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Research Article

Hydro-geochemical Study of the Coastal Aquifer in Tripoli (Lebanon)

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Abstract: Groundwater geochemistry refers to the general chemical properties of water, particularly groundwater. Precipitation, volatilization, oxidation/reduction, sorption/partition, and complexation are processes involved in the distribution and fate of organic molecules in water. Determining hydrogeochemical facies is a great help for determining relationships and similarities among the chemistry of waters in an aquifer. This study focused on the coastal aquifer of Tripoli (Lebanon) with Mio-Quaternary age. It is considered as a confined aquifer and an important hydraulic reserve for domestic water use in the region. Recently, it underwent an urban development that leads to an increase in water demand causing a decrease in the piezometric level and a high-risk of deterioration to water quality through seawater intrusion and anthropic pollution. To understand the origin of mineralization and the mechanism of water hydro-chemistry variation and to provide a vision to underground water recharge, this study aims to analyze the hydrodynamic, piezometric, and geochemical characteristics of the coastal aquifer. The fluctuation of physicochemical parameters for cool and warm seasons has been studied and monitored for 16 coastal wells during April, May, and June 2020. Results were interpreted by using a statistical analysis called Principal Components Analysis (PCA). Cartographic of groundwater levels and concentrations for nitrate, chloride, sulphate ions, the ratio sulphate/chloride were determined by using SUFFER8 software. It can be noticed that the Mio-Quaternary formation at Tripoli consists of thick sedimentary sandstones and conglomerates with argillaceous roots, which provide significantly high permeability characteristics. It is mainly recharged from precipitations through karstic formations. Chemical analysis shows that bicarbonate ions (HCO_3^-), characterized by dissolution of carbonate rocks from geological upstream formations of Tripoli, means that the aquifer is subjected to intensive recharge of fresh water and snow melting making a hydrostatic equilibrium facing marine intrusion [1]. High contents of chloride and Sodium are due to anthropic contamination or seawater intrusion. However, Magnesium ion concentration assures this intrusion. Meanwhile, nitrates, sulfates and phosphorus high concentrations are related to wastewater leakage or agricultural activities [2].

Keywords: Hydro-geochemistry; Seawater intrusion; Aquifer; Sustainable development; Lebanon

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1. Introduction

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet. At its heart are the 17 Sustainable Development Goals, whereas the sixth goal emphasizes ensuring availability and sustainability management of water and sanitation for all [3, 4]. Based on this goal, we relied on the study of a coastal area, in northern Lebanon, that was converted from an agricultural area to an urban one without considering any hydrological, environmental, or even health studies. This area has become crowded with residential buildings that depend on private wells as freshwater and without any sewage treatment plants or networks. Several studies have previously been conducted on the relationship of groundwater and the sea on several sites in Lebanon, such as Jiyeh, Damour, Beirut, Tyre, Ibrahim River and Litani River, but these studies were expected in their results because the human impact was not radically different from our study, which relied on a transformed region during only 10 years [5, 6].

Coastal aquifers are important water resources in coastal areas where they are affected by strong population density and intense agricultural activity. In such areas the demand for water is growing increasingly due to the shallowness of the groundwater. However, the exploitation of these aquifers poses complex problems because it combines the notion of reserves that of groundwater quality. In addition, salinization is a major cause of coastal water quality degradation [1].

The hydrogeological functioning of coastal aquifers depends on the contact between continental freshwater with the seawater. This contact freshwater/saltwater follows a delicate balance mainly conditioned by the density difference between the water and is expressed by the existence of a mixing zone generally are thin and have variable geometry. A break of this balance inevitably leads to a displacement and a dispersion of the study area, inherent in the development of human activities. Seawater intrusion is the influx of salt water in areas that are not normally exposed to high salinity, such as marine invasion in fresh water. Coastal aquifers have a special character as a groundwater reservoir, where continental fresh water meets with sea water. This contact freshwater/seawater obeys a delicate balance mainly controlled by the difference between densities of two types of water. A rupture of this balance inevitably leads to displacement and dispersion of the mixing zone and makes continental groundwater unusable [7].

The study area is part of the coastal area of Tripoli presents an increasingly migratory flow of population, demographic, and urban development with an increasing number of anthropogenic activities, this will cause an increased need for water and produce a deterioration in the quality of hydro-chemical groundwater by pollution and seawater intrusion. With the beginnings of the 90s, the Lebanese government has modified the land use plan of the southern plain of Tripoli, transforming the agricultural plain into an urban area where 800 residential buildings must be built in a new urban area calling "Dam and Farz". The network of the drinking water supply has not been achieved for financial reasons, each building had to dig a private well for daily needs, despite the water being microbiologically polluted [8]. These wells, which developed anarchically without official authorization, operated 24 hours a day free of charge without any control and without worrying about the quantities of water pumped without permission of public authorities.

The daily consumption for domestic purposes was estimated to be 255 l/d/inhabitant and the annual consumption was estimated at 350,000 m^3 [9]. With an extrapolation of water consumption resulting of urbanization increased in the years to come combined with the climate change impact [10]; this will result in a catastrophic situation on the quality and quantity of groundwater. The coastal aquifer will face many problems of salinization and contamination with different types of pollutants. This uncontrolled exploitation of groundwater resources will soon pose very serious health and economic problems to people in this area. The study area has been monitored by setting a data logger to know the piezometric level, then it has followed its fluctuation, and the natural recharge axis has been determined, and this information will facilitate the remediation of the professional ministries that preserve groundwater or prevent pollution in a sustainable manner.

