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Nasser Farhat
The Lebanese Center for Water and Environment, Lebanon

Walid Sleiman
Ph.D. Candidate, Azad University of Iran, Iran

Corresponding Author:
Nasser Farhat
The Lebanese Center for Water and Environment, Lebanon

Potential natural obstacles to groundwater engineering

Nasser Farhat and Walid Sleiman

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Abstract

Countries have constantly experienced problems with water resources: much, little, polluted, variable. Over generations, humankind has tried to manage these water resources problems by intervening in its natural courses through redistribution, storage, and regulation. Management and exploitation resulted in systematic knowledge of the behavior of surface and underground water. The center of importance subsequently shifted to groundwater at the beginning of the 20th century, notably because of its importance for the development of semi-arid areas, like the study area, to accommodate their requirements, particularly in connection with the search for unpolluted drinking water for the growing villages, under controlled conditions. In this respect, the groundwater studies performed earlier in the study area revolved around very simplistic conceptualizations for estimated the groundwater volume far away from the obstacles that may face these works, especially to understanding and modeling subsurface flow and transport. In this study, some values of the mathematical equations used to model subsurface flow and transport have been highlighted, which are subject to uncertainty in determining their actual values, hindering groundwater engineering.

Keywords: Bint Jbeil zone, groundwater recharge, precipitation, aquifer, geological layers

Introduction

The recent drought in the eastern Mediterranean (Syria, Lebanon...), from 1998 to 2012, is about 98 percent drier than the driest period of the past 500 years. (Cook *et al*. 2016) [2].

Despite advances in the ability to model the subsurface, modern models are full of uncertainty in input data, and hence, the output is uncertain (Haverkamp *et al*., 2006) [11]. Therefore, this study is to get some model investigates of those natural obstacles that prevented reaching more certain results in groundwater engineering.

Many natural factors affect water resources and groundwater engineering. As the region's topography is of medium-altitude, with sharp edges and strong slopes, it negatively or positively becomes a high impact factor. Tectonic movements in the eastern basin of the Mediterranean Sea and the common area between the continents of Asia and Africa left their mark in the study area; this led to the geological layers' exposure to significant events that deepened and complicated the problem even more.

The region's climate and the changes that occurred through climate change, particularly warming, are indicators of future trends. Future predictions of precipitation, temperature, and evapotranspiration are uncertain. Land cover plays an essential role in controlling the groundwater infiltration and recharge into the ground.

The geological layers in the region are potential aquifers, but the stratigraphy may limit the recharge gained from the quantities of water infiltrating these layers for passing and storing water, but their depth and location will judge whether their stocks can be easily calculated and engineered.

Many other factors must study and talk about because of their direct or indirect impact on groundwater engineering in the study area.

Concepts

Natural obstacles mean those that humans have no part in; The natural factors here are those factors that were produced and continued by the emergence of the earth. That is, what is related to the lithosphere, hydrosphere, atmosphere, and biosphere. This research determines the natural factors by specialty topography, geology, hydrogeology, and climate.

Groundwater engineering is how to model water flow both in the unsaturated and saturated zones, set its movement and position, and cover its extraction after studying the physical and chemical properties of the rock layers and the external factors exposed to them, and what resulted from them.

Location of the study area

A study area is an administrative unit in southern Lebanon called Bint Jbeil, located between longitudes 35 ° 18′ 05 ″ and 35 ° 30′ 25 ″ east of the Greenwich line and between latitudes 33 ° 03 ′ 18 ″ and 33 ° 18′ 55 ″ north of the equator Fig. 1. Thus, it is close to the shore of the Mediterranean on the western side of it. As is the eastern mountain range of Lebanon abutting it in the northeast. So it is located in the middle between the sea and the high mountain ranges. It has an area of 270 km^2.

Source: GIS Services online

Fig 1: location of the study area in the region

Materials and Methods

Data Availability

The digitals data for the digital maps are provided by the National Council for Scientific Research, Lebanon (CNRS-L), data of the layers of geologic, rainfall, aquifers, faults, land cover, and elevation. Some of these data were retrieved by remote sensing.

Geographic Information Systems (GIS) have become essential tools in efficiently solving many problems, including groundwater. This study has significantly benefited from GIS to analyze spatial, quantitative data and digital images. Moreover, we obtained tangible results in showing the characteristics of natural factors through this number of maps and some data related to temperatures and precipitation, which we got from the Lebanon Climate Atlas.

The data relating to the groundwater depth map or the water table, obtained through the data of tens of wells dug in the study area, then we used the ArcMap program to get and analyze the digital map.

This text has many equations for analyzing and modeling subsurface flow and transport without using them calculably because the goal was to determine the factor that cannot be controlled and calculated in every mathematical equation mentioned due to the nature of the study area. There are mathematical equations not mentioned because they are old and known only by their names, like the water budget equation.

Results and Discussion

1. The relation of topography to groundwater resources.

The study area is considered a plateau region with distinction, with an average elevation of 700 meters above sea level and its highest peak at 944 meters Fig. 2. Some valleys and base hills are interspersed with oak forests, While the tops of the hills are almost devoid of trees, and spread some fields on their convex tops are suitable for rain-fed agriculture due to the lack of water.

The region lacks surface water like rivers and lakes, and there are seasonal springs that feed some streams and streams in the valleys, which drain quickly with the end of the rainy season. Karst aquifers share both groundwater and surface water properties, leading to the concept of groundwater basins with well-defined boundaries that do not necessarily coincide with overlying surface water basins. Carbonates rock terrain that makes up the watersheds of the study area led to the existence of three main components to the catchment system: internal runoff, allogenic recharge, and dispersed infiltration.

The influences of all the natural factors mentioned determine the substantial differences in the formation of groundwater recharge. Moreover, this leads to substantial heterogeneity of the mean annual recharge volumes in a river basin area Grinevskii (2014) [10].

The Reliefs in the area make groundwater engineering more complicated; this is clear through some of these equations Eqs (1), (2), (3).

The Relief gradient is the ratio of basin relief to basin length. While low values are characteristic of Pedi plains and valleys, high values are characteristic of hilly regions, Eq (1) Pike and Wilson (1971) [24].

$$Rg = \frac{\text{Mean elevation} - \text{Mini elevation}}{\text{Maxi elevation} - \text{Mini elevation}} \qquad (1)$$

Where Rg is the Relief gradient, Maxi, Mini, Mean for elevation above sea level.

Relief Ratio (Rh): A unitless measure of the overall gradient across a basin. Calculated by dividing the relief of a basin by its length. Eq (2) Schumm (1963) [30].

$$Rr = \Delta H / Lb \qquad (2)$$

Where Rr is the Relief ratio, ΔH difference between the hauteur, Lb is the length of a straight line parallel to the stream.

Elongation ratio (Re) value varies from 0 (in highly elongated shape) to unity, i.e., 1.0 (in a circular shape), which may be defined as the ratio of the diameter of a circle of the same area as the basin to the maximum basin length. Eq (3) Chorley *et al.* (1984) [3].

$$Er = \frac{2}{Lb} x \; (A/\pi)\; 0.5 \qquad (3)$$

Where Er is the Elongation ratio, A is the area of the watershed.

The elevation Fig. 2 and slope maps Fig. 3 show us that the plateau gradually decreases towards the West and the north; these elevations are insufficient to form a barrier to the south-westerly winds laden with rain.

The foothills of these plateaus are characterized by steep slopes (between 15 and 60 degrees) Fig. 3, to form deep valleys with semi-vertical ridges. This steep slope negatively affected runoff, which forms strong torrents in the belly of valleys in winter, and also negatively affected groundwater so that the land could not store this precipitation.

The lack of high mountain ranges in the region has hurt rainfall amounts because the mountain ranges, if are found, often lead to relief rain.

In those equations Eqs (1), (2), (3), it was found that the engineering of the watersheds enhanced the speed of the runoff, and it complicated the process of recharging the groundwater. Therefore, the region's topography, through the barren plateaus, the steep slopes of its foothills, and the absence of high mountains, has been an obstacle to increasing the region's rainfall rate. Thus, it led to fluctuation and irregularity in groundwater recharge, which complicates calculating annual recharge.

