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Assessment of groundwater quality in Berrechid Aquifer, Morocco

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Abstract

The aquifer of the Berrechid plain is the most important of Morocco. It sustains many activities closely linked to regional and national socio-economic development (farming, industrial). High concentrations of chlorides, nitrates, electrical conductivity in the soil, and the risks to the environment and public safety are the subject of increased interest in the Berrechid aquifer. The main objective of this study was to analyze the quality of groundwater in the region of Berrechid. This region is subject to high agricultural and industrial activity. The mapping of physicochemical parameters were realized with ArcGIS Software, Version 10.3. These distribution maps were generated by Distance Weighted Inverse interpolation (DWI). For comparison analyses, the simplified groundwater quality grid was used. The physicochemical and bacteriological characterization of the Berrechid aquifer showed high values for electrical conductivity (EC) (7100 µS/cm), Chlorides (Cl^-) (2409 mg/L), nitrates (NO_3^-) (190 mg/L), ammoniacal nitrogen (NH_4^+) (0.02mg/L),organic matter(OM) (4.55mg/L), fecal coliforms (FC) (40000UFC/100mL). Generally, the approaches developed in this work proved to be promising for real-time and low-cost groundwater quality prediction by using physicochemical parameters.

Keywords: *Aquifer Berrechid, physicochemical characterization, bacteriological, GIS, IDW.*

1. Introduction

Groundwater resources are classified as primary natural resources that support the socio-economic advancement of the country. However, agriculture is the primary sector that uses groundwater worldwide [1]. In the last years, intensive degradation of groundwater, exploitation caused by population growth, and heavy pressure from agriculture and industry have become a global problem [2]. Each year, around 2.7 million tonnes of pesticides are used in the world to prevent crop losses [3].Groundwater may be affected and degraded, both directly and indirectly, by climatic change and human activity, such as excessive pumping and infiltration of pollution into the recharge zone of the aquifer [4]–[7]. In Morocco, irrigated agriculture is increasingly dependent on access to groundwater [8]. The intensification of irrigated agriculture is causing an increase in groundwater use in Morocco. It accounts for 50% of groundwater overexploitation [9]. Our study focuses on the Berrechid plain, located in the south of Casablanca, Morocco, with a zone of 1500 km^2. This aquifer is very vulnerable due to its overuse for irrigation purposes. In contrast, domestic, industrial, and agricultural uses have risen sharply to groundwater contamination and caused significant changes in the aquifer system. The population of the Berrechid region was only about 712 people in 1926 but has increased to 484518 in 2014 [10]. The total area irrigated for exploitation has increased from 7,147 to 13,300 ha. The annual volume increased from 46 Mm^3/year to 58 Mm^3/year during 1986-2007. The result is a deficit of 20 Mm^3. The wastewater from this area is discharged without any prior treatment. Its physicochemical characteristics have shown a high organic load and a significant dissolved oxygen-deficit downstream of the discharge point [11]. In addition, this region has many industrial facilities whose discharges are responsible for a significant portion of groundwater pollution. The existing companies operate in various sectors: (textiles, surface treatment, battery manufacturing, nickels, painting of agricultural machinery, lacquering of aluminium sheets, municipal slaughterhouses, and tanneries). Under the pressure of this situation, hydro geologists have focused their attention span and research on the effects of global warming and human being; actions on the groundwater supplies [12]–[14]. Many studies focus on assessing groundwater vulnerability following different models and critical levels of groundwater contaminants caused by anthropic activity, leaching of wastewater, and utilizing the high quantity of fertilizers in agriculture [15]. Nevertheless, many projects are devoted to the dynamic operation of the model in the Berrechid plain. This research is still insufficient to determine the recharge and its chemical progress of groundwater or describe the geochemical processes that take into the system in response to reactive water requirements. The purpose of this study was to assess groundwater quality using ArcGIS software with IDW interpolation. Most of the population uses this groundwater, without any treatment, for irrigation and daily needs.

2.Study area

The Berrechid aquifer is located in the Atlantic coastal basin, between Rabat and Azemmour, covering a surface area of approximately 10470 km^2 [16]. This tablecloth is located south of Casablanca and differs from other tablecloths in the region by its surface area of about 1500 km^2. It is part of the quadrilateral formed by Settat, El Gara, Mediouana, and the center of Bouskoura (Figure1). This area is semi-arid with an annual rainfall that varies from 280 to 320 mm, while the temperature ranges from 6.5◦C (January) to 38◦C (August). This study area has been researched for more than six decades [17]. The basin is endorheic and does not have an outlet to the sea. The natural feeding of this basin is done by infiltration of rainwater and watercourses coming from the south and disappearing under the plain [18]. Topographically, the basin is a flat area characterized by elevations and gradients ranging from 140 m and 0.2%, respectively, in the north to 350 mands 0.8% in the southern portion [19]. However, the lithostratigraphic sequence of these formations is as follows: Primary, the bedrock consists of shales interbedded with layers of quartzite and

