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Assessing Water Quality Using GIS: The Case of Northern Lebanon Miocene Aquifer

M. Saba, A. Iaaly, E. Carlier, N. Georges

Abstract—This research focuses on assessing the ground water quality of Northern Lebanon affected by saline water intrusion. The chemical, physical and microbiological parameters were collected in various seasons spanning over the period of two years. Results were assessed using Geographic Information System (GIS) due to its visual capabilities in presenting the pollution extent in the studied region. Future projections of the excessive pumping were also simulated using GIS in order to assess the extent of the problem of saline intrusion in the near future.

Keywords—GIS, saline water, quality control, drinkable water quality standards, pumping.

I. INTRODUCTION

WATER pollution can be either due to its native characteristics (i.e. hydrogeological formation) or to anthropogenic contaminants. Both aspects affect the quality of water and prevent their consumption by individuals either for drinking purposes or to support the communities. Groundwater is among the most critical natural resources; and is considered the only source of drinkable water in Lebanon. Lebanese cities rely mainly upon groundwater for providing drinkable water and daily usage and consumption. Hence, the conservation, protection, and management of groundwater became a necessity. To meet this goal, the basics of groundwater hydrology, supply, and water quality must be examined thoroughly. The specific context of the urban environment on the Northern Lebanese coastline will be examined as a case study for saline water intrusion.

The area studied in this paper represents the city of Tripoli and its surroundings as shown in Fig. 1. Tripoli City is the second largest city in Lebanon located in the Northern shoreline with a population of approximately one million. The city is suffering from a saline water intrusion due to various reasons such as the unplanned expansion of the urban areas due to population growth, the increase in water demand and the random drilling of wells. This situation has therefore

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affected negatively the water quality in the Miocene Aquifer and has led most importantly to the outbreak of the seawater intrusion all along the offshore of this fractured aquifer. The seawater is contaminated with untreated sewage disposable and the presence of bacteria's such as salmonella, *E. coli*, and coliform. On the other hand, the lack of awareness and commitment among citizens and their weak obligation towards conservation and pollution prevention has contributed to the exaggeration of the problem. Measures have to be taken to resolve this problem. There has been a considerable lightness and negligence among responsible in implementing existing policies and in incorporating new laws and policies. The individual initiative taken by the academic institutions, even though not sufficient by it, constitutes a small brick toward solving the problem. The University of Balamand in collaboration with Polytech Lille initiated a research to address this problem. Its objective is to assess the hydrochemical, hydrophysical, and microbial parameters of the groundwater basin in the region. These parameters will be linked with water level testing to develop hydrodynamic and hydro-dispersive maps using GIS. These maps will constitute the visual tools to support decisions regarding the sustainable development and management of water.

II. LITERATURE REVIEW

Lebanon was the subject of many researches addressing this problem over the last decade. The first study conducted on the region has been between 1949 and 1951 aiming at developing the geological formations of the area [1]. This map has been re-designed later on in 1977 [2]. The Ministry of Hydraulic and Electrical Resources with the Food and Agriculture Organization (FAO) performed a detailed geological study in 1971 [3] and was complemented by a hydrogeological research in 1972 on the Miocene limestone aquifer [4]. In the last decade, the Council for Development and Reconstruction (CDR) contracted several groundwater development studies and drilled many boreholes in the Koura, Zgharta as well as Tripoli area for public water supply. Most of these studies were performed by the Bureau Technique pour le Development (BTD) [5]. As for the water quality control, many hydrogeological studies and monitoring studies were performed to set conceptual models of the North Lebanese aquifer and its coastline. In 2005, a hydrochemical and isotopic study of submarine Fresh water along the coast in Lebanon was carried [6]. It was followed by an assessment of the water situation in Tripoli [7]. Monitoring the water quality in the coastal area of Tripoli (Lebanon) using high-resolution satellite data was done in 2008 [8]. Also, assessing

groundwater quality in a coastal area using the GIS technique was studied [9]. However, all these studies did not focus on the interrelation between the hydrochemical, physical and microbial water testing with the potentiometric water leveling studies and the impact of saline water intrusion on the area. As such, the problem of saline water intrusion, degradation of the

water quality as well as water leveling in this karstic fractured area are still prominent and is increasing.

Section III presents the analysis of the combined hydrochemical, physical and microbial water testing and water leveling parameters using GIS. Results aim at verifying the interrelation of water depth with saline water intrusion.