2. Tectonic and geological status and their effective role in groundwater resources: Fig 4: A geological section from east to west showing the fractures and the inclination of the geological layers in addition to the Bint Jbeil syncline.Tectonic movements affected the Bint Jbeil region through the pressures resulting from the emergence of the Red Sea after the appearance of the great Afro-Asian Rift Valley. These tectonic forces led to Major faults that large dimensions in terms of lateral (i.e., several kilometers) and vertical displacement (i.e., several hundreds of meters) and the appearance of fractured and collapsed zones along with the extension of the significant faults result from the fracturing of limestone rocks from Cretaceous and Tertiary periods (Shaban 2013) [33].

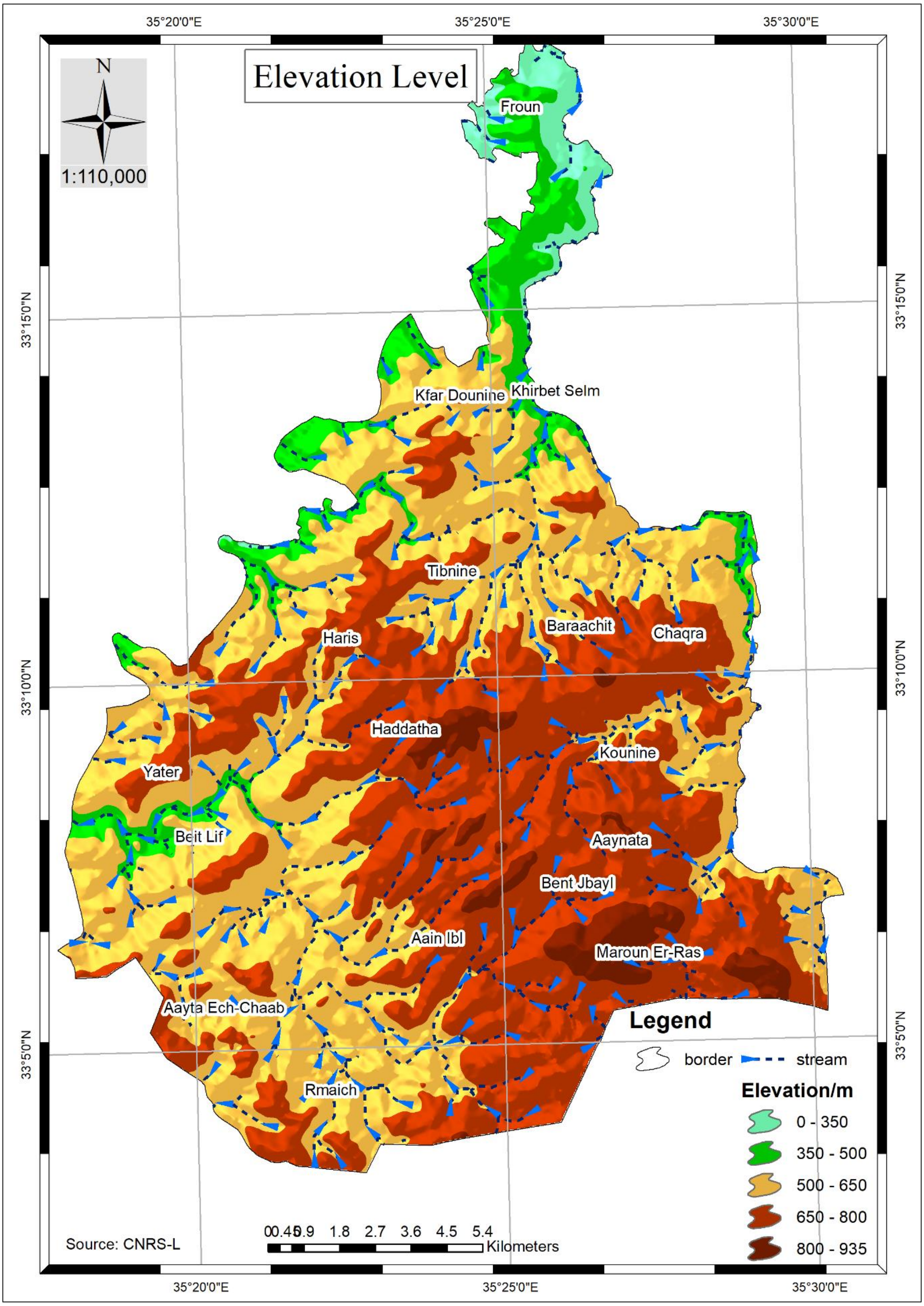


Fig 2: map of the elevation level in the study area

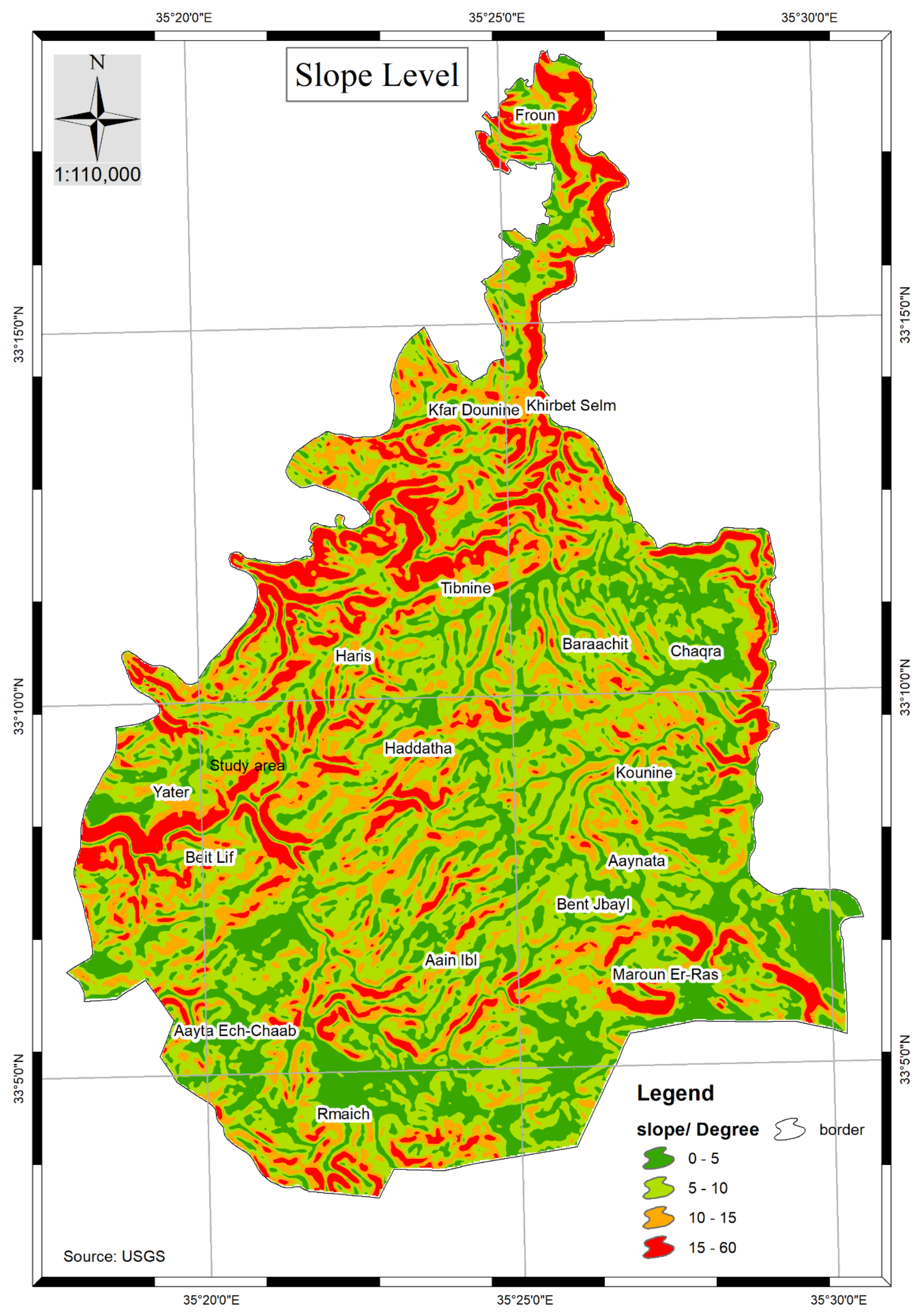
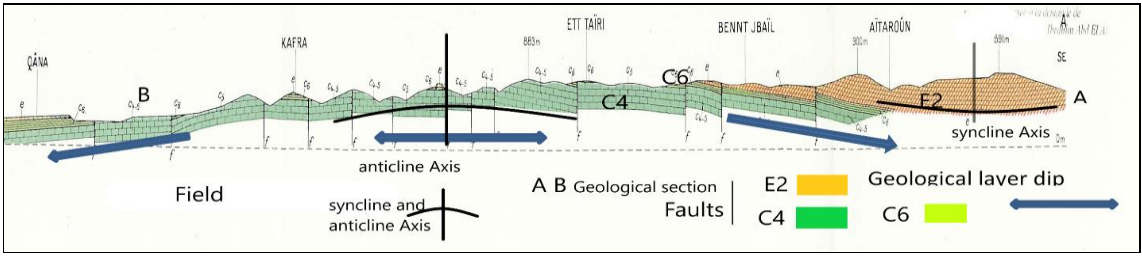