2. Materials and Methods

2.1. Characteristics of the Study Area

Tripoli is located on the coast 85 km north of the capital Beirut. The population is approximately 350,000 inhabitants over an area of 17,664 km^2 with a distribution density of around 684 people/ha [11]. The city was predominantly agricultural, but recently urban development has led to the disappearance of the plains. The study area is located at the coast of the Mediterranean Sea, it is characterized by a Mediterranean climate.

Tripoli Basin is surrounded by the West Flexure of Mount Lebanon from the east, the Mediterranean Sea from the west, the anticline of Terbol from the North and Qalhat anticline from the south. Tripoli watershed is fed by the following 4 rivers/springs: Abou Ali, Hab, Abou Halqa and Rachiine. The main sources of aquifer recharge are rainfall and rivers with a total annual recharge estimated at 71 million m^3/year, rainfall recharge is estimated at 42 million m^3/year, and recharge by rivers is estimated at 29 million m^3/year. The total discharge of the aquifer is estimated at 75.9 million m^3/year, 15 million m^3/year constitutes the pumping of groundwater by about twenty public wells and nearly 500 private wells, the remained is drained by the groundwater flow at sea (60.9 million m^3/year) [9]. Comparison between the values of the load and the discharge shows that the annual deficit of water in the aquifer is 4.9 million m^3 due to the permanent overexploitation of groundwater, hence a risk of contamination by marine intrusion.

In the southern part of the city, hydrogeological basin is formed from marly Senonian C6 aquiclude formation. At the Neogene age this layer was overcome by the Miocene m2 formed from limestone which is an aquifer, and it can be noted in some places that there is a small layer of conglomerate formed at the Quaternary age. All layers above C6 are aquifers and have a total thickness of 200 m. The thickness of the aquifer stratum is considered thin to recharge the hydrological basin which requires conserving it as a scarcely renewable water resource (Figure 1).

In recent years, the city of Tripoli has undergone a very important urban and demographic development, which has resulted in the transformation from Gardens and agriculture plains into residential areas causing severe seawater intrusion presented in fluctuations of electrical conductivity of underground water.

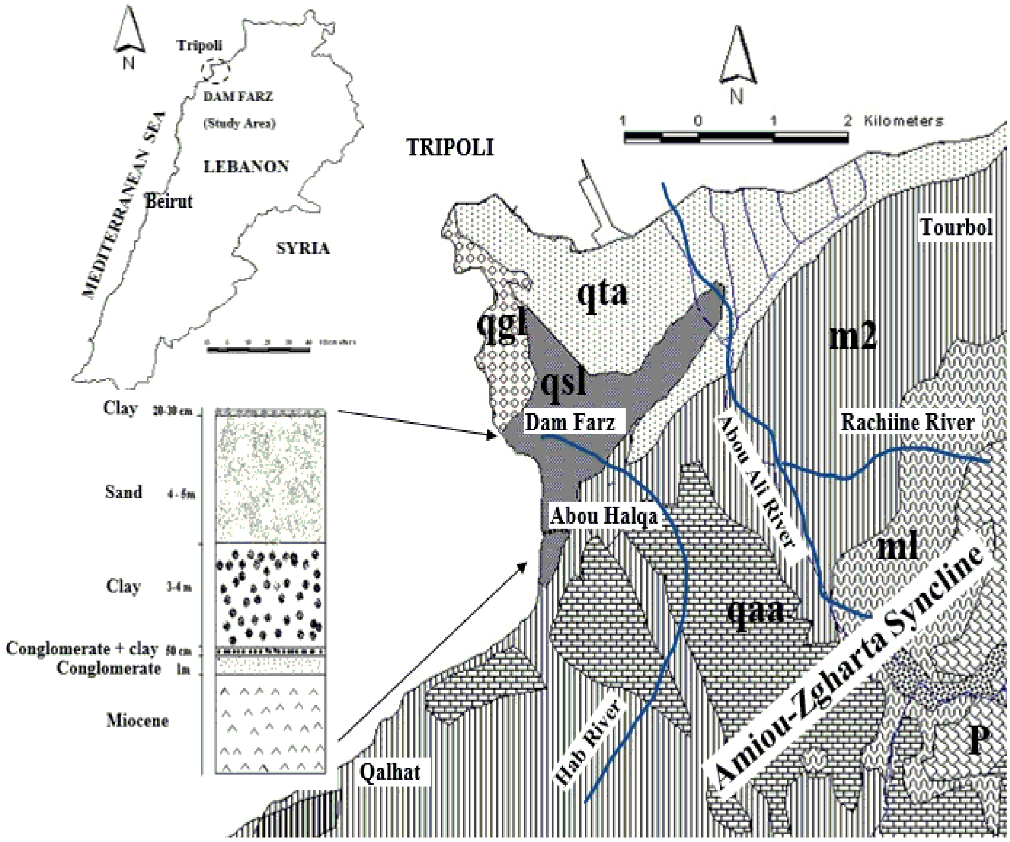
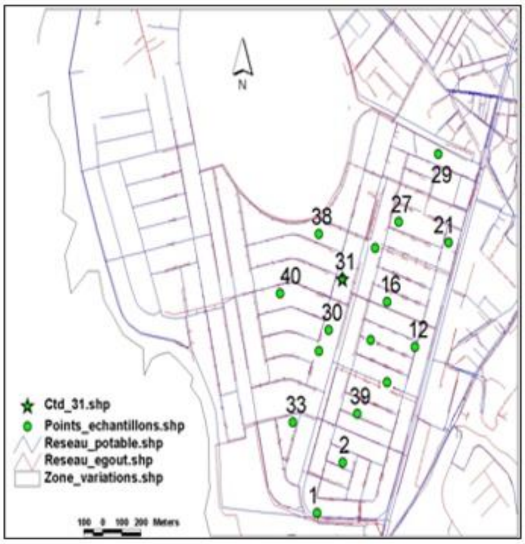


Figure 1. Hydro-geo-morphology of the study area.