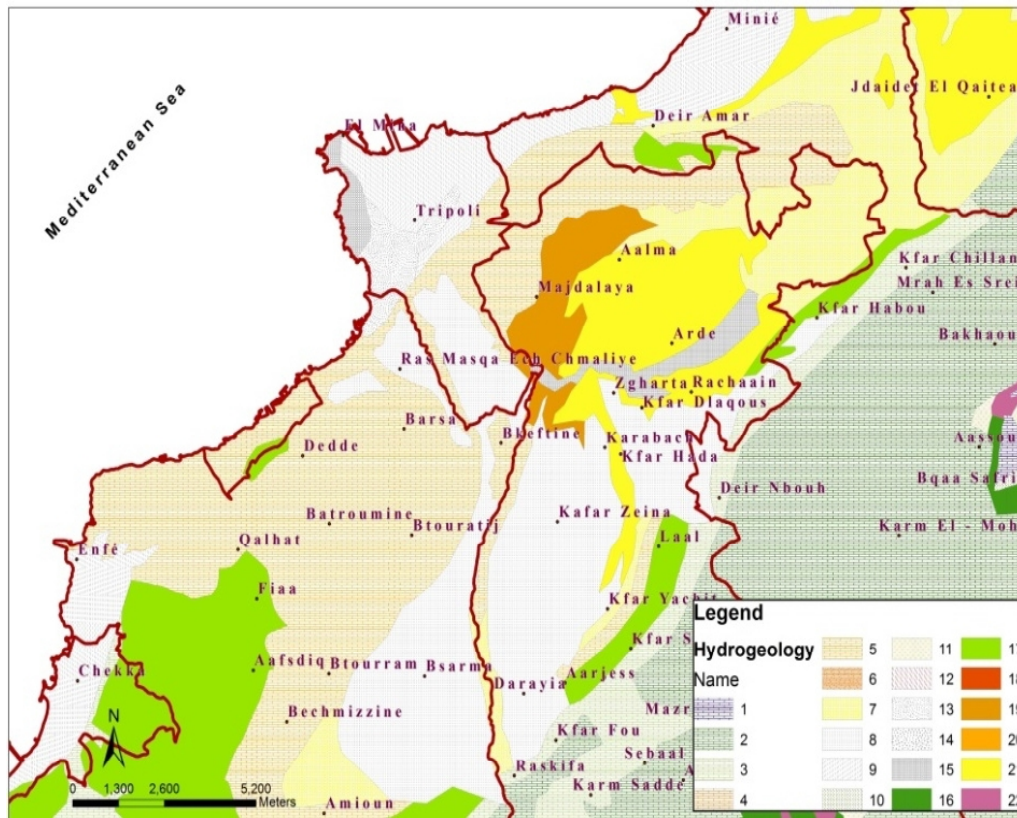


Fig. 1 Hydrogeological Formations of Tripoli Region

III. ANALYSIS

The feature of karst in the Mediterranean makes groundwater resources relatively important. A Karst system is defined as the catchment area of a source or group of karst springs including geological formations in which developing a network conduits leads to the source [10]. Firstly, these aquifers are subject in terms of complex recharge by melting of snow and infiltration in sedimentary geological formations (Fig. 1). Similarly, the discharge of the aquifer is often complex outputs provided by multiple, lasting or temporary presence of different stages of karstification. These outlets can both occur in upper levels, ashore, and at lower levels under the sea level. Therefore, due to the depth development of karstification, coastline aquifers such as the one studied, can be directly related with the sea, where the presence of very numerous submarine springs occur. Therefore, the exploitation of coastal karst aquifers is an important solution for water management but requires detailed knowledge of the hydrogeological regional and local levels of water. It also requires the establishment and management of units for controlling the salinity intrusion [11]. Thereby, in order to

prevent the risks of pollution, it is necessary to understand the mechanisms by which groundwater acquired its physical and chemical composition; and in a next step study the static and dynamic water levels. Representation of our results will be handled with GIS maps in order to better visualize and interpret the different results collected from the field work applied on the Northern Lebanese caza's. In this context, the characteristics of water are presented to help develop further the hydrochemical and hydrophysical study of the groundwater in the North. It relies on the water analysis from the dry season and wet season 2013/2014. Different sets of water samples were taken from 86 wells (private and public) as shown in Fig. 2, in order to provide the following elements of this research: the physio-chemical parameters such as temperature, pH, conductivity, salinity, TDS, and they key cations and anions Li^{+} , Ca^{2+} , Mg^{2+} , Na^{+} , K^{+} , Cl^{-} , SO_4^{2-} , NO_2^{-} , NO_3^{-} , PO_4^{2-} , F^{-} , and Br^{-} were tested. To them microbial and water level testing (static and dynamic) were applied as well.

From the physical testing a pragmatic notion of salinization become more and more familiar when it comes to groundwater quality in the area. Generally, groundwater recharge in the

aquifers moves down grading and eventually discharges to low-lying coastal areas and into the sea. The studied aquifer extends from upper areas such as Koura and Zgharta until it reaches the offshore of Tripoli, Qalamoun, Anfe and a small part of Chekaa area (all of the mentioned cities are coastal ones). With the excessive pumping of the groundwater, a reduction of the weight of the overlying freshwater occurs and will in turn decrease or even reverse the seaward flow so that seawater moves landward into the aquifer; this is known as seawater intrusion.

According to the results seen, many factors could be behind the salinity concentrations seen in the 86 studied wells. To begin, the Northern Lebanese region is famous for its agricultural activities such as olive cultivation as shown in Fig. 3. With time, and due to the constant usage of fertilizers and pesticides, irrigation could increase the salinity of the soil. Thus with the natural infiltration of the groundwater, these high levels of salts will end up in the water leading to its contamination.