Fig 3: map of the slope level in the study area



Major faults are always evident and easy to recognize in the study area as this resulted in several transverse fractures and longitudinal folds in the study area, including Bint Jbeil's syncline and Jabal Amel's anticline which are adjacent to each other. Often, fractures and folds aid in forming underground reservoirs after precipitation water infiltrates into the ground, where fractures play a positive role in accelerating the passage of this water to the depths. However, it can play a negative role in a relatively small geographical area if the dip of the geological layers resulting from tectonic movements leads to water infiltration outside the borders or into the sea (Fig 4. This, in turn, will not allow us to estimate the quantities of underground water infiltrating outside the aquifers existing in the region, and thus the inability to develop an equation through which we can engineer these aquifers.

2.1 Inclination and fold

- **Bint Jbeil Syncline:** This Inclination Fig 4 Fig. 5 would not exist without the presence of soft and soft rock layers that tectonic movements cannot break (Senonian C6, and Albian C3), which allowed it to form rock ripples that contributed to the creation of water reservoirs inside them because these soft rock layers are impermeable to water. Moreover, due to the high horizontal pressure on both sides, the rock masses decreased in the middle and formed a concave fold, or what we call a Syncline.

  This syncline takes a rectangular form from south to north; Eocene rocks (E2) appear in the center on its axis, and the rocks of the Cretaceous appear on the sides (C4). axis syncline is tilted from north to south, while its sides are uneven, tending to the east, which leads to the infiltration of groundwater into another area
- **The Jabal Amel anticline:** Alongside the concave fold Fig 4 Fig. 5 and the continuation of the ripples of the rock layers, a rock mass also rose due to the high horizontal pressure on both sides of the rocky layers, which we called the convex fold.

  This convex complements concave Bint Jbeil on its west side and begins to descend towards the sea, and contributes to the transfer of groundwater to the sea so that the springs burst several kilometers away from the shore.

2.2. Faults

Faults and fractures play a positive role in the groundwater flow and storage systems. However, the existing rock deformations often play a negative role in transit water from the coastal aquifers into the sea (Shaban 2019) [34]. In the study area, a cluster of fractures most of them are of a type thrust fault - a dip-slip fault in which the upper block, above the fault plane, moves up and over the lower block, and there are also secondary faults that appear semi-parallel, this type of faulting is common in areas of compression such as the study area.

The general direction of these faults is north-east-south-west. Moreover, there are occasional minor fractures in an east-west direction.

These fractures increase size cracks resulting from the lateral pressures that accompany the fracture process and facilitate the work of dissolution depending on the structure of the rock. It is in the study area that affected the structural structure and led to a change in the inclination of the rock layers, some of them being raised and lowered for others. It also contributed to the penetration rate of water into the soil and facilitated the process of Karstification. However, its location to the left of the axis of the Jabal Amel anticline led to rapid water infiltration towards the Mediterranean Sea.

Because these fractures reach deep underground layers, that is, more than four hundred meters below the surface of the ground, and the presence of an impermeable rocky stratum above it, these fractures do not find outlets for them except at a few miles from the shore, this leakage of water quickly became towards the sea.

Due to the inability to determine the size of the subterranean fractures and the resulting corridors and galleries due to the karstification process in limestone, in this case, Darcy's law (1856) [5] of laminar flow Eq. (4) becomes invalid, and the results are in a state of uncertainty as we shall see by explaining this formula.

$$R_e = \rho v d/\mu \tag{4}$$

where R_e = Reynold's number, ρ is water density, v is average pore velocity, d is average pore diameter, and μ is the dynamic viscosity of water at a given temperature.

The problem is in " d " and " v " because their actual value cannot be determined. So that a critical variable occurred to them, namely the significant gaps left by the fractures, in addition to the karst processes, these variables cannot be computed, and therefore the formula becomes more uncertain. Despite these uncertainties, hydrogeologists generally accept the assumption of laminar flow throughout a granular porous media with $R_e < 100$ for the sake of simplifying the mathematics of flow (Leap and Belmonte 1992) [19].

Under the inability to estimate the volume of groundwater infiltrating through these channels, the geometry of groundwater resources in quantitative terms will become more complex, adding a natural obstacle new to this task.

2.3 Stratigraphic distribution

The Cenomanian layer (C_4) and the Eocene layer (E_2) are separated by the Senonian dielectric layer (C_6), in addition to a small area for the layers (C_{4_5}) and (M), and a small area of the quaternary geological formation (Q) Fig. 5. We will go through these layers in the following table.

The Cenomanian layer (C4) occupies about 57% of the study area, and that the Eocene (E2) represents about 37%, showing in Table 1, based on the study area's geological map, which means these two calcareous layers control 95% of the area. These limestone formations have a great permeability capacity (30-40%) (Girard *et al*. 2004) [9] because of their physical properties, represented firstly by the presence of small voids inside the rock and between its grains, which allows it to retain the quantities of water inside it. Moreover, the presence of a connection between these spaces through tiny corridors allows the water to pass through them to form vast stores of fresh water inside the depths of the ground, which is what we call aquifers.