sandstone whose outcrops, 150 m thick, are Siluro-Devonian and Acadian green along the southeast and northwest, respectively. Triassic: the sediments indicate the presence of red saline clays and silicates. They are distributed in the eastern part of the aquifer [20]. Sub-Cenomanian: they include detrital red clays, with a total depth of about 40 m. The deposits are rich in gypsum. Calcareous and white layers followed some layers of the yellow marl conglomerate. Cenomanian: they are composed of dolomitic limestone and yellow marl with intercalation of green marl over a thickness of about 120 m [21]. Pliocene: they form the aquifer system of Berrechid and consist of sandstone, sand, sandy limestone, and minor conglomerates with a total thickness that varies from 5 to 40 m [22]. Quaternary: These deposits constitute the dominant facies and are mainly composed of series of silts and conglomerates followed by red silty clays, then pebbles and gravels with a thickness of 0-50 m. Regarding water quality, this table is classified into three hydrogeochemical facies (Na-Cl), (Na-Mg-Ca-Cl), and (Ca-Mg-HCO3-Cl). This region is known for its fertile soils, which cause the depletion of groundwater and the degradation of water quality. The latter becomes non-compliant with consumption standards [10]. At the same time, the water is mainly used by farmers for vegetable and livestock production [23]. However, water quality is monitored by the Bouregreg and Chaouia Basin Agency through fourteen monitoring stations.

3. Materials and methods

3.1 Sampling Collection

Within the framework of this study, twenty-two quality samples were taken in the Berrechid aquifer in the following monitoring stations (Figure 1). The sampling protocol was conducted during pumping for irrigation purposes twice in spring and summer 2018 (Figure 2). The depth of the wells ranged from 40 m to 140 m. All wells are used regularly for domestic consumption, irrigation, and industry. We used prewashed and labeled one-liter polyethylene bottles for sample collection. These samples include measurements of the following parameters: Electrical Conductivity (EC), Chlorides (Cl^-), Nitrates (NO_3^-), Ammonium(NH_4^+), Organic Matter (OM), Fecal Coliform (FC). These parameters give an indication of the quality of the aquifer based on a simplified groundwater grid. The location coordinates (X, Y coordinates) of the collection points were determined using a portable global positioning system (GPS). The samples are directly forwarded to the laboratory for analysis.

2.1Physicochemical analyses

Conductivity was determined using a YK-2001PH smart conductivity meter. Nitrate as measured by the spectrometric method in the presence of sulfosalicylic acid. Ammoniacal nitrogen NH_4^+ as measured by the spectrophotometric method with indophenol blue. The determination of chloride was performed by the MOHR method, according to AFNOR 90-014. The use of the gauge method measured the biological oxygen demand (BOD) (EN 1899 May 1998) (T90-103) using BOD counter brand VELP. According to the AFNOR standard NF T90-101 February 2001 (T90-101), the COD was determined using the titrimetric method.

2.2*Bacteriological analyses*

The inclusion technique was chosen to determine fecal coliforms by using Mac Conkey agar for the enumeration of coliforms in Petri dishes, followed by incubation at 44°C for 24 h. The results were expressed as Colony Forming Units (CFU) per 100 mL of Colonies (CFU) per 100 mL of water [24].

2.3 Dataset

All data relevant to groundwater quality were collected. Groundwater vulnerability was compiled, including, for example, topography, geology, hydrogeology, land occupation, and precipitation.