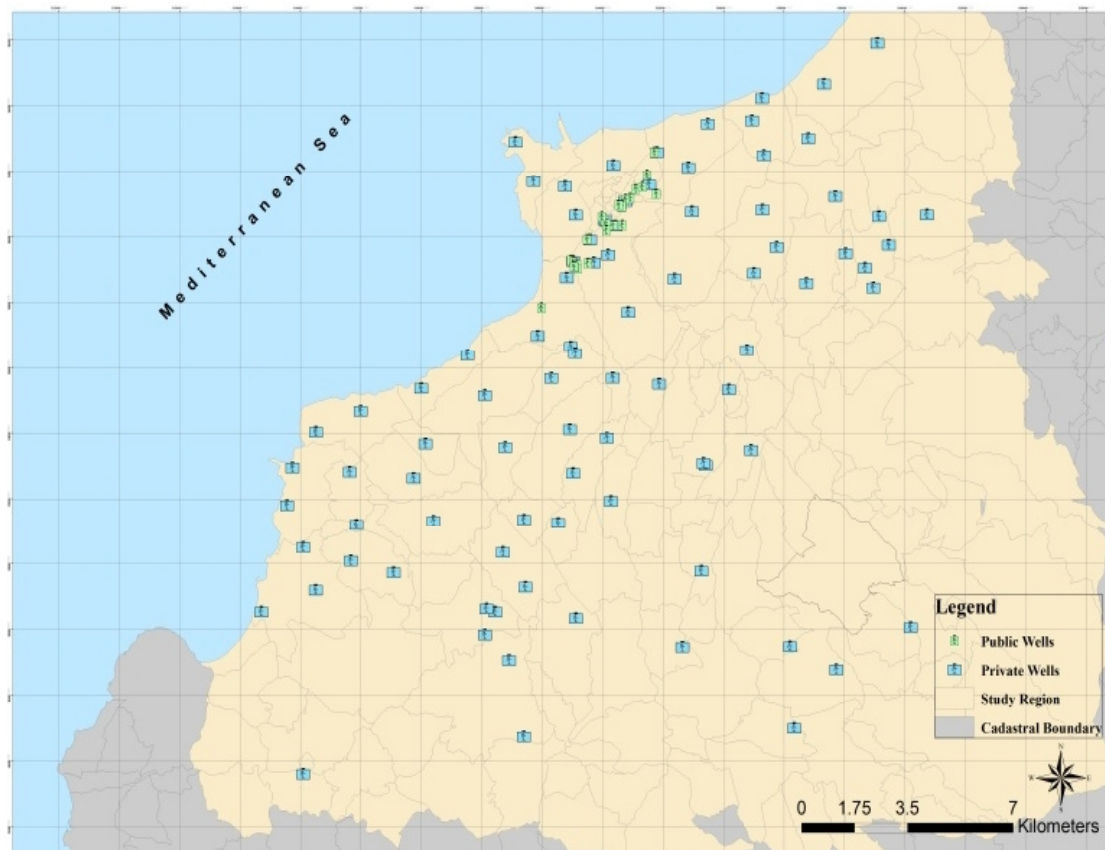


Fig. 2 Private and Public Wells Locations

Another reason is the geological layout of the region leading to an aggravated saline water intrusion. As such, the exposure of the Karstic Miocene Aquifer to the sea has increased the possibility of the seawater intrusion specially that the area is encountering an over-pumping due to the excess demand of groundwater. These factors explain the increase in the salinity percentages seen in both wet and dry seasons. It defines the case of Tripoli and its surrounding. This water penetration contains sea water as well as untreated waste water that lead with time to a greater contamination of the aquifer. Fig. 4 indicates the promulgation of salinity percentage in the area; giving us a proofreading on the previously mentioned factors. First, the high levels observed on the coast imply the beginning of a coastal line salinization, moreover, some sites facing high salinity percentages superior to 0.05%, implies that the geology of the land, such as

limestone affects the salinity of the land [12]. Another factor that will increase the salinization is the land having low porosity potential that will permit the infiltration of many impurities to the ground. From this perspective, the GIS map represented in Fig. 4, indicates the salinity values observed in the dry season 2013, which could be an indication of seawater intrusion. The closer to the coast, the higher is the salinity, based on this phenomenon; salinity reaches 0.6% in S35, a site located near the coast while it reaches 0.05% in upper Tripoli area. This is also due to the presence of groundwater on very shallow elevation leading to easier intrusion of saline water. To confirm the assumption of saline intrusion, hydrochemical testing's were applied in the studied wells across the second largest city in Lebanon and its surrounding.

One of the most important indicators of seawater intrusion in an aquifer is an increase in chloride concentrations; as

chloride is a major constituent of seawater, it is chemically stable and moves at about the same rate as intruding seawater. In this study, chloride concentrations of 100 milligrams per liter (mg/L) or more were assumed to indicate seawater intrusion [13]. Fig. 5 links salinity percentages to elevation of the sampling locations, confirming the interrelation between water level and elevation affecting the percentage of salts in the groundwater.

