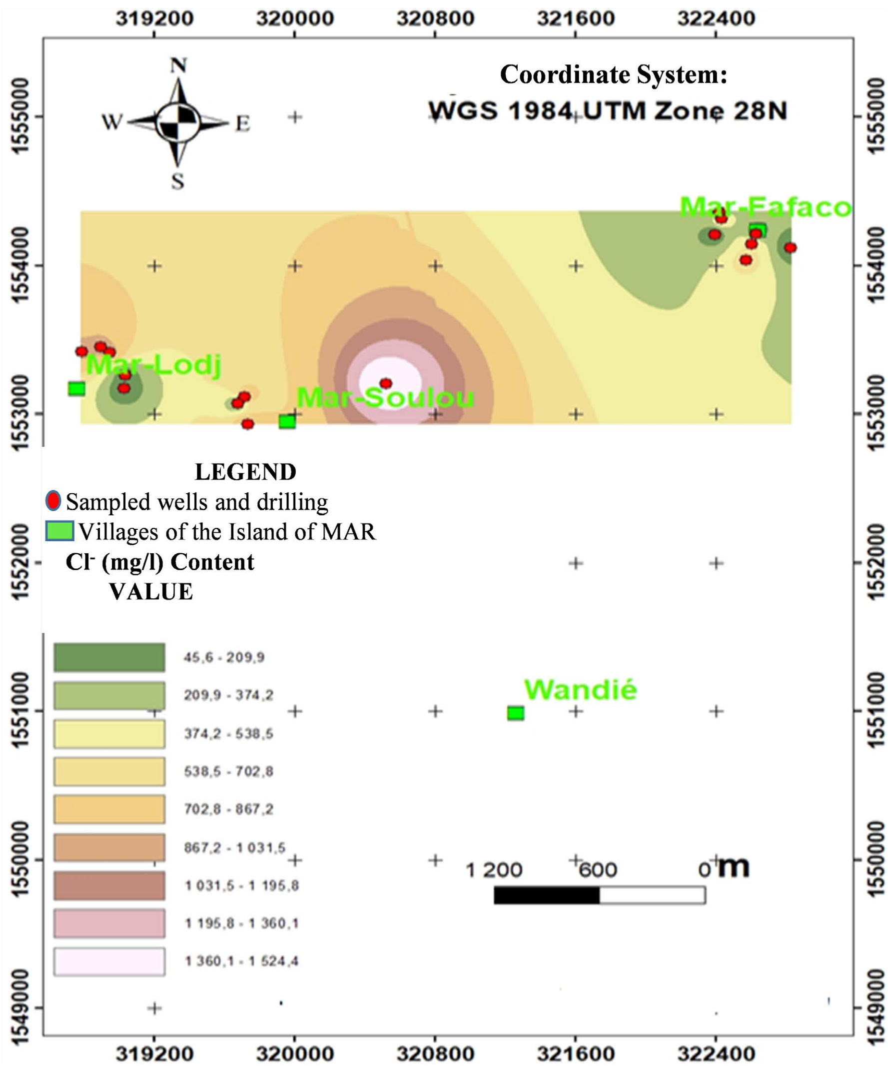

Figure 7. Map of Chloride concentration (mg/l).

3.2.5. Nitrate (NO_3^-)

The nitrate levels in groundwater vary from 1.6 to 63.9 mg/l (**Figure 9**). The lowest values are located at the level of the borehole and part of Mar Fafaco while in Mar Lodj, Mar Soulou and the other part of Mar Fafaco, the concentration is high varying from 50.1 to 63.9 mg/l and exceeding the value recommended by the WHO (50 mg/l). This high content could be due to the siting of wells near the septic tanks. In fact, the transformation of nitrates in the human body gives rise to nitrites which in turn are transformed into nitroamines which can be carcinogenic, especially fatal for children [7] [12] [14] [16] [18] [19].