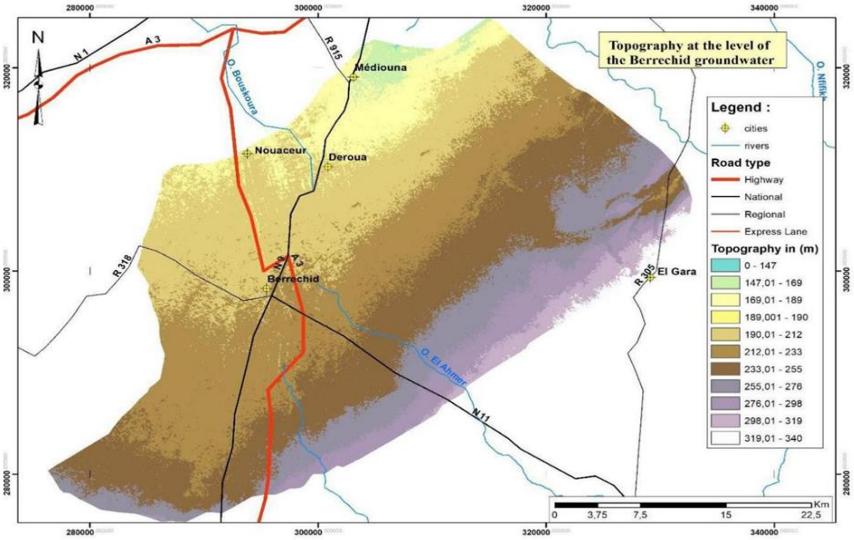

Figure 1. Study area and topography at the level of the Berrechid groundwater

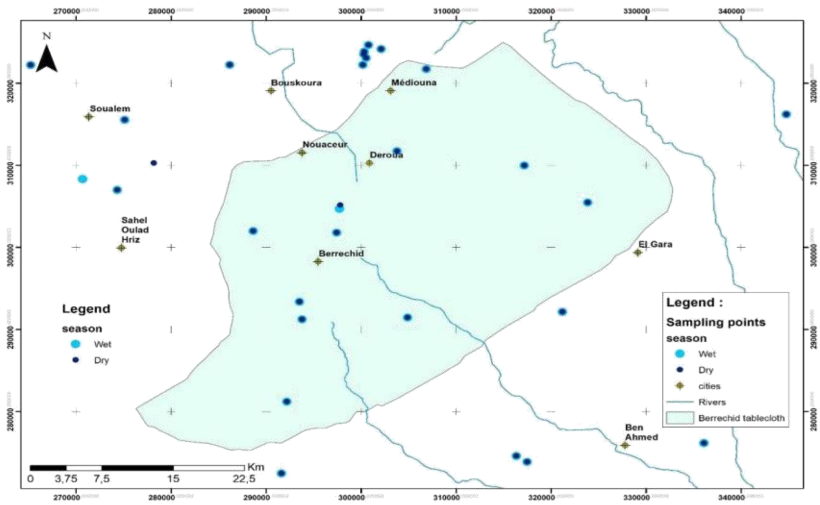

Figure 2. Map of sampling point

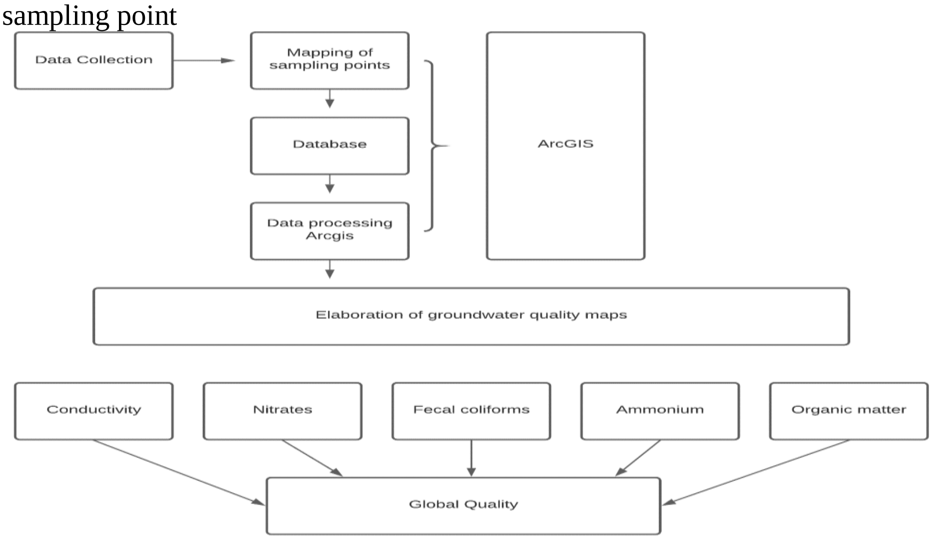

Figure 3. Simplified functional approach to characterize the groundwater in the Berrechid aquifer

The software ArcGIS was used to compile the geospatial data and to generate the quality map. In this study, the integration of the results of the field surveys carried out during the year 2018 knows the territory provided by the compilation of existing data. After the data collection, we used GIS to structure the data (Database modeling) then data display and processing (transformation of point/vector data into raster data and standardization of raster data format). The results obtained, in particular, the mapping of water quality, has allowed us to evaluate the characterization of groundwater stored in a geodatabase created in the ArcGIS ArcCatalog environment. These data follow a succession of treatments to create raster and parametric maps. The distribution was generated using the Inverse Distance Weighting (IDW) interpolation method (figure 3).

3. Results and Discussion

The results of the physicochemical analysis are reported in Table 1 and 2. A large variation was observed for electrical conductivity (EC), which varied from 910 to 7100 µS/cm.