2.2. Methodology

At "DAM FARZ" area, 16 representative wells were selected (according to the spatial distribution since the aquifer is homogeneous), some of which belong to the public sector and others to private operators. On these boreholes piezometric measurements and chemical analyzes were made for 3 different dates: April 1, May 15, June 23 (Figure 2, Table 1).



Code	Building's name	X coordinate (Lambert)	Y coordinate (Lambert)
1	Diab	156977.90	275848.25
2	Nachabeh	157109.95	276060.23
6	Al wafa	157309.49	276257.22
11	Assanabel	157261.94	276568.85
12	M. Nachabeh	157487.81	276545.92
16	AlHadika	157343.46	276736.12
20	Najwa	157285.72	276928.87
21	Ghaleb Nachabeh	157663.57	276982.36
27	Loouat AssibisbiB	157402.05	277070.67
29	Tarek Kabbarah	157610.93	277355.12
20	Arij (NadiaChahal)	157037.78	276617.24
31	AlBustane	157108.25	276832.92
33	AlBissar	156853.52	276229.20
38	AlRabih	156985.13	277019.72
39	Faculty of Health	157186.37	276266.56
40	Alwafaa	156784.74	276771.78

Figure 2. Table 1. Spatial distribution and coordinates for sampling sites.

To detect seawater intrusion as well as sensitive and vulnerable areas we adopt the following approaches:

- Study of the soil texture, as well as its permeability coefficient and its contribution to the underground diffusivity of pollutants. The purpose of soil texture analysis is to highlight the deposited quaternary formation which will lead to evaluate its permeability coefficient and discharging capacity. Thus, facilitates seawater intrusion or transit of pollutants. Based on AFNOR NF X31-107 protocol, 50 grams of the soil from study area were taken and analyzed then soil type is detected according to USDA textural classification triangle. Permeability coefficient is estimated from soil texture type and combination of both characteristics lead to soil permeability type [12, 13].
- Piezometric monitoring and hydrodynamic study of the aquifer. To understand the functioning of the aquifer, a CTD Diver and TD probes from Schlumberger Water Services Company was placed in well number 31 to record from April 15 till June 23 electrical conductivity, temperature, atmospheric and barometric pressure with an interval of 5 min. The CTD and TD can record 48,000 measurements of Pressure, temperature, and groundwater conductivity (measurement range conductivity is 10 μS/cm up to 120 mS/cm) with corresponding date and time in sampling intervals from 1 second to 99 hours. The CTD is installed in the borehole 4 m below the piezometric level, and each month, the CTD data is retrieved with the LMD software. Indeed, the CTD gives a precise measurement of the fluctuations of the water table and the effect of the marine intrusion from the variations of the physicochemical parameters already noted. The TD Diver is a groundwater monitoring instrument used specifically to record atmospheric pressure. In boundary conditions and relative to coastal zones, SHLUMBERGER Company proposed that the value of the piezometric level of the aquifer is equal to CTD Pressure – TD barometric pressure. The values provided are in cm, and to adjust the scale, we have converted them to meters (m). From this equation we draw the map of piezometric level in the study area.
- Depending on accessibility, 8 wells were chosen, and static levels were registered as well as their drawdown. This approach gives an idea of the speed of seawater intrusion, the vulnerability of the aquifer to the transit of pollutants and an idea on soil permeability coefficient used to calculate the recharge rate given by Darcy's law, for porous media and confined free aquifers. Finally, the knowledge of underground waterflow direction and seasonal fluctuation measurements of water table, as well as the variations in high and low water, were made on 13 wells using piezometer where registrations were overlayed and translated in piezometric map using Surfer 8 software.
- Chemical study of groundwater facies. Water flowing in the underground formations reacts with rock components and even with any natural or anthropic factor, trapping and dissolving many minerals and organic matter. This water will take on the chemical facies of the aquifer that contains it and according to the residence time. To define the geochemical quality of underground water, and to know the problem of recharge and discharge of the aquifer, chemical analyzes are carried out on 16 representative wells for 3 companions, April 1, May 20, and June 23. Chemical parameters are: temperature T, pH, and Electrical Conductivity EC (Conductometer device, Mettler Toledo MC126 at 25°C in °C and μS/cm), Bicarbonates HCO_3^- (titration method NF T90-036 in mg/l), Total Hardness (titration method with EDTA, French norms NF T90-003 in mg/l), Calcium Ca^{2+} (titration method with EDTA NF T90-016 in mg/l), Sodium Na^+ and Potassium K^+ (flame photometer, Model 420 - Shewood in mg/l), Chlorides Cl^-, Sulphates SO_4^{2-} , Nitrates NO_3^- (ion chromatograph, Shim-Park IC-A3 (S) in mg/l).

To better understand the chemical composition of groundwater, several types of diagrams exist to graphically represent its chemical facies. We used the Schoeller-Berkaloff diagram using the "Diagrams" software. Each sample is represented by a broken line. The concentration of each chemical element is represented by a vertical line on a logarithmic scale. The broken line is formed by connecting all the dots that represent the different chemical elements. A group of water with variable mineralization but whose proportions are the same for the dissolved elements, will give a family of broken lines parallel to each other. When the lines cross, a change in chemical facies is highlighted.