4. Conclusions

The aim of this article is to study the salinity of the groundwater of the island of Mar. The study is allowed to characterize the hydraulic system from the hydrochemical point of view of the aquifer. For a better characterization of groundwater, we needed detailed, reliable and well-organized information on the state of

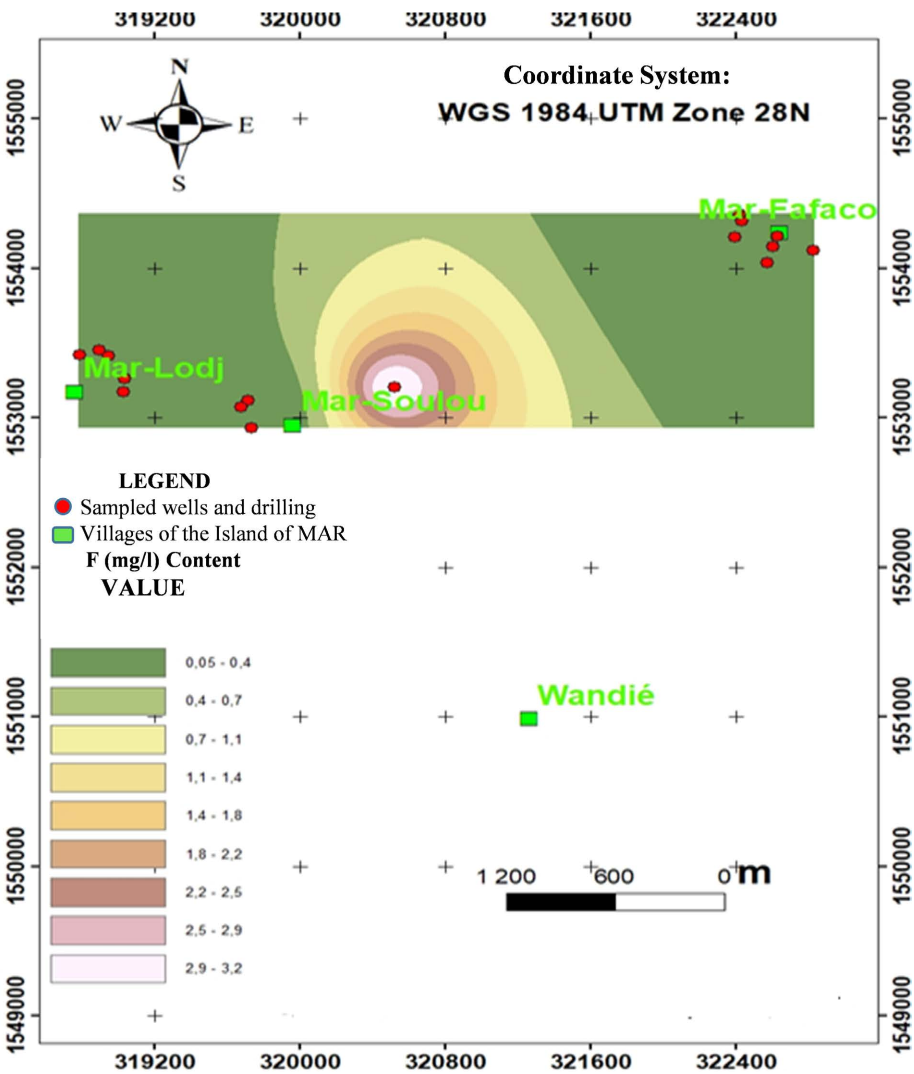

Figure 8. Map of the Fluorine concentration (mg/l).

the hydrogeological environment. With this in mind, this article has enabled us to reproduce a series of spatial themes of maps. The Geographic Information System (GIS), Geophysical methods are used as tools and methods well suited to this mapping.

The geophysical profiles carried out in the drilling area have identified a high conductivity of the aquifer according to geophysical surveys with the EM31 electromagnetic method. The sainity map produced using the Surfer software showed that the conductivity exhibits an increasing gradient towards the South and towards the West. We therefore have an increase in conductivities as we progress towards the inlets.