Table 1. Results of Hydro chemical Analysis of Collected Samples from Berrechid Aquifer

DATE	IRE	X (m)	Y (m)	Cd (µS/cm)	Cl- (mg/L)	NO3- (mg/L)	NH4+ (mg/L)	OM (mg/L)	FC (UFC/100mL)
16/03/2018	102/27	2938002912503970			1120	46.8	0.021	2.6	280
07/03/2018	3942/20	3171773099823300			1024	17.5	0.020	2.6	72
20/02/2018	5168/20	3068673217385760			1833	85.2	0.057	2.6	175
28/02/2018	5169/20	3238563054764200			1385	65.4	0.020	2.6	18
16/03/2018	671/20	2977383047115700			1394	135	0.021	2.6	4400
17/03/2018	R1951/27	2921902812133310			818	69	0.021	2.6	6
16/03/2018	R2845/20	3037873117363780			1043	37.8	0.021	2.6	10
17/03/2018	R3100/27	2935322933854140			1150	23.9	0.021	2.89	32
16/03/2018	R-565/20	2886503020016570			2043	71.4	0.021	2.6	40000
07/03/2018	R-804/28	3049002914502090			595	29	0.020	2.6	10
16/03/2018	R-907/20	2974333018113870			1021	76.7	0.021	2.6	95
16/08/2018	102/27	2938002912503840			1177	44.9	0.041	2.39	320
20/07/2018	5168/20	3068673217385520			1695	93.5	0.020	2.16	1300
10/08/2018	5169/20	3238563054764470			1182	37.8	0.020	2.35	5
16/08/2018	R1951/2729210		28123	3330	956	78.5	0.021	1.86	0
17/08/2018	R2845/20	3037873117363600			1124	22.6	0.020	1.06	30
16/08/2018	R3100/27	2935322933854110			1262	23.4	0.057	2.12	2000
28/08/2018	R-565/20	2886503020016670			2250	74.2	0.020	1.6	310
31/08/2018	R-671/20	2978093051447100			2409	190	0.046	4.55	85
18/08/2018	R-804/28	304900291450910			183	5	0.026	2.12	15
31/08/2018	R-907/20	2974333018113970			1124	80.8	0.021	3.9	0
17/08/2018	R3942/20	3171773099823290			1065	21.8	0.020	1.33	152

(EC): Electrical Conductivity - (Cl^-): chlorides - (NO_3^-): Nitrate - (NH_4^+): Ammonium; (OM): Organic Matter- (FC):Fecal Coliform

The amount of chemical elements varied from 183 to 2409 mg/L for chlorides (Cl^-), from 5 to 190 mg/L for nitrate (NO_3^-), from 0.041 to 0.02 mg/L for ammonium (NH_4^+), from 0.77 to 4.55 mg/L for organic matter (OM), from 10 to 40000 CFU (100mL) for fecal coliform (FC).The water (EC) electrical conductivity showed values ranging from 910 to 7100 µS/cm with an average of 2090 µS/cm and based on the analysis of the EC (decree n° 1275-01 of October 17, 2002, of law 10-95). Five classes have been distinguished: excellent class (EC <400 µS/cm), good class (400 <EC <1300 µS/cm), medium class (1300 <EC <2700 µS/cm), poor class (2700 <EC <3000 µS/cm) and very poor class (3000 µS/cm >EC), describing low, medium, moderate and high salinity respectively.

Table 2. Statistical analysis of the measured parameters

Parameter	Mean	Min	Max
EC(µs/cm)	2090	910	7100
Cl^- (mg/L)	595	183	2409
$NO3^-$ (mg/L)	46.8	5	190
NH_4^+(mg/L)	0.041	0.057	0.021
MO(mg/L)	2.63	0.77	4.55
CF(UFC/100mL)	57.5	6	40000

(EC): Electrical Conductivity - (Cl^-): chlorides - (NO_3^-) Nitrate - (NH_4^+): Ammonium; (OM): Organic Matter- (FC): Fecal Coliform

Figure 4 depicts the spatial variation in electrical conductivity, showing a significant progression of water from upstream to downstream in the larger irrigation areas with values above 3000 µS/cm. The high mineralization of groundwater in the Berrechid plain, which can often exceed the limits recommended by WHO [25] and specified by Moroccan standards (EC <750 µS/cm). This mineralization is mainly related to a high content of cations and anions in these waters, probably caused by the drainage of Triassic soils very rich in salts and gypsum, degradation of the organic matter within the same compartment and on the site of the wells, according to human activities, and by various urban and industrial discharges. Previous studies have reported similar results [26], [27], which considered Doukkala, Haouz, and Chaouia aquifer as a saline aquifer. Consequently, the groundwater of the Berrechid plain need normal or intensive treatment for drinking water production, as high EC values in water may lead to degradation of the water quality. The anions are mainly represented by Cl^-, ranging from 183 to 2409 mg/L with an average of 595mg/L. Based on the simplified Cl^- grid, five classes could be distinguished: excellent class (Cl^-<200 µS/cm), good class (200 < Cl^- <300 µS/cm), average class (300 < Cl^- <750 µS/cm) and poor class (750 < Cl^- <1000 µS/cm), very poor class (Cl^- >1000 µS/cm).

