



# Assessment of Seawater Intrusion in a Coastline City Using GIS (Tripoli Lebanon)

Marianne Saba, Amal Iaaly, and Najib Gerges

## Abstract

This paper evaluates the impact of seawater intrusion on the Miocene aquifer that covers the area of Tripoli. The existing aquifer, located under the city of Tripoli, spanning from Abou Samra hill toward the Mina shoreline, suffered a severe reduction of the stored water volume due to the unplanned urban expansion, the increase in water demand, the random drilling of wells and the untreated wastewater that spills exactly in front of Tripoli coastline. All these factors combined led to the saline water intrusion due to the reverse injection flow from the sea toward lower emptied cavities onshore. This has in turn led to a severe deterioration in the water quality of Tripoli city. To assess the current situation, a field survey was conducted to collect and gather underground water samples from various sites across the city and its surroundings in an attempt to analyze the Miocene aquifer of the North Governorate. The Geographic Information System was used as the main tool to both investigate and visualize the hydrophysical, hydrochemical, microbial onshore and water levels of the collected samples in the studied region. The maps generated using GIS constituted visual aids to support decisions regarding the sustainable development and management of groundwater.

## Keywords

GIS • Seawater intrusion • Hydrochemical • Hydrophysical • Pumping

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## 1 Introduction

Lebanon is known for the availability of abundant surface and groundwater resources. However, the Lebanese citizens are suffering from a severe shortage of water within their households. The lack of good management makes the exploitation of water less feasible due to the shortage of public water networks and wells. The shortage in water is due, primarily, to the lack of appropriate legislation regarding the management of water resources, and, secondly, to physical and geological factors, such as overexploitation, climate change and the acute geologic setting (Metni et al. 2004). This resulted in a number of problems in groundwater, namely: quality deterioration, alteration of springs and groundwater runways, variation of water level, flushing of groundwater into the sea, and saltwater intrusion.

Hence, the aim of this research is to assess the groundwater quality, i.e., the hydrochemical, hydrophysical, and microbial parameters of Tripoli over a period of two years. Results were assessed using the Geographic Information System (GIS) due to its visual capabilities in presenting the extent of pollution in the studied region (Shaaban 2010; Nafyad and Shankar 2018; Muzenda et al. 2019).

## 2 Method

The study is based on four sampling campaigns that gathered samples from 46 locations during various wet and dry seasons. Several criteria were taken into account to ensure the proper collection of the samples, such as the conformity to rigid quality control standards; the lookup for the appropriate casing for the piezometric study; the identification of all the parameters that need to be analyzed and associated logistics (number and type of containers, coolers, etc.); the selection of sampling sites using aerial photos, maps, and geographical locations; and last but not least the setting of sampling

cycles both static and dynamic for water leveling (Nafyad and Shankar 2018; Muzenda et al. 2019).

Thirty-one wells were selected as shown in Fig. 1 in both public and private locations. The depth of these wells varies from 5 to 500 m, according to the North Lebanese Water Establishment (NLWE). The studied groundwater watershed covers the miocene aquifer, the depth of the wells varies quite considerably according to the location. The studied wells that are close to the seashore have a depth between 5 and 7 m below the sea level, whereas the wells located further up in the hills of Abou Samra and the upper areas near Sir Al Daniye have a groundwater level as deep as 300–550 m below mean sea level. The physical parameters were tested on-site by the use of HORIBA apparatus. The test collected the following parameters: pH, temperature, conductivity, total dissolved solids (TDS), and dissolved oxygen (DO). On the other hand, the hydrochemical analysis required carrying the sampled water in 250–500 mL plastic polyethylene bottles, while sterilized cups were used for the microbial study.

The Microbiological Tests: *E. coli*, Coliforms, and *Salmonella* were measured using the membrane-filter method. As for the chemical parameters, the water quality was tested in the environmental laboratory using an ion chromatography (IC). It is commonly used for the analysis of common

anions and cations. In our case, anions such as fluoride, phosphate, bromide, chloride, nitrite, nitrate, and sulfate were detected. As for cations, the IC covered sodium, potassium, calcium, magnesium, ammonium, sodium, and lithium. The samples were injected into the ion chromatograph (Dionex ICS-2000 Ion Chromatography System (ICS-2000)) where samples underwent ion analyses using suppressed conductivity detection. The water samples were injected to the IC with the help of disposable syringes (1 cc) and syringe filters (0.45  $\mu$ m).

