RESEARCH PAPER 2022

LAND USE, LAND COVER CHANGES AND THE LINK WITH GROUNDWATER

GOVERNANCE IN NAHR AL-JAOUZ RIVER BASIN, LEBANON

RESEARCH PROJECT ON LAND GOVERNANCE IN THE ARAB REGION

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LAND USE, LAND COVER CHANGES AND THE LINK WITH GROUNDWATER: GOVERNANCE IN NAHR AL-JAOUZ RIVER BASIN, LEBANON

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Cover photo: Ricardo Santeugini (2015). Port of Byblos, Lebanon.

Sponsor: Federal Ministry for Economic Cooperation and Development (BMZ)

ABOUT THIS PAPER
The Research Innovation Fund - This paper was developed as part of the Research Innovation Fund of the Arab Land Initiative, addressing students and young land professionals from the Arab region interested in conducting research on land governance-related topics. The Arab Land Initiative, led by UN-Habitat and Global Land Tool Network (GLTN) with the financial support from the Federal Ministry of Economic Cooperation and Development of Germany (BMZ), launched the Research Innovation Fund in July 2020. The GLTN partner Urban Training and Studies Institute based in Cairo, Egypt managed the first edition of the Fund, which assessed over eighty research proposals and selected seventeen to be developed, with the support of a pool of senior reviewers from the Arab Land Initiative's network.

GLTN and the Arab Land Initiative - GLTN is a multi-sectoral alliance of international partners committed to increasing access to land and tenure security for all, with a focus on the poor, women and youth. The Network's partners include international rural and urban civil society organizations, research and training institutions, bilateral and multilateral organizations, and international professional bodies. In 2016, GLTN Partners, led by UN-Habitat and the World Bank, launched the Arab Land Initiative to promote equal access to land, peace, stability and economic growth in the Arab region through good land governance and transparent, efficient and affordable land administration systems. The Initiative aims at empowering land champions from the region by developing capacities, increasing collaboration and promote innovation, learning and sharing of best practices. It also supports the implementation of land gender-responsive and fit-for-purpose land tools and approaches at national and local level. The Research Innovation Fund is one of the streams of work of the Arab Land Initiative.

For more information, please consult the referenced documents, visit **www.gltn.net** or write to **unhabitat-gltn@un.org**

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Water is one of the most important resources for humanity. The largest freshwater supply lies under the Earth's surface. Globally, the demand for water has grown by around 1 per cent per year due to population growth, economic progress, and shifting habits of use, among many other factors. This demand is likely to increase dramatically in the next two decades.

Lebanon is known to provide more water resources to its people than its neighbouring countries. Its ample water supply is mainly due to the country's topography with moderately high rainfall (rain and snow). A large amount of these rainfall flows into its aquifers and become groundwater. The total annual volume of groundwater in Lebanon is estimated at 567 million cubic metre. With agriculture's major role in the fight against poverty in rural areas, around 60 per cent of available water are used for agricultural activities. In 1993, it was estimated that 54.3 per cent of the land was irrigated by surface water and 45.7 per cent by groundwater (wells, and springs).

Access to groundwater enables farmers to expand and diversify their farming practices, boost domestic food and income security and protect themselves from droughts. While the use of groundwater has considerable potential to improve future agricultural yield, food production in some regions of the world is progressively contributing to the depletion of groundwater supplies. This means that the abstraction rate exceeds the replenishment levels.

Nevertheless, for groundwater to help intensify sustainable agriculture, it is essential to know where to invest in groundwater exploration and how to control groundwater supplies sustainably. Massive changes in land use that affect groundwater are taking place today as a consequence of population growth and increasing and evolving food requirements. Although the link between land use and groundwater has been recognized for some time, measures to protect and preserve groundwater have not been thoroughly integrated into policies and practices.

Therefore, mapping groundwater potential/recharge zones is important to understand the link between land and groundwater. Researchers have used geospatial technologies for groundwater mapping by integrating thematic maps like geology, stream density, lineament density, soil, slope, and land use/land cover. Geospatial technologies are systems that collect and control the Earth's location-specific data. Remote sensing and Global Navigation Satellite System or GNSS collect information about the terrain surface. GIS is a mapping method to establish and analyse information.

Groundwater is getting more attention because of drought, rural water plans, irrigation projects, and other socioeconomic developments.
However, regardless of the extensive research and technological progress, groundwater studies remain riskier as there is no advanced method to observe water below the surface. Over the years, the increasing demand for groundwater and its growing value have contributed to unscientific exploitation of groundwater resulting in stressful conditions for the land and for societies.