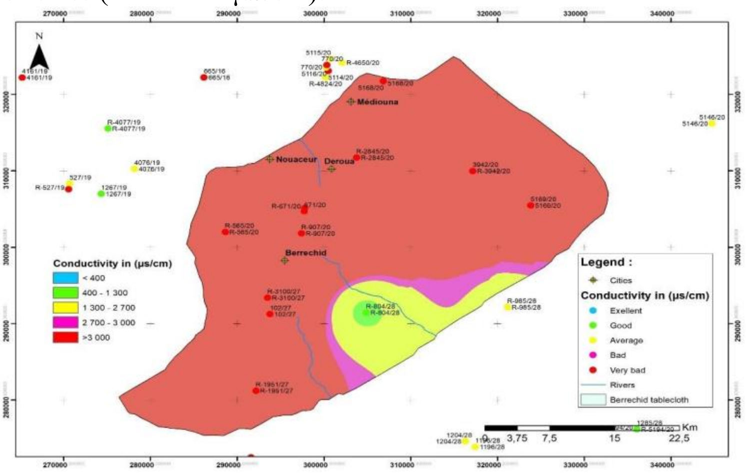

Figure 4. Spatial variation of water electrical conductivity

Figure 5 has reported the spatial distribution of chlorides and indicates a significant increase from upstream to downstream with values above 1000 µS/cm. The peak of chlorides recorded in groundwater is due to the geology of the land (leaching of gypsum and clays), agricultural contamination (pesticides), and domestic and industrial discharges, as well as percolation through saline soils and infiltration of irrigation water [11], [28]. Alternatively, multiple studies show that chlorides were considered a conservative element in groundwater and do not contribute to chemical reactions such as ion exchange or form insoluble precipitates [29]. Saltwater intrusion could be the cause of the high chloride levels in groundwater found in many coastal aquifers [30].

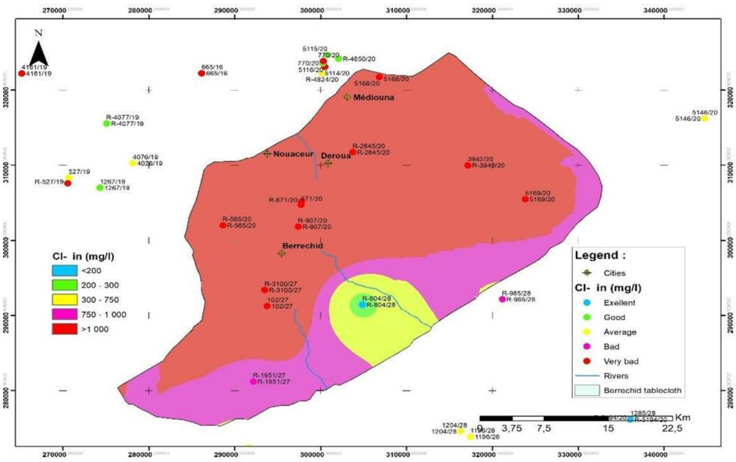

Figure 5. Spatial variation of chlorides

Figure 6 has reported the spatial distribution of nitrate. The concentration range of NO_3^- was 5 to 190 mg/L with an average of 46,8 mg/L. Based on the simplified NO_3^- grid, five classes could be distinguished: excellent class (NO_3^- <5 mg/L), good class (5 mg/L < NO_3^-<25 mg/L), average class (25 mg/L < NO_3^-<50 mg/L) and poor class (50 mg/L < NO_3^{--}<100 mg/L), very poor class (NO_3^->100mg/L). Figure 6 reports the spatial variation of nitrates during 2018. It shows a significant increase of NO_3^- compared to the international standards (50 mg/L) prescribed by WHO [25]. Nitrate contamination comes from anthropogenic factors such as septic tanks or fertilizers. As for industrial fertilizers, they are used by 100% of the farmers surveyed. The latter is convinced that their use is essential to obtain a good yield. These fertilizers were used once a year in variable proportions: ammonium nitrate 33.5%N was used by 98% for a mean of 130.9 kg/ha, NPK 10-30-10 was used by 95% of farmers for a mean of 175 kg/ha, ammonium sulfate 21%N was used by 66% for a mean of 121.9 kg/ha, and 46%N urea is used for 46% at a mean of 67.9 kg/ha [3]. No one performs physicochemical soil tests or follows the recommendations of agronomists. The pretext that it is not necessary and that their experience is sufficient. They apply the same amount of fertilizer each year as the previous year. Most of the surveys and diagnoses have shown that fertilizers are used in a practical manner in most cases, which rarely proves to be in line with the soil's needs, which threatens surface water, groundwater, and causes eutrophication problems. Similarly, the results obtained agree with those found by many studies [31]–[33]. These studies have shown that the origin of nitric pollution is related to the oxidation of nitrite by nitrifying bacteria caused by the infiltration of wastewater and the excessive use of pesticides or animal fertilizers. In addition, high nitrate drinking water (>10 mg/L) caused and developed the blue baby disease in children, as reported by Galmiche-Tejeda et al. [34]. In addition, nitrates take a long time to appear in groundwater depending