In general, chloride concentrations in groundwater are associated with the presence of salts originating from many sources. According to the World Health Organization (WHO) and Lebanese Standards, the Maximum Contaminant Level (MCL) of Chloride is 25 mg/l. Therefore, from Figs. 6 and 7 it is noticed that the levels of chloride are almost all above the standard. The results obtained could be explained by many factors [14]. For instance, in the case of Tripoli, over-pumping from wells implies that the rate of water abstraction is higher than the rate of recharge, leading to groundwater mining [15].

The chloride concentrations in coastal groundwater are attributed to seawater intrusion due to excessive drilling from wells as a source of drinking water [16]. This problem has reached a new scale of severity over the last two decades due to the expansion of coastal agglomerations. Rural-urban migration and population growth have increased demand for water all along the coast, and most particularly in Tripoli. In Zgharta and Koura, a new urban development in the villages is occurring; which increases the need for water demand and of groundwater pumping. As a result, the increase of extraction of water from deeper ground leads to its infiltration from upper lands. In the absence of strict enforcement of borehole specifications and permissible abstraction rates, the salt-freshwater interface shifts inland [17]; this explains the higher levels of chloride. In the locations where moderate amounts were seen it was often attributed to fertilizer applications.

The 2013/2014 study found chloride concentrations of 100 mg/L or more in 26.9 percent of total sites sampled, indicating possible seawater intrusion. Chloride concentrations from the rest of the groundwater samples ranged from 12 mg/L to 100 mg/L, with a median value of 80 mg/L. When seawater intrudes, three trends are usually apparent. First, chloride concentrations at a given site may increase over time. Second, for wells opening at the same depth, there may be a strong relation between chloride concentrations and a well's distance from the shoreline, with chlorides' concentration being greater the closer a well is to the shore. Third, chloride concentrations at a given site may increase with depth.

Chloride concentrations in excess of 100 mg/L suggested seawater intrusion and the statistical tests indicated that concentrations had increased over time. This data showed trends of consistently higher concentrations near the shoreline or consistent increase of chloride concentrations with depth.

As for the water level study; Fig. 8 displays the area of the general flow pattern from the boundaries and areas of recharge towards the corridor of Tripoli which is the discharge area. The head values in the Tripoli area are below sea level and this is due to the high demand on water and therefore the high density of wells. These values observed below sea level heads are serious as they could lead to sea water intrusion resulting in changing the properties of the groundwater. In addition, seawater intrusion results in the lowering of hydraulic conductivity especially in carbonate aquifers [18]; thus dropping the productivity of the aquifer. A second general trend that can be observed in this static water level map of the aquifer is that a decrease in groundwater depth is more widely spaced in Tripoli corridor area than in the rest of the aquifer. This movement suggests that the hydraulic conductivity values are higher in Tripoli area than in the rest of the aquifer. Other areas of the aquifer show minimal variations that are most likely due to seasonal head value fluctuations; thus the effect of increased demand on the aquifer can only be detected in Tripoli area.

As for the microbial testing's realized during the four different sampling campaigns, groundwater contains a broad spectrum of microbial types similar to those found in surface soils and waters. These microbes encompass bacteria, fungi and protozoa, and are representative of most physiological types; i.e. *E. coli*, Coliform and Salmonella. Most of the time, these pathogenic bacteria's and protozoans are of gastrointestinal origin from domestic, agricultural and other anthropogenic activities (most importantly untreated waste water), may infiltrate through our soils, and sedimentary rock formations until they reach the groundwater. The presence of *E. coli*, Coliform and Salmonella present in many samples either offshore or in agricultural areas. The offshore microbial presence was primary resulting from the untreated waste water that is withdrawn to the Mediterranean Sea. As sea water intrusion is occurring, these bacteria's reach again the fractured aquifer. The other factor explaining the presence of *E. coli* and Coliform in higher regions is due to agricultural activities and animal fesses that will allow the infiltration of these bacteria into the ground and later on into groundwater.

