Case Study: Assessment of the Hydrophysical and Hydrochemical Parameters in the Groundwater of the North Lebanese Miocene Aquifer

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ABSTRACT

In Lebanon, natural resources such as groundwater are been exploited heavily due to the increasing population followed by urbanization and agricultural activities. Attention towards monitoring the quality and quantity of such a resource is a key role in achieving global sustainable development in the near future. The high demand in water has increased the pumping of groundwater in big cities and has affected negatively its coastline; where aquifers have shown major signs of saline water intrusion which consequently results in a deterioration of the groundwater quality. Understanding the origin and mechanisms of the salinization process is an important key to prevent further deterioration of groundwater resources. This case study will focus on the second-largest city in Lebanon, Tripoli. It is a coastline city that has been facing for the last decade, overpopulation, and an excess of construction all over its coastline. In this study, the analysis of the hydrophysical and hydrochemical parameters in the groundwater of the North Lebanese Miocene Aquifer has shown a prompt decrease in the water levels due to overexploitation of the groundwater and a deterioration of its quality in both wet and dry season. The results of the fieldwork

are represented on GIS (Geographic Information System)

where anthropogenic, agricultural, and domestic factors will be linked to hydrogeological factors to assess the water quality. This will allow us to link the physio-chemical results to observe how the water type is dependent on factors like lithological characteristics of the aquifers, retention time, and flow pattern of groundwater flow. Several tools were used as well such as the Piper diagram, PhreeqC to evaluate the factors affecting groundwater chemistry and observe how seawater intrusion is mitigating from the sea towards the upper areas of the aquifer.

KEYWORDS

Groundwater; seawater intrusion; water pollution; Geographic Information System (GIS).

1. INTRODUCTION

The increasing population accompanied by urbanization and agricultural activities has imposed heavy loads on the natural resources more specifically groundwater. Accordingly, attention towards monitoring the quality and quantity of such a resource is a key role in achieving global sustainable development in the near future. The importance of groundwater as the key supply is increasingly recognized nevertheless a decrease in its quality is been observed. The need for water has produced an increasing withdrawal of groundwater in sensitive areas like the coast, where aquifers may suffer from saline water intrusion and which consequently results in a deterioration of its quality. Groundwater salinization occurs in many aquifers around the world [1]. Understanding the origin and mechanisms of the salinization process is an important point for preventing further deterioration of the groundwater resources. Many investigations have dealt with the origin of saltwater in the coastal aquifer and several sources have been identified like; evaporate dissolution, downward leakage from surface saline water through failed or improperly constructed wells, deep brines, or upward flow from deep saline water, fossil seawater or present seawater intrusion often due to excessive pumping [2-3]. Lebanon has a typical Mediterranean climate with moderately cold, windy, wet winters and warm dry summers. From this, two distinctive seasonal periods are noticeable, one from May to October which consists of the dry season and another rainy season that spans from November up to April. This raining period results in the greatest supply of water at the time of its least demand in winter and the least supply of water at the time of its greatest demand in summer. During the last decades, development activities, both in urban and agricultural sectors, have rapidly increased; often without adequate planning. The enhanced anthropogenic pressure together with improved standards of living has substantially increased the water demand. The consequence has been greater exploitation of groundwater resources, which are the only available source, in this area, for drinking, agricultural and domestic uses. The importance of groundwater in the area should not be underestimated because it is the only water resource for the people living in this area [4-5]. Despite the lack of alternative water sources, the physical and chemical properties of the groundwater of this aquifer remain poorly studied. Salinization and decreasing water levels increase the need for a comprehensive understanding of the groundwater system that would yield better management of the resource. This study aims to analyze the hydrochemical and hydrophysical quality and level of groundwater in the Miocene aquifer in Tripoli, to assess the suitability of the waters for different uses with the use of Geographic Information System (GIS) software.

2. MATERIALS AND METHODS

To appropriately cover the area, 58 private and public wells were considered for sampling the groundwater. The location of the sampling points is shown in figure 1. Field measurements included the physical and chemical characteristics of the groundwater with parameters like pH, EC (Electrical Conductivity), Temperature, Salinity, DO (Dissolved Oxygen), TDS (total dissolved solids), major cations (Na^+, K^+, Ca^{2+}, $NH^{4+,}$ and Mg^{2+}), and major anions ($SO_4{}^{2-}$, Cl^-, F, PO_4^{2-}, NO_3^-, NO_2^- and Br^{2-}). The chemical parameters were quantified by the use of an Ion Chromatography. For the statistical analysis, software's such as Piper, PhreeqC, and Arc GIS was used through data processing.