All the data collected were then entered into GIS, and a spatial interpolation using Kriging was performed. The Universal Kriging interpolation is a spatial interpolation method that forecasts the values of data in areas that are not sampled.

### 3 Results and Discussion

The analyses of the collective hydrochemical, physical and microbial water testing and water leveling parameters were schemed using GIS. The conception of these maps allowed the visualization of the sampling campaign results and aimed at verifying the interrelation between water depths and saline water intrusion. For physical testing, a paramount amount of



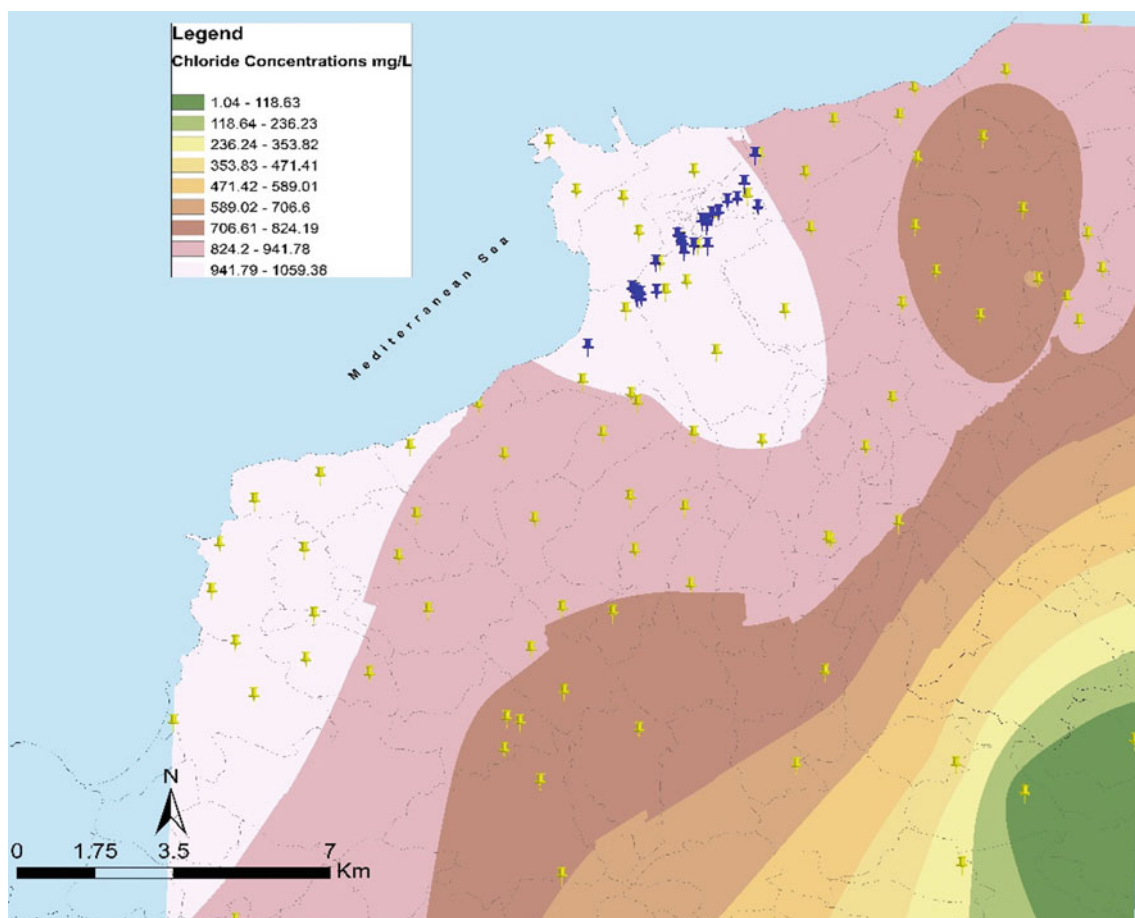
**Fig. 1** Public (blue) and private wells (yellow) sampled in Tripoli (Color figure online)