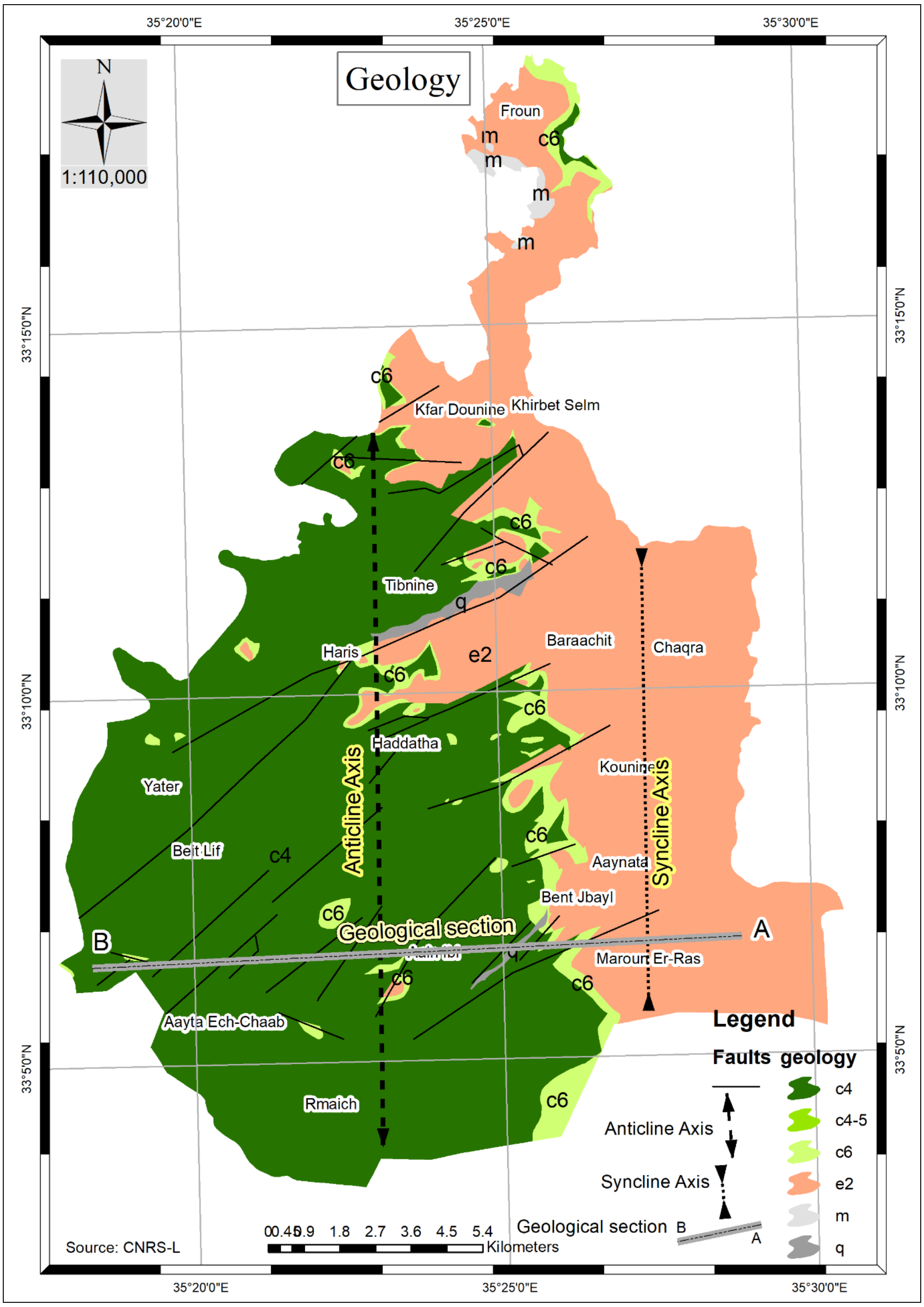


Fig 5: map of geological layers in the study area

Table 1: The geological layers

Time	age	code	the nature of rocks	Area / km^2	% of total area	Permeability %
secondary	Cretaceous	C4	Dolomitic limestone / limestone	154	57,1	34-41
		C4-5	Limestone / Marl Limestone	0,35	0,1	30-41
		C6	Marl	13,3	4,92	2-3
tertiary	Paleogene	E2	Marl / limestone	99,7	36,9	20-35
	Neogene	M	agglomerates of Marl and limestone	1	0,37	9-20
quaternary		Q	silt	1,65	0,61	5-10
Total				270	100	

This factor is positive if we look at it without knowing the state of these rock layers. As for the inclination layers towards the South and the West, the water stored inside these layers will infiltrate outside and cannot be used only in small quantities.

2.4 Characteristics of the most important rock layers

Cenomanian layer (C4): are the most widespread and vital, it is a thickness 700-1000 M, and can take advantage of economically considerably, in terms of its ability to capacity the water infiltrating it, and it is safe from pollution and healthy. These rocks are distributed on the west side of the study area with an area of 154 km^2 of the general area, and it is divided into:

(C4c): These are dense clusters of dolomitic rocks.

(C4b): limestone rocks interspersed with a few sections of the Marne in the middle.

(C4a): gray and white limestone below, ending in Cretaceous base groups.

These layers are heavily cracked, broken, and karstic.

Senonian layer (C6): The Senonian bedrock usually has a very low permeability so that the infiltrating water can reach the subsurface only by operating laterally along the crevices and trenches until it reaches an open fracture or shaft descending into an aquifer. Because it is a marly limestone, often containing sections of flint, it is considered the ceiling of the Cretaceous period. Its remains are spread in low and isolated areas, and according to the geological map, Fig. 5 prepared by the Lebanese National Council for Scientific Research (CNRS-L), the thickness of this layer is approximately 150 meters. It occupies approximately 4.9% of the general surface area.

This layer plays a prominent role in the isolation process that it does, as it is not possible for water to cross it to the depths, it also works to pressure the water below it and prevents it from ascending to the top, and this helps in the presence of artesian wells in some areas adjacent to the study area.

Eocene layer (E2): This layer is on the east side of the study area over an area of approximately 100 km^2. The rocks in this layer are marl and limestone with flint, dolomitic, and soft limestone, their thickness in the study area, is about 250 meters (UNDP 1970) [37].

The geological formations located in the study area are considered suitable for storing vast amounts of water, but the inclination of its layers and the fractures and folds produced by the tectonic action has led to the loss of its good structural characteristic in water storage. In addition, according to the geological map Fig. 5 prepared by the Lebanese National Council for Scientific Research (CNRS-L), these limestone rocks, which control 95% of the general surface area, create favorable conditions for the karstification process within their rocks.

Just as karst has a positive role in storing precipitation water inside rock layers due to the cracks and paths created by the water, it has a negative role in contributing to the speed of d flow of water within the earth (Zaatiti 1983).

In the study area, dip and strike towards in multiple directions contributed to the speed of flow resulting from the Karstification to weaken the geological layers of their content. Of water and the isolation of these geological formations from any adjacent formation caused them to lose any external supply of groundwater due to their stratigraphic distribution.

Here, the tectonic movements and the geological structure played a negative role in adjusting the estimates of potential groundwater within it due to those tectonic and geological conditions that governed the location of the study area and formed a natural obstacle to engineering water resources.

3. Groundwater resources are related to the region's climate:

The availability of water at sustainable quality and quantity is threatened by many factors, of which climate plays a significant role (Kumar and Singh 2015) [18]. The situation of Lebanon on the eastern basin of the Mediterranean Sea made it under the influence of the Mediterranean climate, considered a climate of transition between cold temperate regions and desert regions.

In winter, the study area is exposed to moderate climatic influences. It becomes under the direct influence of the meeting of rainy westerly winds with cold air masses, which leads to the emergence of depressions, which causes instability that leads to precipitation and snow accumulation on high mountains (Traboulsi 2014) [36].

In summer, the region is under the influence of high subtropical pressure, which results in a stable state, leading to a rise in temperatures. This prevailing climate allowed two clear seasons, the rainy and relatively cold season extending from December to March and the dry and hot season extending from June to September.

We need to study the climate in this area of our research, which affects water resources, especially groundwater, because, in Lebanon, such replenishment is being provided by precipitation (Arkadan 2008) [1] as surface water is almost non-existent in the region. Perhaps the most influential climatic factors are temperature and precipitation, whether rain, snow, or otherwise. From the quality and amount of precipitation, we determine the effect on the hydrological system of the region.

3.1. The effect of temperature on water storage

Temperature is one of the essential climatic elements and plays a vital role in water balance, other climatic elements, and geomorphological processes (Panizza 2007) [23]. Average temperatures in the Middle East increase by 1.5 degrees Celsius (IPCC 2018) [13]. These are the results of global warming (Flageollet 2012) [8]. The Middle East region will suffer from a 17% drop in available freshwater when temperatures rise by 2 degrees Celsius (Schleussner *et al*., 2016) [29].

Climate data recorded in Lebanon indicates an increase in annual temperatures of about 2.3 degrees Celsius from 1975 to 2018 Fig. 6. This issue has negatively affected the region's water resources, especially it lacks surface water.