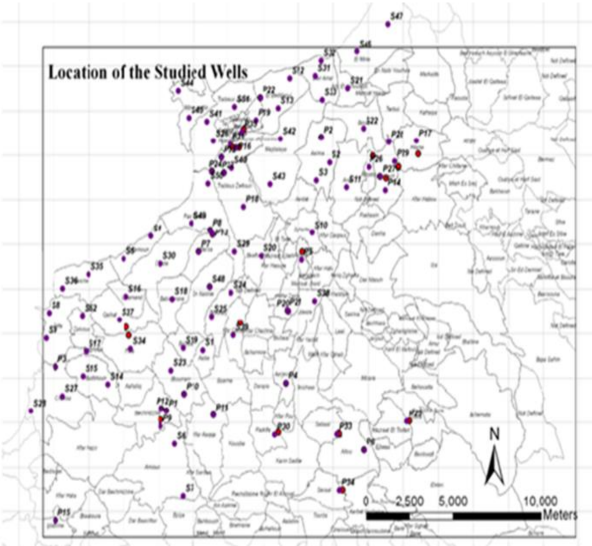

Figure 1. ***Sampling Locations***

3. RESULTS AND DISCUSSION

3.1 Hydrochemical and Hydrophysical analysis

The results of the hydrochemical analysis of the groundwater samples taken from Tripoli and its surrounding showed different water patterns. In general, sodium appeared to be the dominant cation, while chloride had relatively higher concentrations in comparison with other anions [6]. Regarding EC and TDS, almost all of the reported values were higher than the accepted limits for drinking and agricultural use.

To make the spatial analysis possible, the spatial distribution of EC, Na^+, K^+, Ca^{2+}, $SO_4{}^{2-}$, and Cl^- was required [7]. The various parameters concentrations conducted within the many sampling campaigns highlighted a general increasing pattern from west to east alongside the groundwater flow direction which is eastward [6]. The high concentrations observed are generally either due to over-pumping that is leading to the forthcoming of deeper saline waters or the geological sedimentary formations of the North of Lebanon, thus affecting the quality of regional waters.

To confirm the source of high levels observed in the physical and chemical characterization, factors like lithological characteristics of the aquifers, retention time, and flow pattern of groundwater flow are assessed to better identify the dominant water type through the aquifer. As such, values obtained from sampling were plotted in the Wilcox method. It aims to observe the majority of water samples trend. Wilcox is based on a combination of two methods: SAR and electrical conductivity, thus allowing to generally draw major affinities. In Figure 2, the groundwater samples were seen to have low saline content, thus highlighting the beginning of contamination.

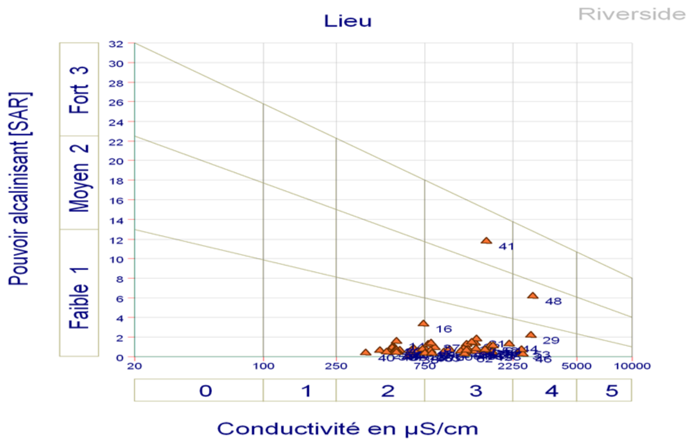

*Figure 2.**Wilcox Diagram for Dry Season (PhreeqC)**.*

Moreover, PhreeqC software linked the chemical to geological parameters to interpret the source of the ions present in the groundwater. Thereby, the Piper diagrams obtained in this study have indicated three major poles corresponding to traces of sulfated magnesium and sodium sulfate, hyper chlorinated calcium, and hyper sulfated and calcium samples, which is probably due to the dissolution of evaporates.