Because groundwater chemical concentrations are variable over time and space and are directly related to the environment and flow conditions, a mapping was done with Surfer 8 (Golden software, 2002) to present variation of chemical ion concentration in the aquifer called iso-concentration monitoring. Hence, the number of variables is too large to be able to make an easy synthesis of the data, for this reason we resorted to making the statistical synthesis by PCA (Principal Component Analysis) using XLSTAT software. PCA is a statistical technique for multidimensional factorial analysis which applies to "variable-individual" type tables, whose columns are variables with continuous numerical values (temperature, pH, conductivity, etc.) and whose rows are individuals or observations. The analysis is done between the individuals themselves and between variable and individual [14]. Most PCAs are carried out by naming the variables to make them play an identical role in the definition of proximities between individuals without having either the same units or the same amplitudes [15].

3. Results

All site works and sampling were done during months of April, May and June, but critical values of June were presented because the target is showing the vulnerability/response of the coastal aquifer to seawater intrusion and anthropic pollution and values of first two months will normally be increasing.

3.1. Hydrogeology of the study area

By comparing results of soil texture analysis with the standards of the textural classification triangle, we conclude that soil is Limy-Sandy soil type (sand: 80.04%, silt: 3.08%, clay: 8.88%). According to the international soil classification table, the analyzed soil is considered semi-permeable to permeable, with permeability K= 10^{-4} to 10^{-5} m/s. Studied aquifer belongs to the Mio-Quaternary structures and considered as a free confined aquifer [16] (Figure 3). The soil percentages of sands, clays, and silts explain that the response to the infiltration of the aquifer to rains is fast and that it is even very vulnerable to any contamination, including seawater intrusion in case where the hydrostatic barrier is unbalanced [17].

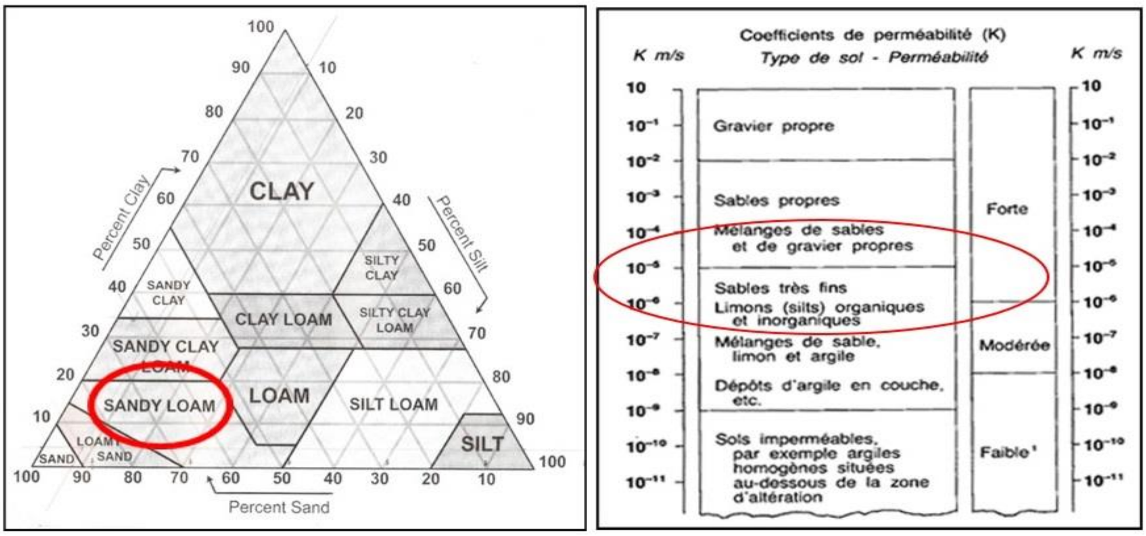


Figure 3. Soil texture classification and standard permeability.

3.2. Hydro-dynamic functioning of the aquifer

According to Darcy's Law, Permeability coefficient K for study area, even its estimated value to x.10^{-4} m/s, didn't help in calculating Q (volume of recharged aquifer) due to the lack of data from both rainfall and recharge/withdrawal aquifer. Then, we focused on representing the axis of recharge from well's piezometric level through mapping software without knowing the quality of recharged water (Table 2). To find out, we turned to values registered from pumping wells, CTD and TD especially fluctuations of electrical conductivity where they were translated into different zones of seawater salinity (Figure 4).

Table 2. Piezometric variations in wells during June.

Code	ø of well (cm)	Initial Piezometric Level (m)	Piezometric Level after 15' (m)
1	26	11.5	11.71
12	27	11.3	11.6
21	24	10.68	10.8
29	24	6.14	7.72
33	25	8.1	8.22
31	21	7.75	7.79
40	12	6.55	6.58
38	12	6.02	6.02