With the hydrochemical study, we were able to carry out a physicochemical characterization of the water and highlight the chemical facies and the various processes which are at the origin of the mineralization of the water. The results obtained after processing the data showed that the dominant waters in the study area are sodium hyperchloride, sulphated chloride. The study on the quality of

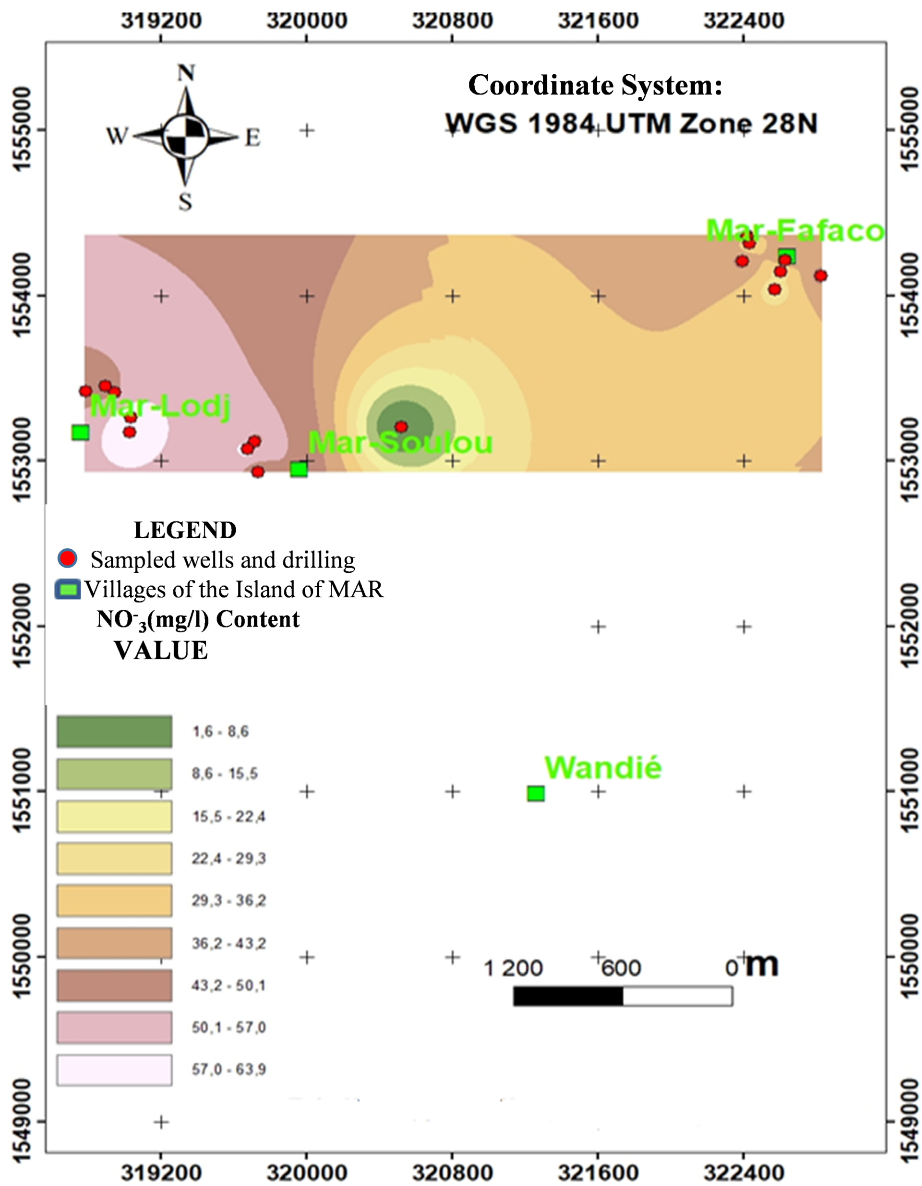

Figure 9. Map of nitrate concentration (mg/l).

the water sampled revealed that it did not comply with the quality benchmarks for the majority of the structures. Water that is of poor quality for consumption could be used for irrigation.