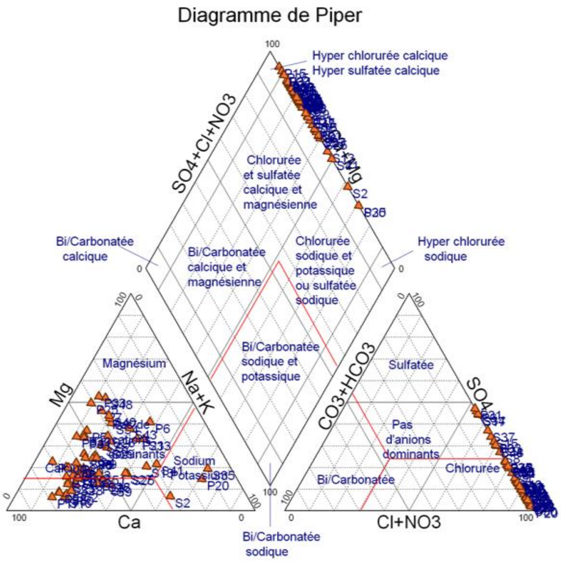

*Figure 3. **Piper Diagram***

3.2 Factors affecting groundwater chemistry

The Saturation index (SI) will reinforce the sources of the ions and state if it is of a naturogenic or anthropogenic resource. The Saturation index SI will tend to dissolve or precipitate a particular mineral. If the value is negative, this means that the mineral is dissolved therefore the chemicals will seep from the rock to the water, however, if SI is positive, this indicates that the minerals will precipitate and therefore the chemicals will percolate from the water to the rock. A value of zero is seen when the water and mineral are at chemical equilibrium with each other. The saturation index (SI) is calculated by comparing the chemical activities of the dissolved ions of the mineral (ion activity product, IAP) with their solubility product (K_{sp}). As such, SI follows the following equation: $SI = \log (IAP/K_{sp})$

The facial distribution of the 58 samples represented in Figure 3 indicated the following:

- The chemical facials predominant are chlorinated and sulfated calcium and magnesium heavily charged with Nitrate.
- 04 samples faced chemically high sulfated – potassium concentrations
- 04 samples facials are chemically highly chlorinated and sulfated with calcium samples
- 2 samples facials are sodium chlorinated chemical samples

Generally, the origin of the dissolved salts in groundwater is due to the migrations of the minerals in the enclosing rock reservoir. Thus giving a general idea of the good correlation between the soil composition and the chemical elements in the groundwater. The dissipations observed with high levels of chlorines indicate the beginning of a clear seawater intrusion.

4. RESULTS AND DISCUSSION

All sedimentary rocks in the Tripoli region and its surrounding area predominately sedimentary with Calcium Carbonate $CaCO_3$ as the main component of these rocks and additional minerals ($MgCO_3$; SiO_2) depending on the layer in which the groundwater is available. Throughout this work, the chemical composition of the sampled groundwater varied mainly because of the complex factors that change with depth and the geographic distance from the shoreline. It was seen that from the dry and wet season sampling, the groundwater quality was affected by the following: composition and solubility of rock materials in the soil or aquifer, water temperature, partial pressure of carbon dioxide, acid-base reactions, oxidation-reduction reactions, loss or gain of constituents as water percolates through clay layers, distance from the sea (seawater intrusion) and mixing of groundwater from adjacent strata. The extent of each effect will be determined in part by the residence time of the water within the different subsurface environments. The high sodium and chloride levels can result from the upward movement of saltwater from deeper bedrock in) areas of high pumping. Besides, the most important cation exchange processes were seen to be the sodium-calcium, sodium-magnesium, potassium-calcium, and potassium-magnesium. Thus emphasizing that the North Miocene groundwater contains detectable concentrations of chemicals that are related to three majors aspects: geological settings, leaching of industrial and agricultural chemicals or decaying organic matter such as animal waste or sewage, and last but not least the development of seawater intrusion on the coastline of Tripoli area.

5. CONCLUSIONS & RECOMMENDATIONS

This study tackled major concerns that affect society every day in Lebanon and the world. Groundwater in the studied area is considered as the main source of potable water. By analyzing the hydrochemical and hydrophysical sets of results obtained from the seasonal variations, a clear delineation relating anthropogenic factors (such as agricultural activities and over-pumping leading to seawater intrusion) and naturogenic factor such as the geologic was established. The study focused on the use of elaborated and developed software's as tools to support decisions and projecting for the better management of water, restoring the quality of water, and enhancing the social and economic development of the region.

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