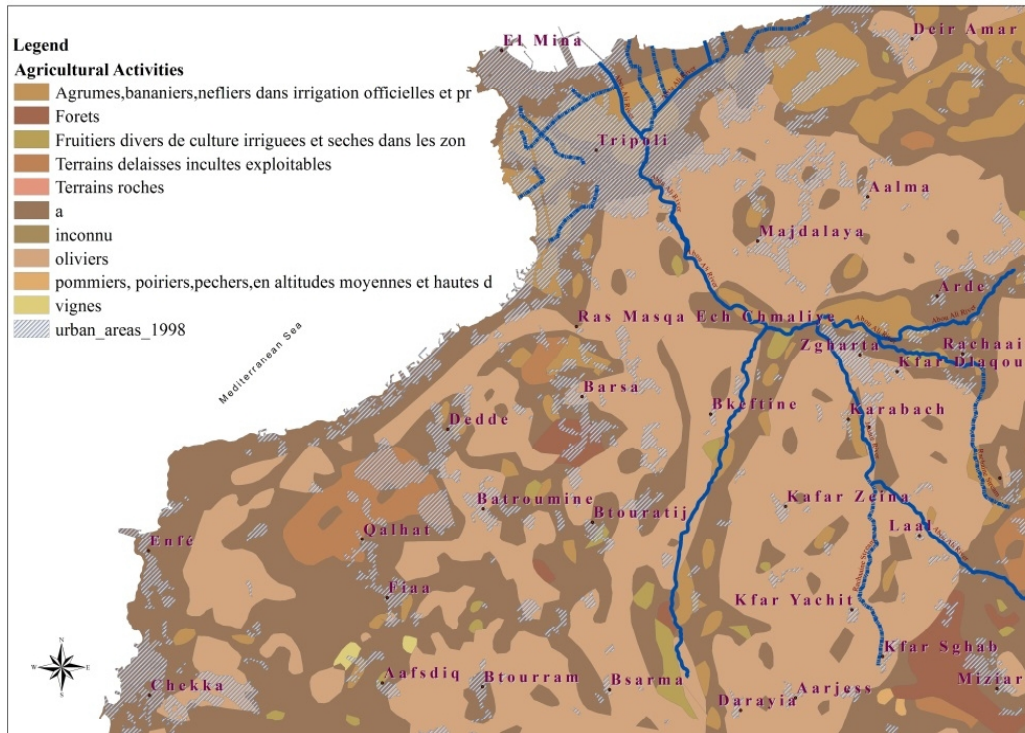


Fig. 3 Agricultural Activities

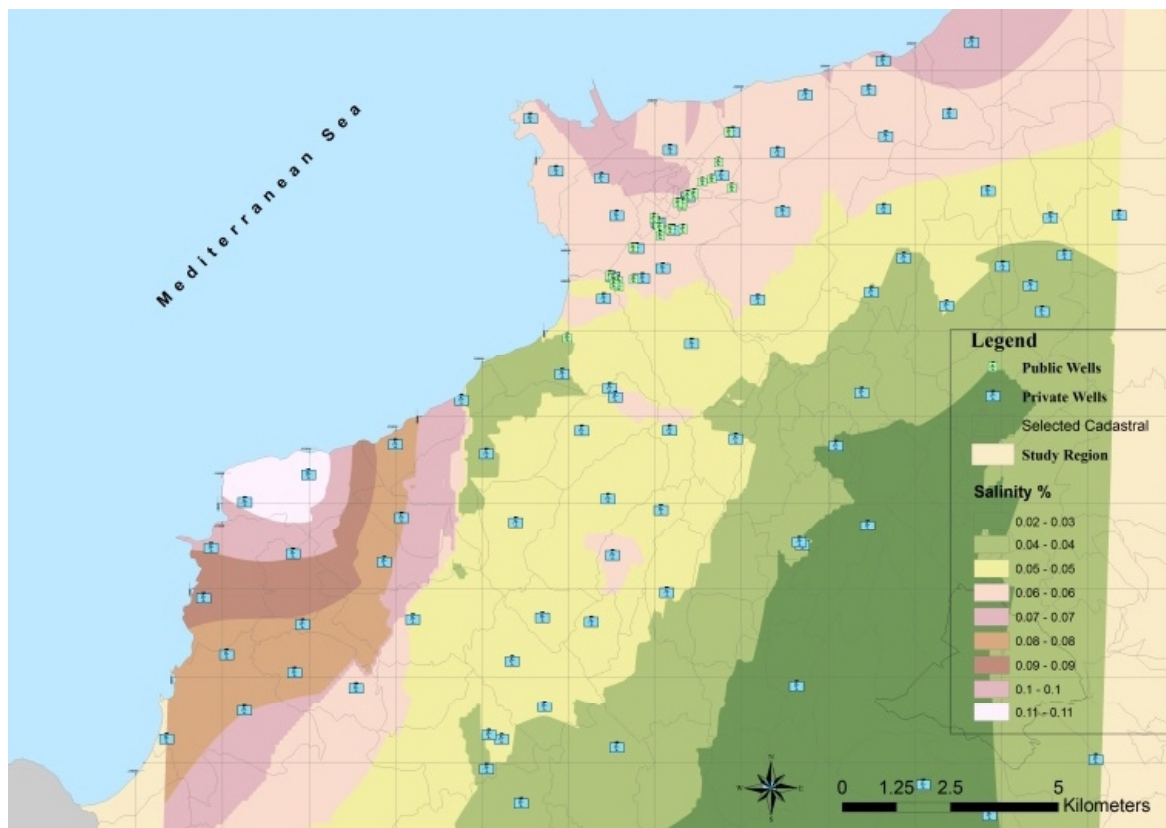


Fig. 4 Salinity% for Wet Season for Year 2013

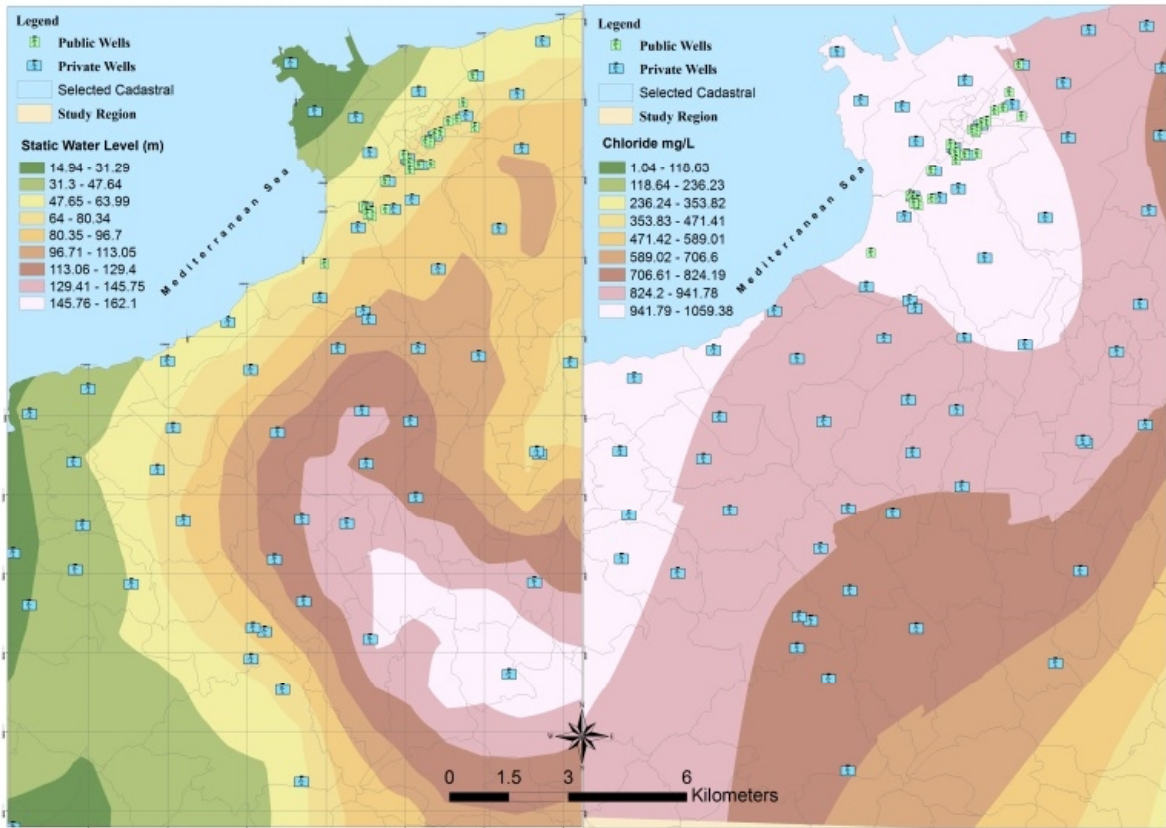


Fig. 5 Chloride versus Water Level of the Sampling Locations

IV. CONCLUSION

This confined, fractured aquifer has shown a general water flow from its upper side located in Zgharta region where some of the highest heads were observed towards the lower, shallower aquifer (Koura and then Tripoli) where most of the groundwater will be withdrawn towards the Mediterranean Sea. The hydrochemical, hydrophysical and water level methodologies achieved in this work gave an idea on the water quality, water level of the watershed; therefore, helping the

consumers to contribute for a sustainable management of groundwater both in quantity and quality. Based on the chemical, physical and bacteriological studies accomplished on the 86 studied wells in the area, the groundwater was found to be clearly affected by pollution mostly due to salinization and agricultural activities; thus indicating sea water intrusion resulted from uncontrolled pumping of wells. The integration of the numerical model by the use of GIS gave a clearer view on the condition of the aquifer.