Topography has played an essential role in influencing temperatures rates which drop at a rate of one degree Celsius for every one hundred meters of height above sea level if the air is dry and at a rate of one half a degree Celsius if the air is humid, an average of 0.65 degree Celsius per hundred meters of elevation, Plassard (1981) [25] Tayara (1998) [35]. The Khamaseen wind blows from the Egyptian desert, which heads east towards Jordan and then turns in the northwest direction and then passes from the south of Syria and enters the study area from its eastern side. These winds are hot, dry, and active, which leads to higher temperatures above their seasonal averages, and as a result, the amounts of water evaporation from the soil increase, as it has been found that the rates of evaporation increase with a decrease in relative humidity during these dry winds. (Farhat 2018) [7]. The average volume of evaporation in this region (private weather station) is estimated at 43 - 51% of the volume of precipitation (Farhat 2017) [41]. This percentage of evaporation has a significant and negative impact on the region's water resources, particularly groundwater. As the high daily evaporation rates lead to the impoverishment of the soil and the upper rocky layer of water, become the soil is dry, water will not flow any significant distance until the water content in the soil is sufficient, and the pressure head becomes less harmful. The specific discharge measured as this equation Cushman, Tartakovsky (2016) [4] Eq. (5)

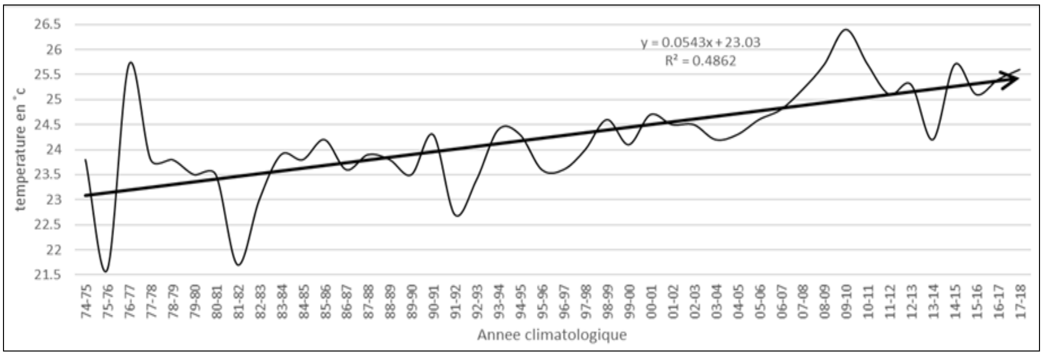


Fig 6: Average annual temperature trend in Lebanon

$$q = -K(\theta)\, \partial h/\partial l \qquad (5)$$

Where q is the discharge, θ is the water content of the soil (θ volumetric soil water content (m3/m3).

Then the maximum infiltration capacity is not reached because the unsaturated hydraulic conductivity is not at its maximum Eq. (5). when the daily volume of precipitation is low, the rock layers do not benefit from these precipitations because of their rapid evaporation. We conclude from the above that temperatures in the region are a natural obstacle to the facilitate passage of the amounts of precipitation to the underground layers, and things tend to be more dangerous with the advancement of time due to climate change because the annual rainfall amounts are expected to decrease, in addition to the decrease in the rainy season in the eastern Mediterranean basin.

3.2 Precipitation cannot meet the needs

The amount of rainfall in the study area varies from region to region, depending on its geographic location and relief structure. It records its lowest level (less than 200 mm) in the Northeast region (Khawlie 2001) [15] (which is approximately 100 km from the study area). While the volume of precipitation increases in the mountain range of West Lebanon (which is approximately 60 km from the study area) to over 1800 mm per year, This is due to the stopping of this chain in the face of humid westerly winds, while these quantities decrease to 750 mm \year in the southern regions where the study area is located in general Fig. 7. This difference in rainfall amounts between Lebanese regions is due to the varied topography of Lebanon and the climate changes occurring in the Mediterranean basin because the region experiences rainy and dry years. This fluctuation in rainfall amounts in one way or another threatens the underground water reservoirs and makes the agricultural sector vulnerable to risks (Farhat 2014) [42], led to the prevalence of low productivity rain-fed crops. They contribute to promoting the excessive extraction of groundwater. The water table slowly falls when we overuse the aquifers, necessitating wells to be dug deeper. Wells may go dry if they are not deep and may happening Ground subsidence and seawater intrusion because of groundwater overuse. This confirms the need to control, regulate, and engineer groundwater as much as possible. As the Lebanese coastal areas often suffer from seawater intrusion (groundwater salination), the entry of salty seawater into the fresh aquifers. Saadeh (2017) [27], Kalaoun (2018) [14], El Moujabber (2002) [6].

Gaussen aridity index is the number of months in which Pa < 2Ta, where Pa is the average monthly precipitation (in mm), and Ta is the monthly mean temperature (in °C) for the same period.

Gaussen index Fig. 8 shows that the dry season in the region extends over six months, from May to October. It is noted that the average temperature in the dry season is the highest, which leads to an increase in crop requirements and population to the water.

The average annual precipitation map Fig. 7 shows that the average annual precipitation varies between 600 and 900 mm, through which we can estimate the average amounts of precipitation in the Bint Jbeil region. Rainy days in this area last about 70 days and are limited to the period of the rainy season from October to April Fig. 8

However, the rainy peak falls in January, and most of the rains fall during December, January, and February. Therefore, the total volume of precipitation in the Bint Jbeil district is estimated to be 209 million cubic meters of water, of which about 100 million remains after the volume of evaporation has been determined based on the following formula Eq. (6) (Zhang *et al*. 2002) [39] within the study area.

$$P_t = R + E_t + I \qquad (6)$$

Where P_t is the annual precipitation rate, R is the Runoff, E_t is the evapotranspiration, and I is the percentage of water infiltration to the ground from the precipitation. (Zhang *et al*. 2002) [39].

4- Vegetation has its effect on groundwater

Vegetation cover plays an essential role in storing water resources, helping to store them in the rock layers, transforming them into underground water reserves by reducing the speed of rain on the ground and thus reducing the process of the appearance of total torrents which do not benefit underground reservoirs. Some study area forestes are distributed on the slopes of the hills steep; so that the vegetation cover does not contribute to improving the condition of the underground reserves, and the percentage of vegetation cover does not exceed 3% of the general area, which means that most of the hills and plateaus are barren.