salinization was detected in the seashore area of Tripoli. In Tripoli, the aquifer extends from the area surrounding Tripoli, Koura, and Zgharta until it reaches the offshore of Tripoli. Its thickness ranges between 100 and 200 m. The aquifer consists of reef limestone, marly limestone, limestone, and horizons of marl and sandy marl. Depending on the nature of lithology, the intensity of the fracturing and karst development and dissolution activity (Bakalowicz 2015), the values of transmissivity varied from 5 to 5460 m<sup>2</sup>/day with a geometric mean of 55 m<sup>2</sup>/day. With the overgrowth of the population, excessive pumping of groundwater has been one of the major issues that are aggravating this situation in the North of Lebanon, with an obvious reduction of the weight of the overlying freshwater which, in turn, will decrease or even reverse the seaward flow so that seawater moves landward into the aquifer. This process is known as seawater intrusion.

Regarding, the hydrochemical and microbial analysis, some parameters exceeded the WHO drinking standards as well as the Lebanese standards. Many factors could be behind the current situation. To begin, the Northern Lebanese region is famous for its agricultural activities, such as

olive culture and orange plantations. Taking into consideration the hard geological sedimentary formation that is quite dominant in this area, in addition to factors such as irrigation and uncontrolled continuous use of fertilizers and pesticides, the salinity of the soil keeps on increasing with time, thereby explaining the high salinity concentrations seen in the 31 studied wells, with TDS values ranging from 500 to 1500 ppm.

The hydrochemical parameters highlighted high values when compared to the standards. One of the most prominent parameters was chloride, stressing the extent of seawater intrusion. Chloride concentrations in groundwater are associated with the presence of salts originating from many sources. Chloride is one of the major constituents of seawater. It is chemically stable and moves at about the same rate as intruding seawater, thus alerting to one of the most important indicators of seawater intrusion into an aquifer. In this aquifer, chloride concentrations are studied in Fig. 2. According to the World Health Organization (WHO) and Lebanese Standards, the Maximum Contaminant Level (MCL) of Chloride is 25 mg/L. In the case of the Tripoli aquifer, as seen in Fig. 2, the values exceeded the acceptable



**Fig. 2** Chloride concentration in Tripoli



standard and reached values higher than 100 mg per liter (mg/L); thereby, the higher Cl content in the areas that are remote from the sea (Bakalowicz 2015) indicates seawater intrusion.

As for the microbial testing realized during the four different sampling campaigns, the groundwater contained a wide range of microbial groups available in surface water and soils. These microbes include bacteria, fungi, and protozoa and are representative of the most physiological types, i.e., *E. coli*, Coliforms, and *Salmonella*. Most of the time, these pathogenic bacteria are from domestic, agricultural and other anthropogenic activities, namely untreated wastewater (Guemaz et al. 2020; Loucif et al. 2020). The lack of the working wastewater treatment plant is leading to untreated sewage being discharged into the Mediterranean Sea, thus, leading, by a reverse process, to the infiltration of this untreated water into the aquifer. This was obvious in the samples taken onshore; *E. coli*, Coliforms, and *Salmonella* were present in all the samples.