on precipitation, depth of the water table, and the presence of silts, which can prevent the percolation of nitrates to the aquifer of Berrechid. Ammonium is the product of the final reduction of organic and inorganic nitrogenous materials in water and soil. It also comes from living organisms' excretion and waste reduction, and biodegradation, not including domestic, industrial, and agricultural sources [35]. The variation in ammonium nitrogen ranges from 0.041 to 0.02 mg/L. Based on the simplified NH_4^+ grid, four classes could be distinguished: excellent class (NH_4^+<0.1 mg/L), good class (0.1 mg/L < NH_4^+<0.5 mg/L), average class (0.5 mg/L < NH_4^+<2 mg/L) and poor class (2 mg/L < NH_4^+<8 mg/L), very poor class (NH_4^+>8mg/L). Figure 7 reports the spatial variation of ammonium during 2018 shows that ammonium nitrogen concentration is low or even zero. This does not mean that ammonium nitrogen is absent from water points, but simply that it has been converted to nitrate (NO_3^-) through oxidation. This modeling indicates that the northern part of the aquifer is not of excellent quality because of the adjacent poor-quality sampling points. These points are located outside the perimeter of the aquifer. However, they may influence quality due to natural flow and infiltration events that may occur. This appears to be identical to the situation reported by Derwich et al. [36]. This parameter is used to assess the organic matter content of well water. Indeed, the organic matter present in the wells varies considerably from one well to another. Based on the simplified OM. grid, four classes could be distinguished: excellent class (OM <3 mg/L), Good class (3 < OM <5 mg/L), Average class (5 mg/L < OM <8 mg/L) and Poor class (OM >8 mg/L).