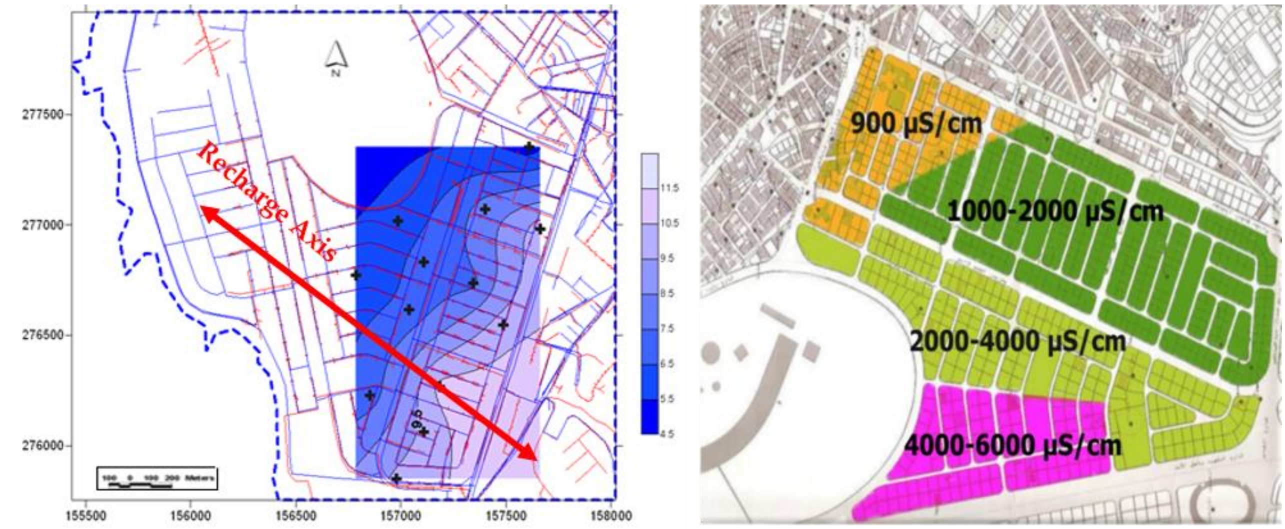


Figure 4. Fresh water axis recharge and electrical conductivity distribution.

3.3. Chemical Analysis of underground water

Table 3 shows chemical results analysis for June sampling campaign. For the interpretation of the data two techniques were used including the diagram of Schoeller-Berkaloff and the principal component analysis (PCA).

Table 3. Chemical analysis of water wells during June 23, 2020

Code	T . °C	pH	EC µS/cm	HCO_3^- mg/L	Ca^{2+} mg/L	Mg^{2+} mg/L	Na^+ mg/L	K^+ mg/L	NO_3^- mg/L	Cl^- mg/L	SO_4^{2-} mg/L
1	23.8	6,69	951	232.1	111.4	17.5	78.9	11.7	25.6	99.4	55.1
2	24.2	6,72	1534	374.3	114.6	34	265.5	16.4	8.2	230	69.4
6	24.3	6,80	1771	432.1	134.7	30.6	378.5	17.4	14.5	288.5	88
11	23,8	6,60	1156	282.1	151.5	36.5	93	9.9	39.32	117.1	65.8
12	24.2	6,41	1048	255.7	153.1	25.8	70.3	7.6	62.3	40.7	48.8
16	23.6	6,61	1175	286.7	158.7	30.6	85.9	7.1	41.1	96.3	61.1
20	24.5	6,57	1652	403.1	204.4	41.3	79.1	7.5	41	219.7	79.3
21	25.1	6,70	890	217.2	122.7	20.4	50.3	9.2	75.5	43.1	47.2
27	24.5	6,54	977	238.4	137.1	36.5	52.5	4.2	5	63	39.6
29	25.2	6,58	971	236.9	130.7	33.1	60.2	10.8	4.3	61.1	52.2
30	23.7	6,56	1674	408.5	222.9	20.4	79.1	13.1	152.5	181.1	105.8
31	24.5	6,73	904	220.6	98.6	51.1	72.5	5.8	8.8	64.7	73.1
33	23.52	6,60	3280	800.3	306.2	74.9	373	11.8	132.8	599.8	187
38	23.8	6,50	1664	406	201.2	39.4	94.7	13.2	19.6	207.7	73.2
39	23	6,41	1101	268.6	149.1	26.7	86.7	10.1	13	81.6	55.4
40	26.7	6,80	1631	398	153.1	64.7	89.8	3.5	89.4	199.7	78.3

The analysis of Scholler Diagram in June shows the same chemical facies for approximately the whole aquifer, following the analysis of the bicarbonate ions where all the points take the same shape as the previous months. It means the impact of freshwater recharging for the entire coastal aquifer from upstream carbonate structures.

For the chloride ion, we found 2 groups, the first is that of wells close to the coast where their concentrations are higher than those of the farther one, then we can conclude that at the beginning of the summer we will have a hydrostatic equilibrium and a local diffusion of seawater intrusion. Whereas the high content of chloride at Al-Rabih site (38) is due to contamination or urban local seawater intrusion.

Sodium and Potassium ions, generally, are in low concentrations, so it is more likely due to urban pollution (as Sodium is an indicator of seawater intrusion). Thus, at Nachabeh center, Na^+ and K^+ ions are high, which are characteristic of a high infiltration zone, so they can be caused by direct agricultural pollution or sewage leaks (Figure 5).

For Arij site (20), the Mg ion concentration is high; the same level of chloride ions, then it is a possibility of presence of local seawater intrusion. In Diab center (1), the Mg is very low, assuming that it could be related to the recharge water, or ion-exchanged by Calcium [1].

Figure 5. Schoeller Diagram results during June 2020

The principal component analysis (PCA) may be used in karst hydrology to group the hydro-geochemical parameters whose variations are related to each other based on factors explaining these groups [14]. The represented data by PCA has the factorial plane 1-2 to extract mainly the total variance of the samples:

- **Axis 1:** corresponds conventionally to the main elements responsible for the mineralization of water: Calcium, Magnesium and Bicarbonates.
- **Axis 2:** opposes the major elements of secondary Chlorides, Nitrates and Potassium.

PCA for June 2020, as shown on figures 10, from the analysis of F1-F3 axis explains much of the structure of water with 71% of the total variance. This plan provides certainty vis-à-vis the presence of Na and Mg alternating with chloride, this is due to seawater intrusion. The presence of sulfates and nitrates is due to the presence of agricultural and urban pollution. Na ions are in front of Ca ions, the presence of seawater intrusion in the face of charging. At F1-F2 axis, the individual takes approximately the same order of variance, except well number 33, which is close to the coast, then, it can be concluded that the seawater intrusion is local. Then, well No 40 (Al-Wafaa) was affected by wastewater pollution (Figure 6).