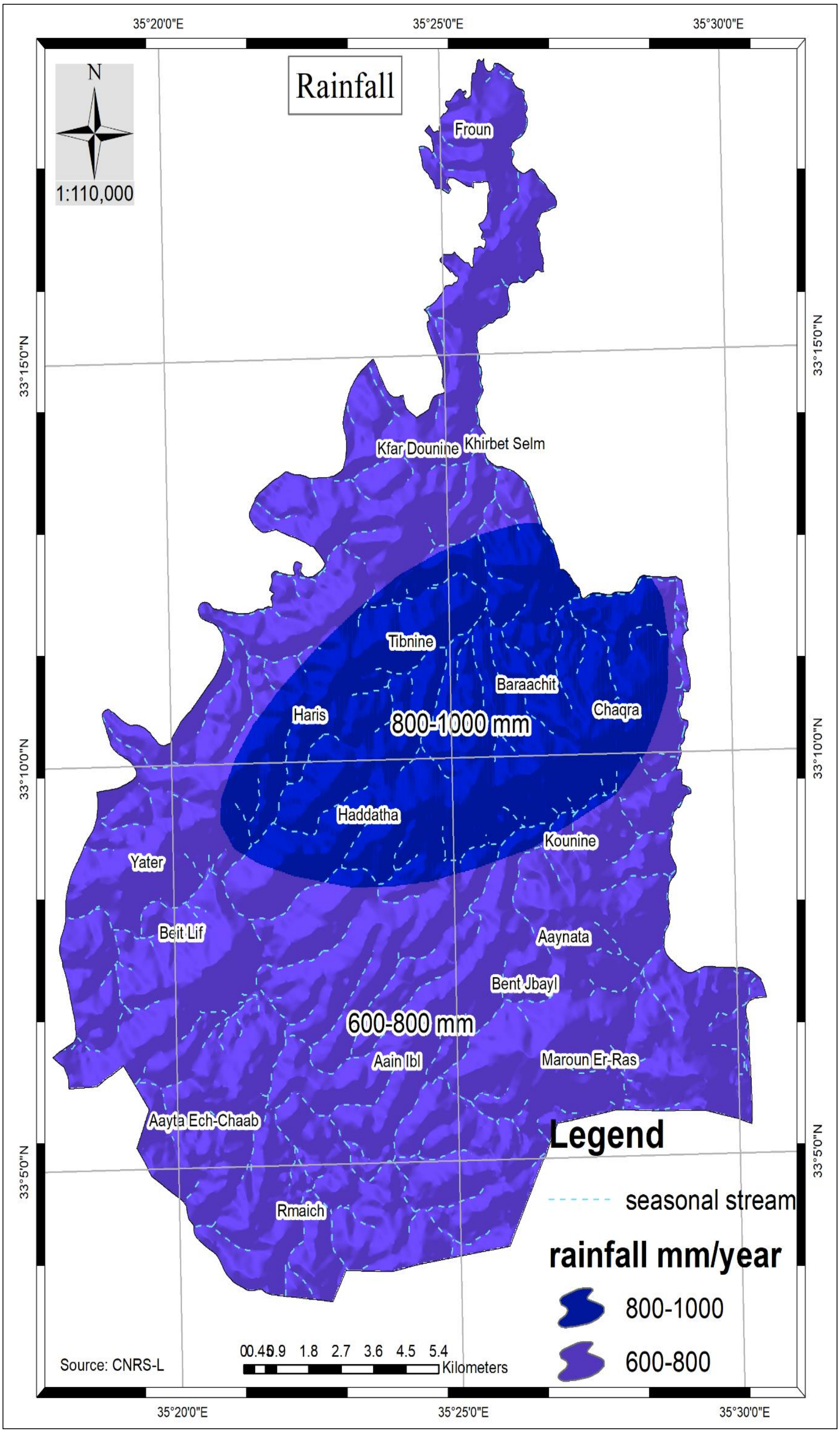


Fig 7: map of the average annual precipitation in the study area

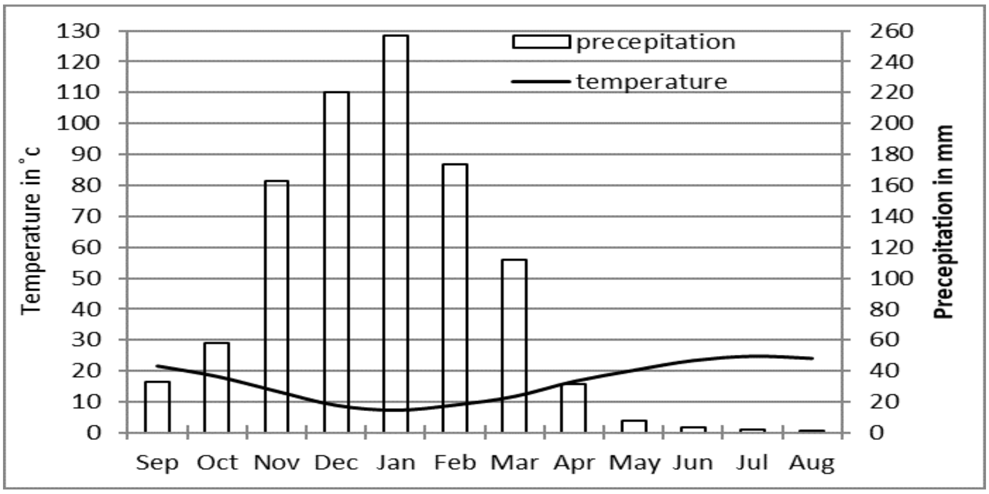


Fig 8: Gaussen aridity index

Therefore, the loss of vegetation cover is seen as one of the obstacles that have prevented it from reducing the region's water cruising. It should be mentioned that the region's climate favors the existence of rainforests (such as oaks) sufficient for the amount of precipitation currently available.

Due to the vegetation cover distribution map Fig 9, we were found that about 241 km^2 of the general area of the study area, or about 89%, is rocky and herby areas or neglected agricultural land, which means that they are devoid of permanent vegetation. This case hurts the precipitation storage process inside the layers of the earth in the study area. On the contrary, the loss of vegetation cover is considered one of the obstacles that strongly affect the improvement of groundwater resources and the satisfaction of the needs of the population of the study area.

In addition, half of the cultivated area is covered with deciduous trees (almonds, apples, and vines), which means that the effectiveness of these trees in preventing the appearance of torrents and receiving precipitation in winter is negligible due to the fall of their leaves in autumn. Therefore, the benefits of vegetation cover are limited to an area that constitutes only 4.5% of the general area of the Bint Jbail area.

Thus, the loss of plant cover in general and the characteristics of some of these existing crops constituted a natural obstacle to improving the state of groundwater resources in the study area.

5. The aquifers in the region

Groundwater is the most precious natural resource and must be used judiciously for sustainable groundwater management (Senthil and Shankar 2014) [31].

Groundwater is related to the geological composition of rock layers and the structure of these rocks. The groundwater basin arises when the aquifer acquires a well-developed conduit system. Its capacity is linked to several natural factors, the most important of which are: the volume of precipitation, the permeability of rocks, the thickness of the load-bearing layers, and the dip and strike of these layers. Usually, an aquifer is a specific rock formation with a well-defined thickness but an indefinite lateral extent.

The rocks in the study area are considered one of the most water-storing rocks due to their limestone and limestone-dolomitic composition as the commonly occurring soluble rocks. Moreover, it has a high permeability because it contains dissolution-generated conduits that transport groundwater, often localized, fast-moving, and in a turbulent regime under appropriate conditions (Khawlie *et al*., 2000) [16]. The Cenomanian (C4) and Eocene (E2) rock layers are two aquifers, separated by the upper Cretaceous layer, which is the Senonian (C6) impermeable layer, where this layer appears in the study area between the two layers as mentioned above Fig. 10.

Each layer of water-bearing rock has a percentage of voids inside (porosity) in which the leaking water is located, and the volume of these voids is the same as the capacity of the expected volume of underground water. There is a mismatch of many orders of magnitude in most aquifers between groundwater flow rates in the aquifer and stream flow rates on the land surface above.

Consequently, the volume of water inside the two aquifers is estimated by the following two equations:

$$GW = [P-(ET+R)] * S \qquad (7)$$

GW: capacity (aquifer); *P*: Precipitation; *ET*: evapotranspiration; *R*: flow; *S*: areas.

$$S * H * K \qquad (8)$$

Where S is the area in km^2, H is the height of the water table from the bottom of the layer in km, K is the storage factor (specific storage).

These two equations Eqs. (7) (8) gives a theoretical estimate that is still far from the required accuracy in determining the volume of water within the aquifers. That is due to the karstic process present in the rock layers, dip and strike, and other factors affecting the estimate of the quantities of the aquifer. The combined natural water balance equation refers to many parameters that cannot be controlled (Knobloch *et al*. 2014) [7] and thus stands an obstacle to groundwater engineering.

We will refer to the water budget equation, which many researchers have used likes Scanlon, Healy, and Cook (2002) [28].