The study of the physicochemical parameters has shown that the groundwater is slightly acidic to neutral with temperatures that reflect that of the ambient environment at the time of the measurements. This proves the proximity of the water table, and therefore its vulnerability to pollution. Most of the water has high conductivities which exceed the value allowed (1100 µS/cm) by the WHO. Therefore, it must be remembered that the groundwater of the island of MAR cannot be considered drinkable. And since the populations need good quality water to survive, we suggest as an alternative to treat the water before any consumption or to transfer water from areas where the water is deemed suitable by the standards set by WHO. Doing such a study could be the subject of another article.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] BRGM (1987) Study of Underground Water Resources in Senegal. 70.

[2] Diouf, M. and Coly, W. (2001) Contribution to the Hydrochemical and Isotopic study of the Continental Terminal Water Table. SNE GAMBIA, D.E.A, UCAD, 103.

[3] Aller, L.T., Bennett, J.H., Lehr, R.J., Petty, R.I. and Hackett, G. (1987) Drastic, a Standardized System for Evaluation Groundwater Pollution Using Hydrogeologic Settings. US Environmental Protection Agency, Washington, DC, 455.

[4] WHO (2004) Quality Guidelines for Drinking Water. 3rd Edition.

[5] American Water Works Association (AWWA) (1990) Water Quality and Handbook of Community Water Supplies. 4th Edition, McGraw-Hill, New York.

[6] Edmunds, W.M. (1994) Groundwater Chemistry and Development. In: Nash, H. and McCall, G.J.H, Eds., *Groundwater Quality*, Chapman and Hall, London, 5-7.

[7] AFNOR (1997) Water Quality. Volume 1: Terminology, Sampling and Evaluation of Methods. 3rd Edition, French Agency for Standardization, Paris, 439.

[8] Rodier, J., Bazin, C., Broutin, J.-P., Chambon, P., Champsaur, H. and Rodi, L. (2005). Water Analysis: Natural Waters, Residual Waters, Sea Waters. 8th edition, Dunod, Paris, 1383.

[9] Kahoul, M. and Touhami, M (2014) Assessment of the Physico-Chemical Quality of Drinking Water in the City of Annaba (Algeria). *Larhyss Journal*, **19**, 129-138.

[10] ANSD (2018) Report on the Evolution of the Population in Fatick. 30.

[11] Salameh, E. (2021) The Hydrogeological Consequences of the Proposed Extraction of the Deep Groundwater in Jordan. *Journal of Geoscience and Environment Protection*, **9**, 111-128. https://doi.org/10.4236/gep.2021.98007

[12] Rodier, J. (1996) The Analysis of Natural Water, Residual Water, Sea Water. 8th Edition, Dunod Techniques, Paris, 1384.

[13] Russo, D. (1988) Determination Soil Hydraulic Properties by Parameter Estimation: on the Selection of a Model for the Hydraulic Properties. *Water Resources Research*, **24**, 453-459. https://doi.org/10.1029/WR024i003p00453

[14] Talabi, A. and Kayode, T. (2019) Groundwater Pollution and Remediation. *Journal of Water Resource and Protection*, **11**, 1-19. https://doi.org/10.4236/jwarp.2019.111001

[15] Hanon, M. and Rouelle, A. (2011) The pH of Mains Water. Portail Environnement de Wallonie, Begique.

[16] Egboka, B.C.E. (1984) Nitrate Contamination of Shallow Groundwaters in Ontario, Canada. *Science of the Total Environment*, **35**, 53-70. https://doi.org/10.1016/0048-9697(84)90368-1

[17] Ribeiro, L., Serra, E., Paralta, E. and Nascimento, J. (2003) Nitrate Pollution in har Drock Formations: Vulnerability and Risk Evaluation by Geomathematical Methods in Serpa Brinches Aquifer (South Portugal). *Proceedings of IAH International*

Conference on Groundwater in Fractured Rocks, *Prague*, *IHP-VI*, *Series on Groundwater No*. 7, UNESCO, Paris, 377-378.

[18] World Health Organization (2006) Guidelines for Drinking-Water Quality [Electronic Resource]: Incorporating First Addendum. 3rd Edition, 595.

[19] Adam, J.W.H. (1980) Health Aspects of Nitrate in Drinking-Water and Possible Means of Denitrification (Literature Review). *Water SA*, **6**, 79-84.