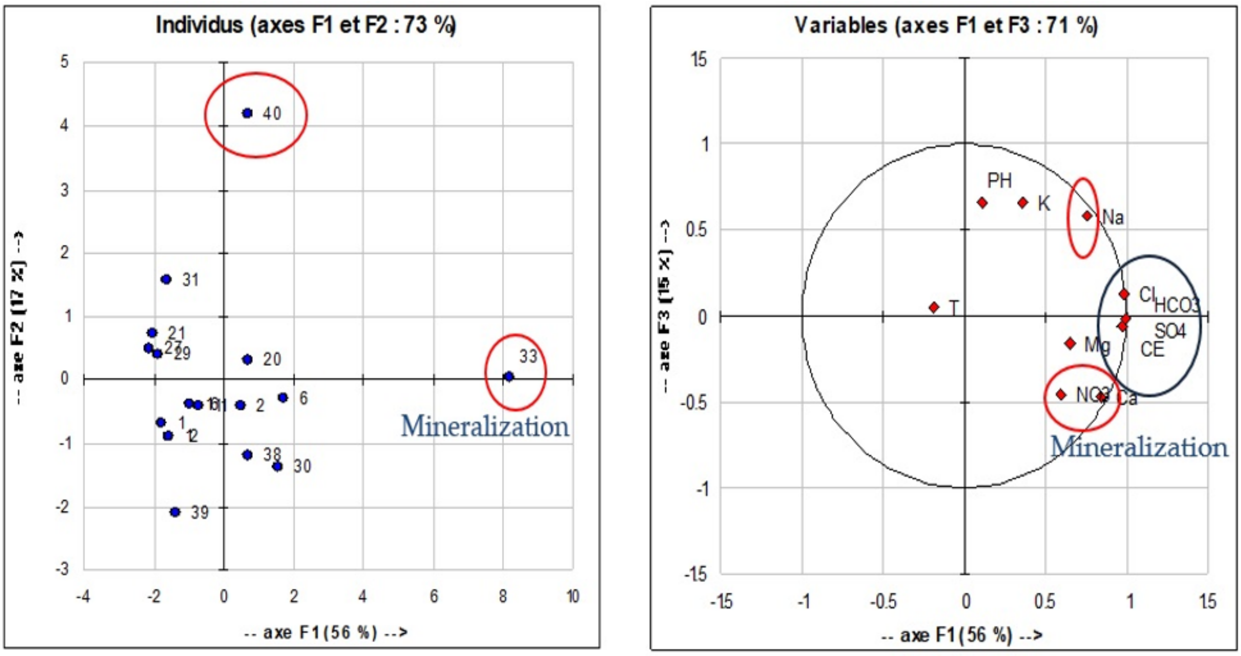


Figure 6. F1-F3 variables and F1-F2 individuals in space (PCA during June).

Once the groundwater recharge axis was detected, and through statistical studies the chemical facies and properties of water were interpreted, and the permeability of the quaternary site through soil texture analysis was confirmed, we still have values on chemical elements that emphasize a natural pollution due to mismanagement of water use or because of anthropic pollution. It was normal to compare analysis results with the standard Lebanese norms for drinking or irrigation water, but we decided to show these numbers in the form of maps by using Surfer 8 software so that the decision maker, knowing the coordinates of the chemical variables, will take the appropriate actions within priorities to protect vulnerable areas. Idea was translated by what we define as iso-concentration mapping.

Chloride ions may be present in groundwater following seawater intrusion or domestic effluent or agricultural dispersion. According to iso-concentration for Chlorides (Figure 7), maps showed the same distribution for this ion between April and June and overlaying the same axis of recharge. It is remarkable that wells close to sea have the highest Chloride concentration, so it's possible the existence of a seawater intrusion.

Sulfates have the same repartition of chloride ions (Figure 7), concentrated in the points near of the coast, that is likely to be of marine origin than in sulfate deposition caused by urban pollution. Sulfate ions have the same distribution in April till June, but its concentration for all the aquifer decreases while remaining more higher in coastal zones. In April, the map shows an area distinguished, may be due to a source of fresh water as in Loulouat Assibssibi B (27). This confirms the hypothesis of the axis of recharge and the area most vulnerable to seawater intrusion, as around Al-Bissar site (33).