$$Re + Ge + Pa = (Ri - Ro) + (Ig - Go) + Eti \qquad (9)$$

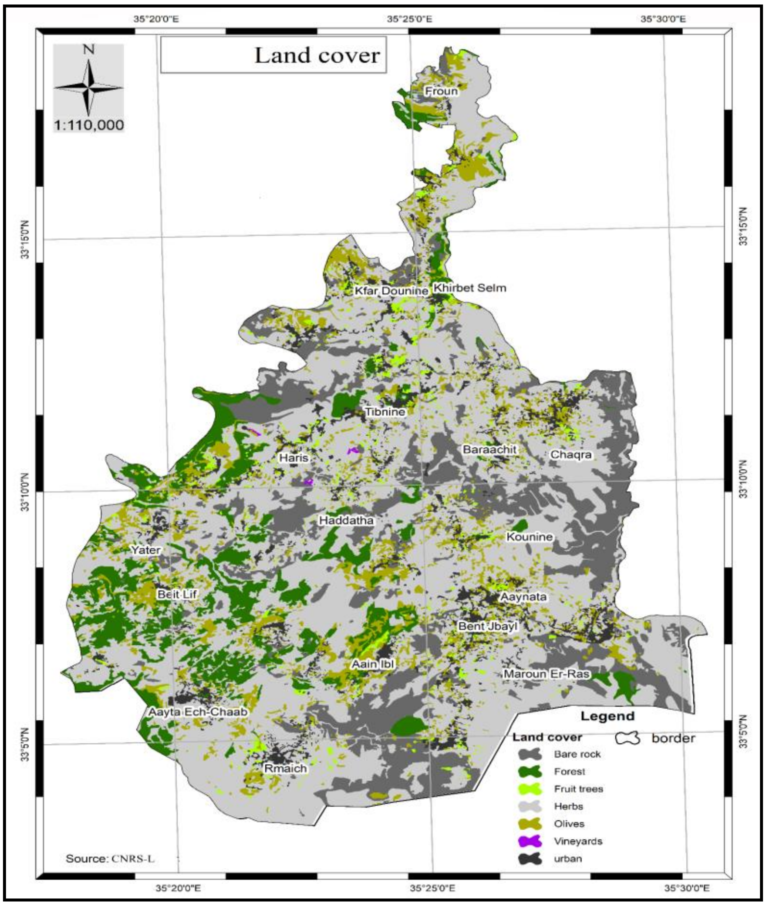


Fig 9: map of the land cover in the study area

Where *Re* is the surface water resources entering the study area, *Ge* is the underground water resources entering the study area; *Pa* is the annual average precipitation, *Ri* is the surface runoff in the basins of the study area, *Ro* surface water resources out of the study area. *Ig* infiltration to the groundwater, *Go* the water infiltrated outside the aquifers, *ETi* evapotranspiration.

Despite the modern technologies reached by science and the creation of algorithms for morphometric formulas that estimate some of the parameters mentioned in the above equation Fig 9 others remain in a state of uncertainty about their results, especially the parameters *Ge* and *Go*, which cannot be estimated in the study area for technical reasons on the one hand and reasons Scientific on the other hand. Therefore, the underground water resources entering and leaving the study area cannot be estimated, and their actual volume is known.

The Eocene aquifer

This reservoir is classified among the free aquifers whose rocks are exposed on the surface, and the recharge is directly received from the precipitation, and thus the storage factor is equal to the volume of the porosity of rock-forming the aquifer layers. In the study area, the thickness of the Eocene layer does not exceed 200 meters, and the water level is a few tens of meters (80 meters) high. In summer, it does not exceed four meters UNDP (1970) [37], Artesian well drilling private reports (2010-2020). Therefore, we find that most of the wells in the region dig deep to reach the Cretaceous layers. This aquifer is part of the Bint Jbeil syncline, which tends to the south (Nader, 2014) [22]. Perhaps this explains the decrease in the water level from 80 meters in winter to 4 meters in summer so that most of the groundwater seeps into Palestine.

It is evident from the decrease in the water level by this amount that the rock layers have been subjected to a karstic action which accelerates the transfer and infiltration of water to other places, noting that the transmissivity of the rocks of the Eocene is high, approximately 150 m^2/Day (Moselhy and Ibrahem 2020) [21].

This process referred to the loss of this amount of groundwater for a period not exceeding three months, and studies do not indicate that the population drained this amount of groundwater through wells dug in the area for these three months. Therefore the only accurate indicator of this loss is the inclination of the syncline axis with the dip of the layers towards Palestine (Zaatiti 2007). It is one of the faults of the geological formations and tectonic movements in the region.

The Cenomanian aquifer

This aquifer is a group of rugged and fissured rocks belonging to the Cenomanian layer, which constitute the basic geological infrastructure in the study area, and it is a valuable aquifer for investment in the region in general (Shaban 2010) [32].

Dolomite and limestone are highly fissured rocks with high permeability. Whose rate of recharge in exposed areas is about 35 - 40 % of precipitation Fig. 11 This water penetrates through fissures and fractures to the depth of the rock layer exposed.

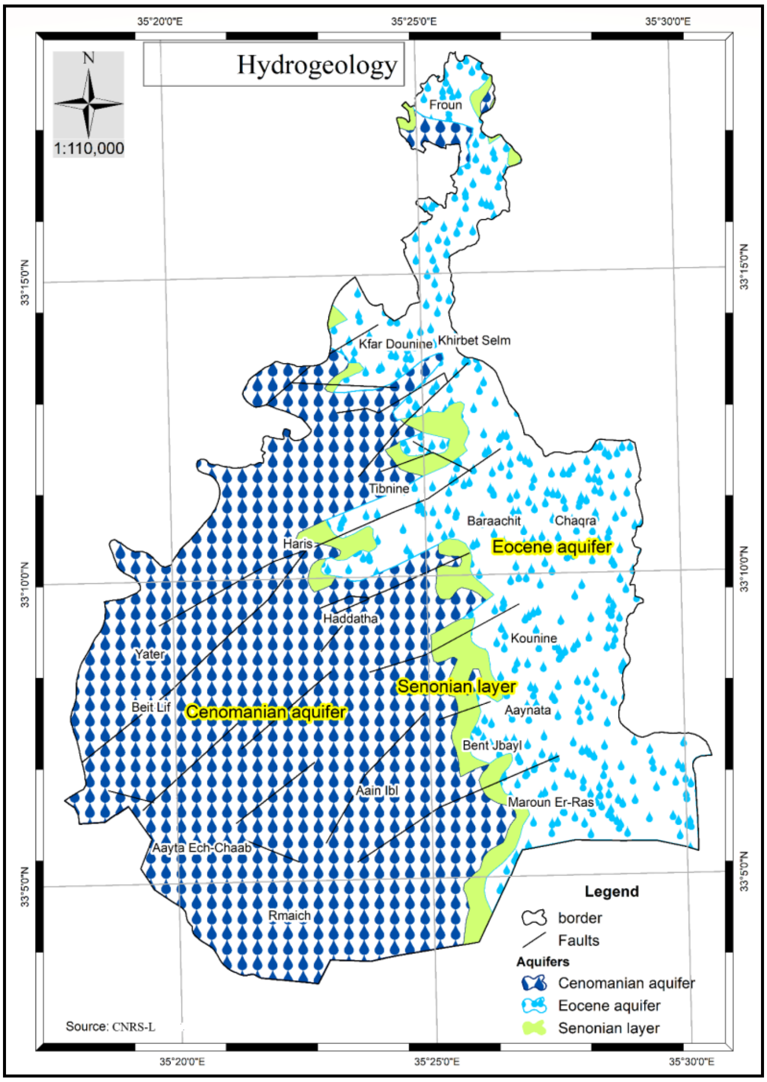


Fig 10: map of hydrogeology in the study area

This layer is deployed in the study area over an area of approximately 154 km^2. However, the tectonic situation that produced the Bint Jbeil syncline caused it to sink below the Eocene layer, and then it was exposed at the eastern international border between Lebanon and Palestine. This process means that we cannot estimate the aquifer capacity for this layer without taking into account its subsided section under the Eocene, as it is recharged from its exposed section on the surface due to the dipping of the layers and their curvature with the syncline, we must therefore calculate the total area of the study area to estimate the capacity of this aquifer.

Reports of wells dug in the study area indicate that water begins to appear in this layer at a depth between 150 and 200 meters from its roof under the Senonian layer (C6), and the thickness of the Cenomanian layer (C4) in the study area is about 700 – 1000 meters, the thickness of the water-bearing layer is equal to 400 meters. This storage area is significant for an area that lacks water during the dry season. However, this vast volume comes with many obstacles without profit and investment economically from it. The Cenomanian rocks exposed in the study area coincide with the Jabal Amel anticline axis. Therefore, by gravity, the water will have leaked to the right and left of the axis of the anticline. Stratigraphy, in this case, controls groundwater flow. So the flow and bedding planes are parallel. What confirms this, submarine springs at the end of the anticline on the coast, offshore, and Hula Plain in Palestine. Understanding small-scale stream-groundwater interactions require knowledge of groundwater flow pathways and their relationship to streams Wroblicky *et al.* (1998) [38]; Roy, Hayashi (2009) [26], Hayashi (2019) [12]. Thus, we will study groundwater movement to see if we can determine its capacity and then work on its engineering.