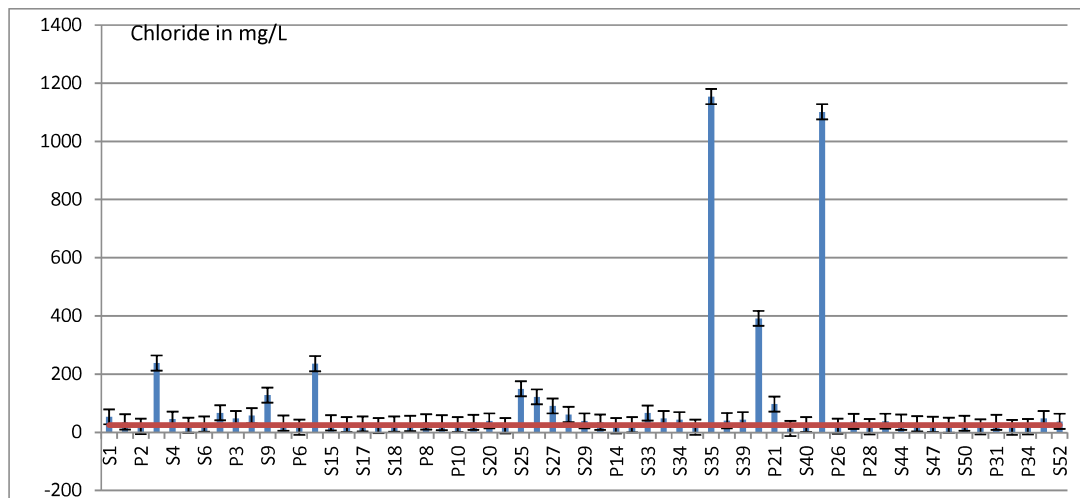


Fig. 6 Chloride Concentrations for Dry Season 2013

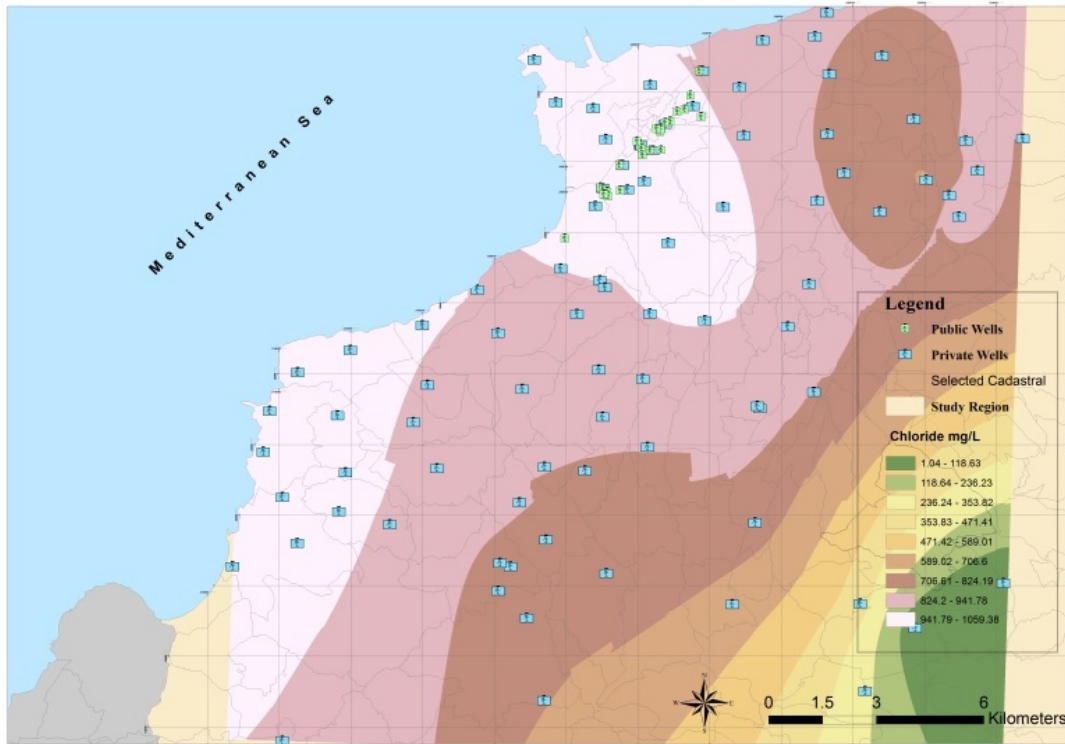


Fig. 7 Interpolation of Chloride Concentrations

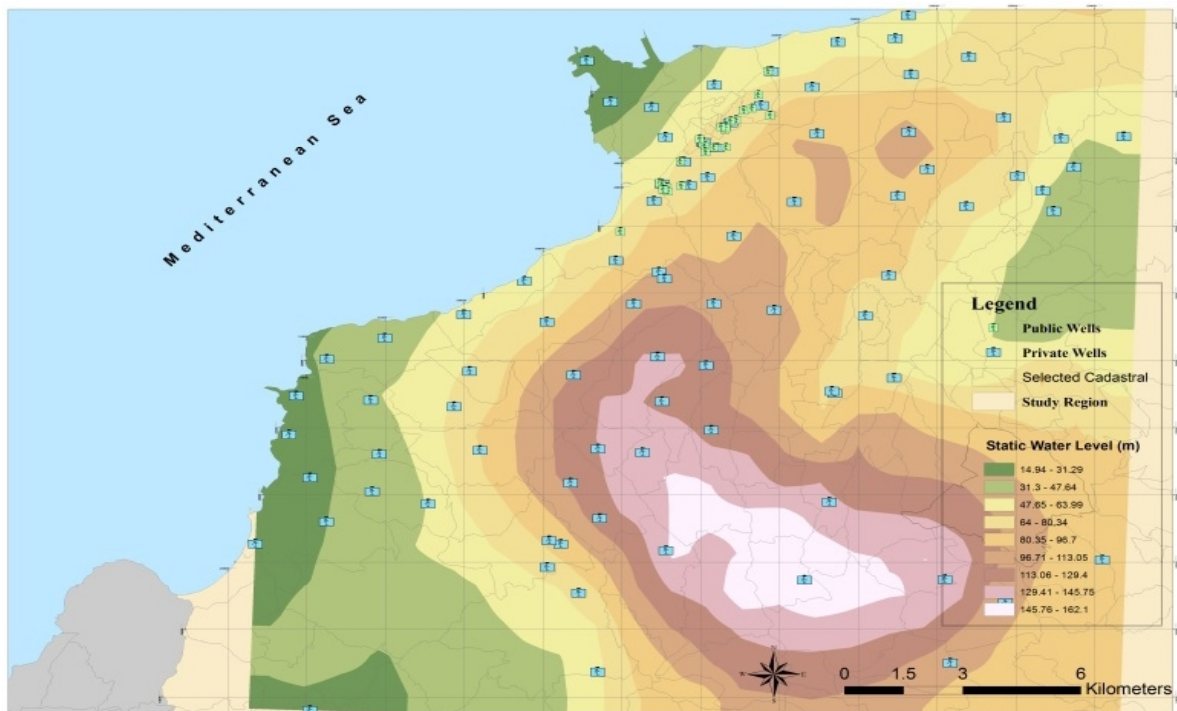


Fig. 8 Interpolation of Static Water Levels

The issue of coastal or submarine outfalls is crucial. Indeed, due to the depth development of karstification, coastline aquifers can be directly related with the sea, where the presence of very numerous submarine springs occurs. Therefore, the exploitation of coastal karst aquifers is an

important solution for water management. However, it requires detailed knowledge of the hydrogeological formations, regional and local water levels and necessitates the establishment of networks of permanent salinity control, in accordance with a management plan [19].

APPENDIX
TABLE I
HYDROGEOLOGICAL CHARACTERISTICS OF THE NORTHERN LEBANESE AREA

Ground Water Reservoirs	Lithology Facies	Age	Flow of Springs l/sec	Most Probable Instantaneous Flows l/sec	Transmissivity m ² /sec	Outcrop Exposures Km ²
Karstic Formations Extended & rich Reservoirs	Massif limestone & dolomitic limestone with intervals of marl Thickness : >1000 m.	Jurassic Bathonian- Portlandian	<100 100-1000 >1000	>100	10 ⁻² ≤ T ≤ 1 Frequently high	1290
	Regularly Layered Limestone 800 to 1000 m.	Cretaceous Cenomanian- Turonian	<100 100-1000 >1000	>100	10 ⁻² ≤ T ≤ 1 Frequently high	4290
	Limestone marly-calcareous with flint layers Thickness: ~ 200m.	Cretaceous Turonian	100-1000 >1000	>100	Frequently high	100
	Dissolved Limestone Thickness: 100 to 800 m.	Nummulite Eocene	100-1000	<100	10 ⁻⁴ ≤ T ≤ 10 ⁻² Regularly high	317
Merokarstic Formations Extended Reservoirs	Reef Limestone Thickness: 200 to 250 m	Neogene Miocene	100-1000	<100	Regularly high	103