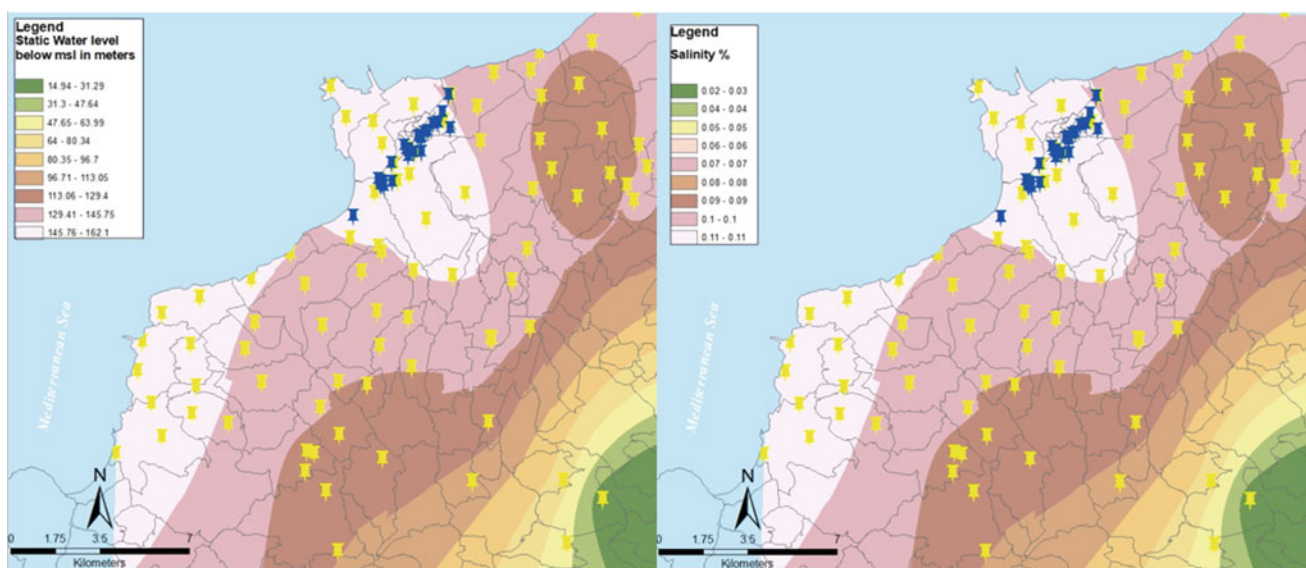
When assessing the static and dynamic levels offshore and in Tripoli, it was seen that an irrational over-pumping of the groundwater has been occurring due to overpopulation which in turn led to an increase in water demand. This implies that the rate of water abstraction is higher than the rate of recharge, leading to groundwater mining (Chami et al. 2009; Khadra et al. 2017).

Through the sampling campaigns, the statistical data resulting from the interpolation done by the GIS software also showed trends of consistently higher concentrations of minerals near the shoreline or consistent increases of concentrations with depth over time. As for the water level study, Fig. 3 displays the area with a general flow pattern

from the boundaries and areas of recharge toward 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 for water, and therefore, the high density of wells. These values observed below the seawater head are serious as they are indicators of seawater intrusion. This phenomenon will result in lowering the hydraulic conductivity, especially in a karstic aquifer, and thereby, lowering the productivity of the aquifer (Bakalowicz 2015). 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 the Tripoli corridor area than in the rest of the aquifer. This movement which is seen in Fig. 3 suggests that the salinity values are higher in the Tripoli area than in the rest of the aquifer.

## 4 Conclusions

In the Tripoli area, the total annual recharge of the aquifer is 71 million m<sup>3</sup>, with a main natural outflow to the Mediterranean Sea and a withdrawal of groundwater from pumping wells. The actual outflow to the sea is 60.9 million m<sup>3</sup>/year, and the discharge by the present pumping wells is estimated at 13.9 million m<sup>3</sup>/year, thus leading to a total discharge from the aquifer of 74.8 million m<sup>3</sup>/year. The overall assessment of the total recharge and discharge rates revealed that the aquifer is currently being mined at an annual rate of 3.8 million m<sup>3</sup>. In addition to the permanent loss of groundwater from storage, the mining of groundwater makes the aquifer in the Tripoli area vulnerable to land subsidence and contamination by seawater intrusion. Based on the



**Fig. 3** Static water level versus salinity impact in Tripoli

hydrochemical, hydrophysical, and bacteriological studies accomplished for the 31 studied wells in the area, the groundwater was found to be clearly affected by pollution, mostly due to salinization and agricultural activities, thus indicating seawater intrusion which resulted from an uncontrolled pumping of wells. The integration of the numerical model by the use of GIS gave a clearer view of the condition of the aquifer.

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