6. Groundwater level and motion

Based on the data of the artesian wells dug in the study area, we were able to draw a map of the groundwater level and its water table Fig. 12 It is clear that the water table was high at the axis of the syncline due to the accumulation of groundwater due to gravity in the center of this concave. On the contrary, the water table decreased at the convex axis due to the dip of the rock layers.

Estimating the capacity of aquifers becomes easy when the equation of motion can be simplified as Cushman, Tartakovsky (2016) [4] Eq. (10)

$$q = -\rho g\ \mu{-1}k \cdot \nabla(\varphi + z) = -K \cdot \nabla h \qquad (10)$$

where $K = \rho g\mu{-1}k$ is the hydraulic conductivity matrix $[L/T]$, $\varphi = p/\rho g$ the pressure potential $[L]$, and $h = \varphi + z$ the groundwater potential $[L]$.

Indeed, field investigations show that natural porous media as aquifers and aquitards exhibit considerable variability in conductive properties. Lee S. Carle S. Fogg G. (2007) [20]. which is difficult to quantify accurately by experimental or deterministic means due to the characteristics of the rocks in the study area, which is characterized by the karst phenomena, an abundance of cavities and caves inside it or other large-sized openings, like cracks, fissures, and the like, it becomes tough to find a law or equations Eq. (10) that help in engineering groundwater.

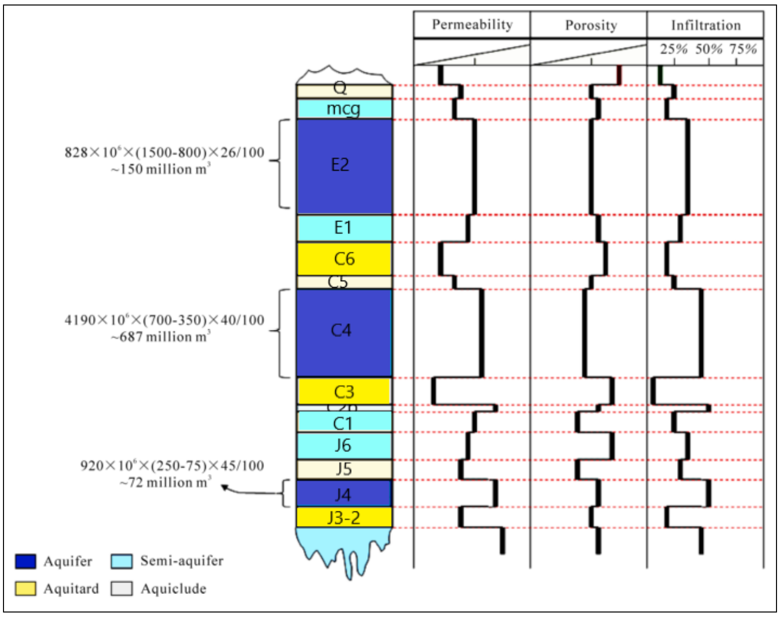


Fig 11: stratigraphic distribution of the aquifer (Shaban 2010) [32]

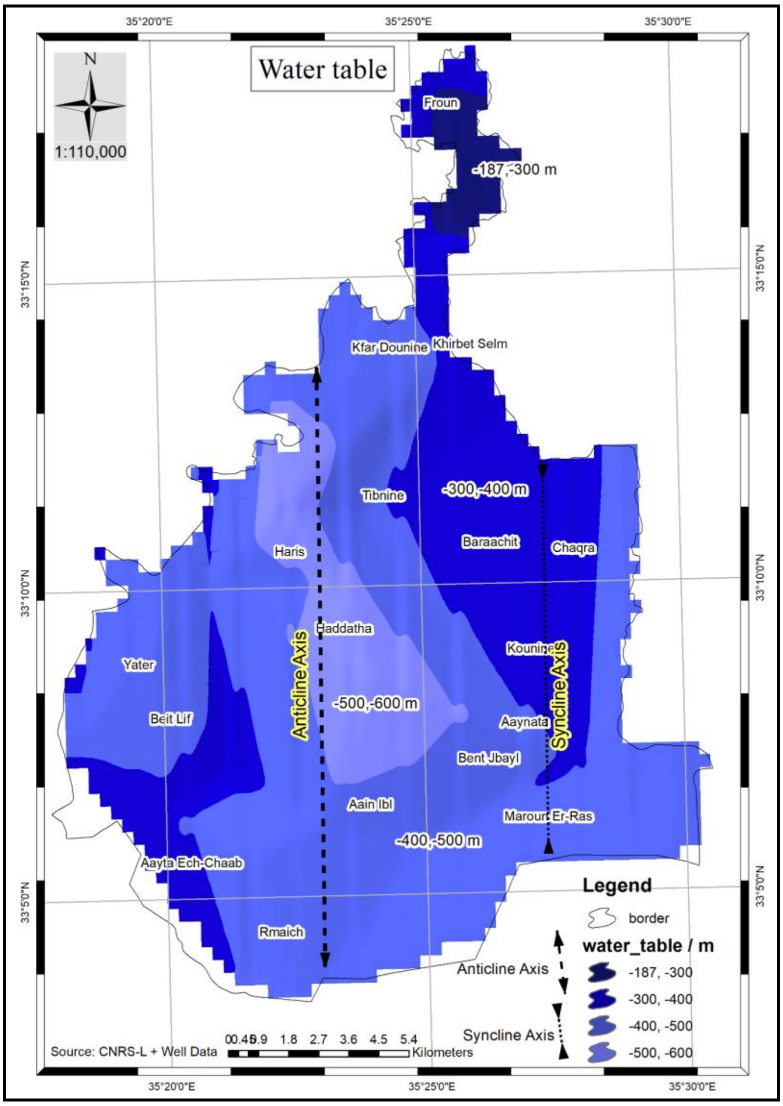


Fig 12: Map of water table in the study area

Conclusion

The role of natural factors affecting groundwater engineering varies from one geographic region to another. These factors may positively impact medium and large areas, but they can hurt a small geographic area, like the study area.

This study resulted in the conclusion of five natural obstacles that prevent the water resources engineering of the study area.

1. In Bint Jbeil, the topography was a negative factor in supporting the groundwater. The intense slopes played a negative role as they contributed to the speed of runoff and formation of torrents in the valleys, which led to impeding efforts in the groundwater engineering process in the study area. Therefore, local stakeholders should encourage afforestation and the construction of terraces on the slopes.
2. The same goes for the tectonics and geology of the region, where the manifestations of tectonic movements (fractures and folds) and the physical characteristics of geological formations (karst phenomena) have not provided safe and stable aquifers. As the volume of the underground infiltration of groundwater cannot be accurately estimated, thus placing another obstacle in front of groundwater engineering.

   Perhaps if we count the number of submarine springs and then estimate their annual discharge, after that, it is possible to overcome this obstacle
3. The fluctuation of annual precipitation quantities, the decline of the rainy season, the absence of snow, the rise in average annual temperatures, and the climatic change affected the recharge of the aquifers in the study area.
4. The lack of vegetation cover in the area indirectly hindered groundwater engineering. If there were vegetation cover in the area of medium density or more, it would help reduce torrents on the slopes, and the rain would help skip the soil to the depths gives the surface runoff parameter its realistic value even with strong slopes in the study area

   Therefore, reforestation is considered one of the most critical activities that contribute to the water infiltration process
5. The aquifers in the Bint Jbeil area are fed only by precipitation, and as soon as the water reaches them, they leak out due to the dip and strike of the rock layers of these aquifers would impede the engineering of the groundwater several wells can be drilled parallel to the anticline axis to determine the water table during a whole year to contribute to removing this obstacle.

   These obstacles may not exist in large geographical areas, but in a small geographical area such as the study area, they have significantly affected the determining the parameters of the mathematical formulas that serve groundwater engineering.

- On behalf of all authors, the corresponding author states that there is no conflict of interest.

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