	Limestone, marl Thickness: 100 to 300 m.	Nummulite Eocene	<100	<50	10 ⁻⁴ ≤ T ≤ 10 ⁻³ Weak	536
Extended Aquifers	Clay torrential-Marly-Conglomerates Thickness: 500 to 600 m.	Neogene Miocene & Pliocene (continental facies)	<100 OU DECHARGE DISPERSEE DIFFUSE	<30	<10 ⁻³ Weak or Changing	746
	Alluvial deposits	Quaternary	DECHARGE DIFFUSE	<30	10 ⁻⁴ ≤ T ≤ 10 ⁻³ Weak	68
	Silt & "terra rossa" Thickness: 600 m.	Quaternary	DECHARGE DIFFUSE	<10	Weak to low changing	830
Porous Formations	Sandstone thickness: 150 to 250 m.	Cretaceous Sandstone base	<10	<10	10 ⁻⁵ ≤ T ≤ 10 ⁻⁴ Weak to poor	275
	Dis-bonded gravel with mudflows Variable thickness	Quaternary	-	<10	Weak to poor	122
Local Aquifer or discontinuous	Red-bed-soils	Quaternary	DECHARGE DIFFUSE	<10	Weak to poor	14
	Shoreline Sands Thickness: variable	Quaternary	DECHARGE DIFFUSE	<10	Weak to poor	12
	Current Alluvium : Thickness: variable	Quaternary	DECHARGE DIFFUSE	<10	Weak to poor	7
	Shoreline Sandstone Thickness: variable	Quaternary	DECHARGE DIFFUSE	<10	Weak to poor	1
Regions Generally without Ground Water or Local Aquifer	Alteration of calcareous marls soils, calcareous benches & marl Thickness: 300 to 400 m.	Cretaceous Aptien_ Albien	<5 (Intermittent Sources)	<5	Poor to very poor	552
	Marl & calcareous Marl Thickness: 100 to 200 m.	Cretaceous Senemonian & early 'Eocene	-	Very Low	Weak	416
	Marl Thickness: 50 m.	Nummulite Eocene	-	-	-	-
	Marl Thickness: 50 m.	Neogene Miocene_ Marine facies	-	Very Low	Low to Very Low	83
	Marls & marly-limestone Thickness: ~ 900 m.	Neogene Continental facies	-	Very Low	Low to Very Low	73
	Clay, sandy calcareous clay Thickness: 250 to 400 m.	Neogene Pliocene Marine facies	-	Very Low	Low to Very Low	73
Basalts Thickness: variable	Cretaceous low. Miocene Pliocene quaternary	-	Very Low	Very Low	365	

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