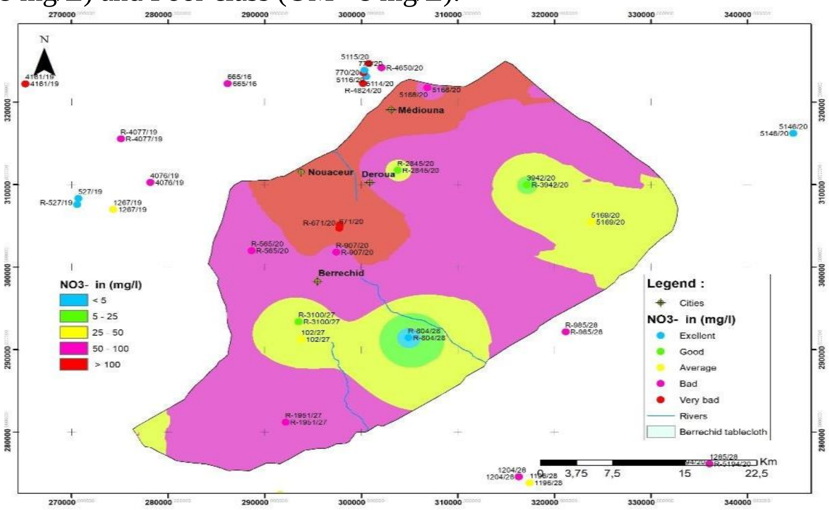

Figure 6. Spatial variation of nitrates

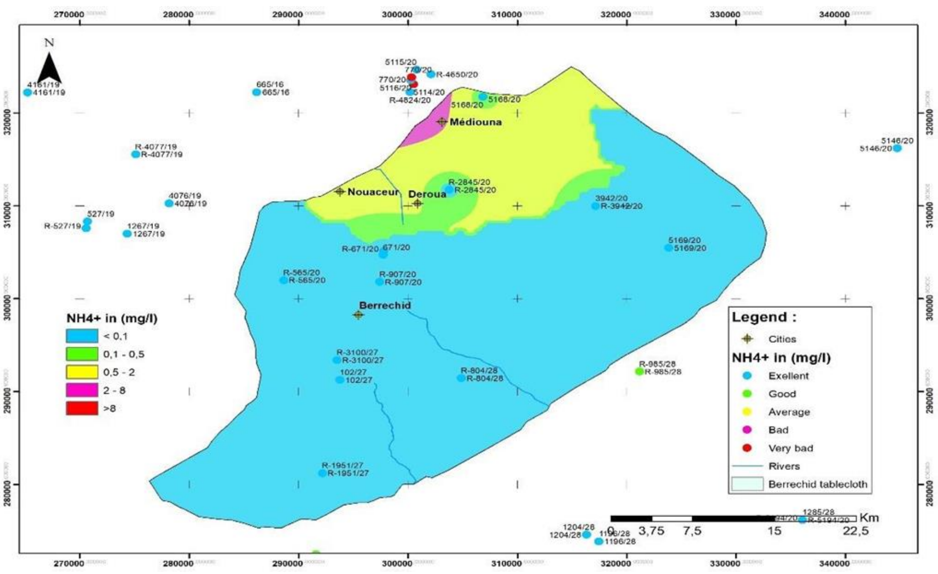

Figure 7. Spatial variation of ammonium

Figure 8 reports the spatial variation of organic matter during 2018. Its content varies between 0,77 to 4,55mg/L. The organic matter contents are recorded in the large irrigation areas, with values that do not exceed 4.55 mg/L generally of good quality. This situation seems identical to that reported by Laaouan et al. [37]. In the waters of the wells of Mohammedia, it varies between 0.3 and 11.1 mg/L while those of the city of Temara present a maximum of 5.1mg/L and a minimum of 1.3 mg/L. However, the wells of Dar Bouazza show a concentration lower than 2.5mg/L. These values show that the water of the various wells cannot be used as a source of drinking water. From a bacteriological point of view, the wells studied show very high levels of fecal contamination germs in all wells without exception, which undoubtedly constitutes a threat to the population. It should be noted that this increase in bacterial densities can be punctual depending on the type of substances infiltrated into the water table. In our study, fecal coliform values reached a maximum of 40,000 units (100mL) to a minimum of 10 units (100mL).Based on the simplified C.F grid, four classes could be distinguished: excellent class FC <20 CFU (100mL), good class 20 CFU (100mL) < FC <2000 CFU (100mL), average class 2000 CFU (100mL) < FC<20000 CFU (100mL) and poor class FC >20000 CFU (100mL). Figure 9 represents the spatial variation of coliforms during 2018 due to domestic and industrial discharges. This situation seems identical to that reported by Papin et al. [38]. This poor quality would be due to human and animal feces, which are often also used as fertilizer in the study area and are washed into the streams by runoff. The interest in detecting these coliforms is indicator organisms whose survival in the environment is equivalent to pathogenic bacteria. Thus their density is globally proportional to their degree of contamination [39].