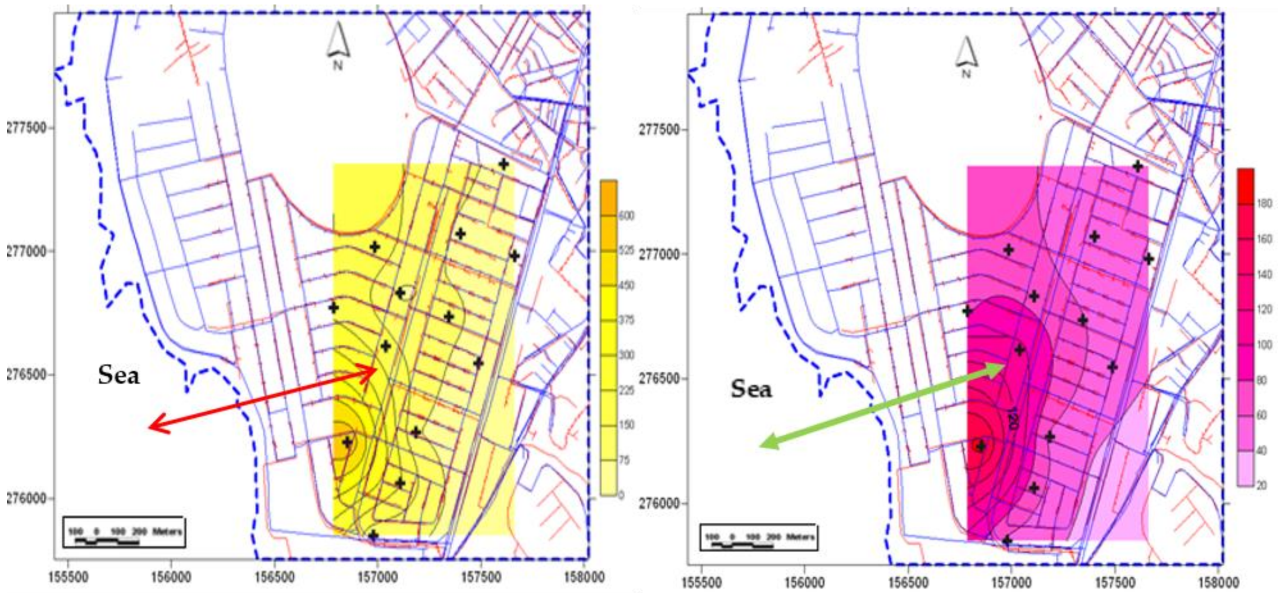


Figure 7. Iso-concentration maps of Chloride and Sulfate in Tripoli coast during June.

By analyzing iso-concentration map for Nitrates (Figure 8), pollution seems local and has influenced other wells, the peak of concentrations of nitrates is in the region of Arij (20) well. The map of June showed high concentration and probably dispersion due to leakage from wastewater networks or it does not reach these sites, or maybe to the massive use of fertilizers in the public park near the coast.

As for the Iso-Concentration maps for SO_4^{2-}/Cl^-, April and June (Figure 8) represent the same distributions of variations, but the ratio increases in June in the inner zone that is far from the sea.

The salinity of seawater is made up of all the dissolved salts, that six major ions make up >99% of the total dissolved salts in seawater, such as Na^+, Cl^-, SO_4^{2-}, Mg^{2+}, Ca^{2+} and K^+ [18]. These major ions are conservative; they have constant ratios, to one another, and to salinity of all ocean waters. By analyzing seawater in front of Tripoli it found that the concentration of SO_4^{2-} is 3400 mg /l, while the concentration of Cl^- is 22100 mg/l; (6.5 times high).The same analysis realized on a groundwater public well in El-Kobeh (Seelftanieh 2), on the Tripoli Hill show Chloride 55 mg/l, Sulfate 51 mg/l, (EC 712 μS/cm, Nitrate 3.2 mg/l), the SO_4^{2-}/Cl^- ratio is almost equal to 1. From these results it can be concluded that the major impact on chemical fluctuation, in the study area, is mainly seawater intrusion effect.

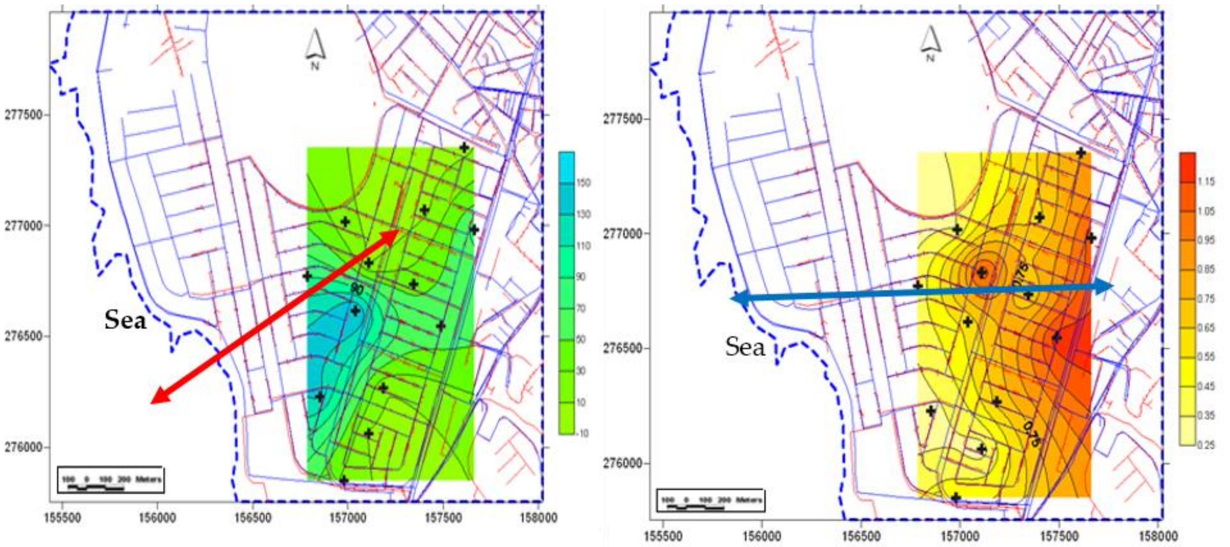


Figure 8. Iso-concentration maps for Nitrate and SO_4^{2-}/Cl^- in Tripoli coast during June.

4. Discussion

Seawater intrusion is the influx of sea salt water on areas not normally exposed to a high degree of salinity, like the marine invasion of fresh water into a coastal aquifer. Coastal aquifers have a special character as a groundwater reservoir, where continental fresh water meets marine water [19]. This freshwater/seawater contact obeys a delicate balance mainly conditioned by the difference in density between these two waters. There are two types of approaches to designing the subterranean contact zone between fresh and salt water. The frank interface models (assuming no mixing between fresh and salt water) and the diffuse interface models (involving a mixing zone, or transition zone, between the two water masses and s expressed by the existence of a generally thin mixing zone of variable geometry). A break in this balance inevitably leads to a displacement and dispersion of this mixing zone and makes continental groundwater unusable [20, 21].

Determining the shape as well as the position of the contact zone between fresh water and sea water has motivated numerous researchers for more than a century. The first works focused on finding analytical solutions in the case of a straight interface. Indeed, fresh water, which is less dense (ϱf=1000 g/L) floats on seawater (ϱs=1025 g/L) with an inclined contact assimilated to a plane [22]. Then, the Ghijben-Herzberg relation considers a hydrostatic equilibrium between fresh water and salt water. In the case of a steady-state system, this approximation turns out to be relatively correct if it is far enough away from the discharge zone of the aquifer at sea [23]. This equation is applied in the case of a free aquifer by replacing the hydrostatic level by the piezometric surface [23].

Under normal conditions, freshwater flows from the aquifer to coastal regions and then to the sea. In general, groundwater flows from a region of high hydraulic level to a lower level. This natural movement of fresh water prevents salt water from entering the coastal aquifer [24]. This zone is called the transition zone or interface, which makes salt water appear stable [25]. This balance can be threatened by a decrease in the piezometric level or by a rise in the sea level [26]. Then, deterioration of the hydraulic balance will be caused by extrinsic factors such evapotranspiration, rising of sea level or the overexploitation of water from an aquifer causes a lowering of the piezometric level and leads to this destabilization as shown in study area where 75% of tested wells reached critical values in electrical conductivity and exceed standard norms for drinking water. A local deformation of the transition zone by significantly modifying the geometry and highlighting the ascension cone process [27]. The development of an ascent cone around a pumping well generates a conical rise of the transition zone. The ultimate interface elevation is expressed by Ghijben-Herzberg principle.

Seawater intrusion has reached choking values in many coastal aquifers in Lebanon, especially in Akkar plain (north) and Beirut where electrical conductivity exceeds 4000 and 12000 µS/cm [33]. Since saltwater cannot be used to irrigate crops (2500 µS/cm is the maximum accepted value for irrigation referred to ICARDA) or to be consumed by people (1000 µS/cm is the maximum accepted value for drinking water referred to LIBNOR). Field studies showed how excessive groundwater pumping has been the main contribution to the encroachment of seawater into fresh groundwater supplies. Between increased pumping and decreasing rains, the seawater intrusion is becoming a matter of concern in Lebanon, and the situation could be critical with the overexploitation of groundwater in such a way. Unfortunately, the Ministry of Energy and Water and the municipalities are not in charge of the general evolution of the salinization of coastal aquifers in Lebanon. If a coastal aquifer has become saline, it is a legacy that is bequeathed to future generations, so it is better to think about prevention. This involves after a hydrogeological study, monitoring the aquifer with piezometer networks to exploit it in a reasoned manner and to provide ways for artificial recharging to act as a barrier to seawater [1].

5. Conclusions

This study allowed us to confirm the hypothesis of saline intrusion in Tripoli aquifer at the DAM FARZ area, and to make a first approach to water consumption per inhabitant per day. This information is very useful in the perspective of the integrated management of water resources to ensure the sustainable development of natural resources and in the first place the water table [28].

The results of the study showed that the annual water consumption during the year 2010 of the study region considering the water demand/inhabitant/day calculated, is of the order of 650,000 m^3 whereas it was estimated in 2008 at 350,000 m^3. In addition, the water requirement/inhabitant/day is equal to 254 L, this quantity of water consumed per inhabitant is very large compared to the water requirement/inhabitant/day estimated for the city of Tripoli which is 120 L. So, there is an overconsumption in this neighborhood classified in the "affluent" category and therefore there is an overexploitation of groundwater, the main reasons of which are: the absence of a billing system for the water withdrawn or consumed and the bad habits of daily overconsumption (housework and personal maintenance), resulting in a waste of water.

Concerning water quality, we notice a continuous deterioration due to amplification of seawater intrusion phenomena. Its tendency will increase in the absence of an official reaction from the public authorities to stop this hemorrhage and put an end to this disaster. Under the overexploitation of the water table at a high rate, the underground water of the DAM FARZ area will turn into brackish water.

Water authorities can implement policies to prohibit private wells and regulate water use. The most important actions would be to:

- Introduce a fixed tax for all private wells with the obligation to install a water meter for each well to determine personal consumption and establish pricing scales according to consumption.
- Prohibit the drilling of other private wells and establish a moratorium for a period of 20 years, which would be absolutely prohibited from drilling during this period.
- Treatment of all water from the Abou Halqa spring at the Hab water treatment plant.
- Complete the (tertiary) drinking water supply network in the DAM FARZ area to cover the entire region.

- Begin studies to supply the Tripoli region with Dannia sources during the winter period.
- Carry out an artificial recharge into olive plains in Tripoli, using rainwater from the villages above Tripoli [29] [30].
- Build another dam on the Bared River with a capacity of 2Mm³ with a nearby treatment station [31] [32].
- Install a groundwater observatory in Tripoli to accurately determine the quality and quantity of groundwater.

These alternative solutions can have many advantages, we can mention:

1. Ensure enough water for future years until at least the year 2050, with daily consumption for human needs of at least 150 l/d.
2. Conservation of the water table of Tripoli and its protection against seawater intrusion and not to solicit the water table except in case of emergency (pollution of surface water, Hab, Abou Halka…).

Water is a precious resource, and its true economic value must be recognized by both decision makers and consumers. It is only through such awareness that it will be possible to bring the demand down to the level of the real and reasonable needs of the populations for the sustainable development of water resources in the city.

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