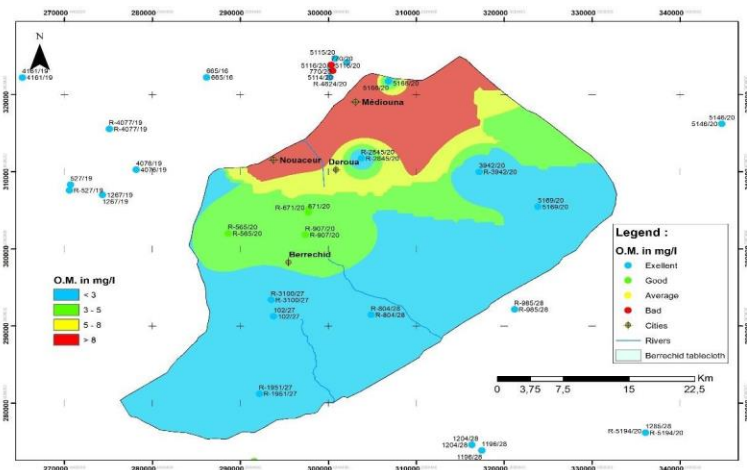

Figure 8: Spatial variation of organic matter

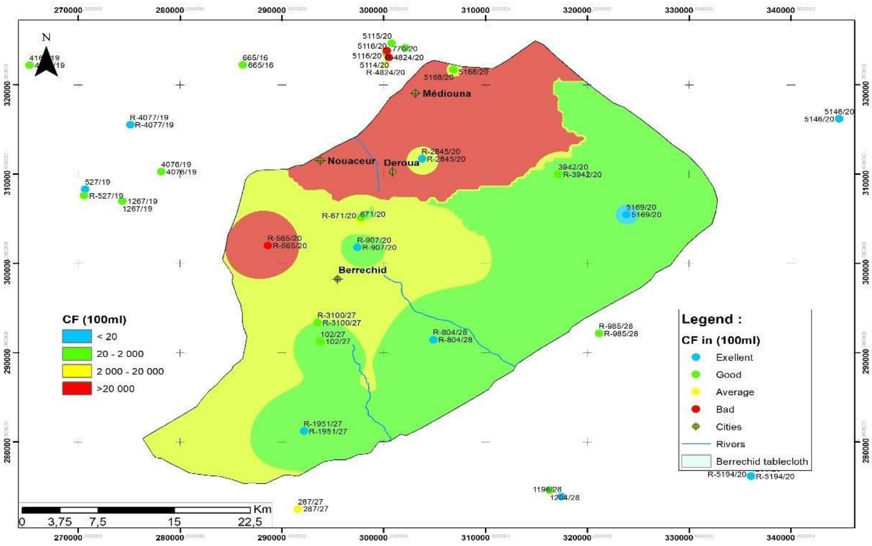

Figure 9. Spatial variation of fecal coliforms

The evaluation of the global quality of groundwater is done by studying the pollution parameters. The interpretation of the results is based on a groundwater quality grid (Order No. 1275-01 of October 17, 2002, of Law 10-95). This grid presents indicators of physicochemical and bacteriological quality. These parameters are electrical conductivity, which informs on the mineralogical quality of water chloride ions, which inform on the mineralogical quality of water nitrates, ammonium, and organic matter, which are the main indicators of groundwater pollution [40]. The waters of sample 1 have an overall excellent quality. This quality status is due to mineralization, at a recorded value of 910 µS/cm (good quality); Chloride content, with a recorded value of 183mg/L (excellent quality); Nitrates, with a recorded value of 17.5 mg/L (excellent quality); Organic matter, with a recorded value of 0.77 mg/L (excellent quality); Ammonium nitrogen, with a recorded value of 0.02mg/L (excellent quality); Fecal coliforms, with a recorded value of 64 (100mL) (excellent quality). These results appear to be identical to those reported by Nouayti et al. [41]. Analysis of samples 2,3,4 through 22 showed that the overall water quality is of poor quality due to nitrate levels ranging from 21.8 mg/L to 190 mg/L. Except for the water point, 2,3,4,5,6,7, which is of good quality, the other points 8,9,10 have an overall average quality. Salinity concentrations are higher than those reported in another study [42]. Conductivity content between 2090µS/cm and 7100µS/cm is classified as very poor quality. Salinity concentrations are higher than those reported by another study [43]. Ammonium nitrogen content is generally of excellent quality; organic matter content is of good quality; chloride content varies between 595mg/L and 2250 mg/L. This appears to be identical to that reported [44]. The bacteriological quality was generally of good quality. Physico-chemical and bacteriological analyses show that: 29% are of good quality, with 71% having poor quality during the dry season. During the rainy season, 36% are of poor quality, 64% of which are of very bad quality.

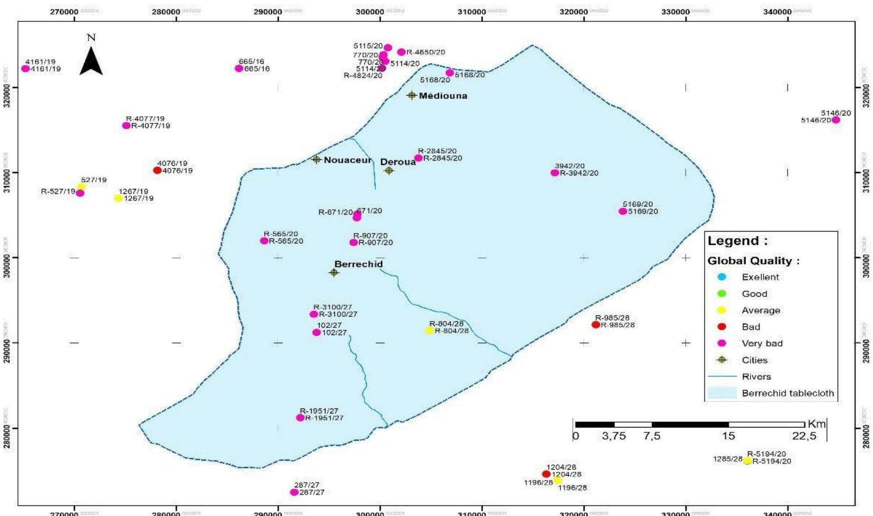

Figure 10. Spatial variation of overall groundwater

Conclusion

During this survey, the collection and analysis of the results made it possible to evaluate the quality of the water table in the region of Berrechid through qualitative and quantitative indices. The quality of groundwater in the aquifer of Berrechid has also experienced instability at an alarming rate. Analyses show an increase and expansion of mineralization of groundwater. Therefore, the groundwater of the Berrechid plain is of poor quality and not meeting drinking quality standards. Potential groundwater quality problems are mainly related to agricultural activities and untreated sewage and household waste disposal. The current state of the Berrechid plain aquifer requires groundwater treatment for rural drinking water production and regular monitoring of physicochemical parameters and salinity risk for irrigation.

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