Unsustainable water resource management adopted since the beginning of the mid-seventies and poor water management have put a strain on the country's water resources, especially on groundwater. Most public and private water wells have been constructed throughout the country without proper planning and monitoring. With the lack of any planned groundwater exploitation approaches, several random drilling bores of wells failed. Such indiscriminate exploration has contributed to a decline in groundwater potential, lower water levels and degradation of water quality.

The Nahr Al-Jaouz River Basin has groundwater potential, which has been partially and badly exploited. This potential could still be developed and managed to establish projects of planned groundwater utilization and sustainable drillings. Analysis of Digital Elevation Model data, soil permeability, lithology, geological formations, climatic data, drainage patterns, land use/land cover patterns and lineaments through geospatial technologies tell us better locations for installing wells. There have been randomly installed wells and many have failed. The low position of these wells has affected retention. Establishing a groundwater potential zone map using geospatial technologies highlights the aquifer's richness, determines the water's potential capacity and shows promising areas for groundwater exploration.

The groundwater potential zone mapping of Nahr Al-Jaouz River Basin is carried out by integrating remote sensing data and conventional maps, including soil sheets scale 1/50,000 provided by the National Center for Remote Sensing. The first step was to convert conventional maps into digital formats, then georeferenced into Deir ez Zor Levant Stereographic. Remote sensing data were used to generate eight thematic maps:

1. Geology
2. Soil
3. Lineament density
4. Stream density
5. Lineament and Stream intersection density
6. Slope
7. Rainfall
8. Land use/land cover

Geology and soil sheets were digitized and then converted into raster maps. Lineaments and land use/land cover maps were derived from Landsat 8 Operational Land Imager and Sentinel-2 satellite images. Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission or SRTM, was used to prepare the slope and stream maps. The lineament-stream intersection map was prepared by applying an intersection algorithm between the stream features and lineaments. Each thematic map was reclassified using GIS ArcMap 10.4 and given numerical values depending on their significance to groundwater potential.

For the weighted overlay method, the groundwater potential zone map was prepared by overlaying all thematic layers and their corresponding classes using the Spatial Analyst tool in ArcMap 10.4. Each thematic map was assigned a weight value according to the influence of different parameters. In setting values, lineament-stream intersect density, lineament density and geology were given a higher weight. Stream density, land use/land cover, slope and rainfall were given the same weight, and soil was given a lower weight. Each sub-variable was assigned to a value, where the highest value was given to the layer with the highest groundwater prospect and the lowest value to the lowest prospect layer.

The results from the Groundwater Potential Zone model were validated based on the list of wells from the Ministry of Energy and Water. Afterwards, it was necessary to do a survey campaign for the wells in the study area. Each well was located via GPS points based on the stereographic projection of Deir Ez Zor and assigned an ID. When analysing the result of the groundwater potential zone and the reports of the wells, we noticed that three of the wells that failed were located in the low groundwater potential zone, one in the high potential zone, and two in the moderate zone. The successful wells were either in the high or moderate potential zone.

During the French Mandate, the French authorities created a land registry based on cadastral zones but left the project unfinished. It has not been completed by the Lebanese State since 1943, either. Therefore, some areas have never been delineated, while others have never been validated or officially registered for land parcel surveys. This is the consequence of having different actors involved with contradictory logics : public administrations (judiciary, army), landlords, and societies reflect the changes in the cadastral work process between 1965 and 2003, where only 11 regions were registered in 1965 and 14 in 2003. Gathering information from the Directorate of Land Registry and Cadastral was necessary to update the data. The research team then updated the map of the land registration and cadastre, where 29 of the 71 regions were registered in the study area. Due to lack of data, the team worked at one scale, with the boundaries of all the regions within the Nahr Al-Jaouz River Basin.

After prospecting the groundwater potential zone of Nahr Al-Jaouz River Basin, the team applied a zonal statistic between the cadastral boundaries of all regions and the groundwater potential zone map. The high mean of the groundwater potential cover 86 km^2 of the study area, with 66 km^2 covered with moderate values and 41 km^2 with low values. This means that Nahr Al-Jaouz River Basin has good groundwater potential that needs further investigation so that groundwater can be explored and utilized sustainably and with good governance since the study area is an agricultural vocational zone.

In a 2013 study, Varady and others described groundwater governance as the mechanism by which groundwater is controlled through responsibility, participation, information availability, transparency, tradition and state of law. It is the art of managing administrative activities and decision-making, one of which may be global within and between different jurisdictional levels. Groundwater is a common-pool resource and is frequently used individually despite cumulative effects on an aquifer that may result in catastrophic scenarios. It can easily be abused and issues can just as quickly escalate since most groundwater can be explored without monitoring criteria or standard costs. The negative impacts on the resource remain unnoticed until detrimental effects arise on ecological and human health due to pollution and/or excessive water withdrawal.

The intensive use of groundwater resources in Lebanon began in the late 1950s. Improved pumping installations also encouraged groundwater use for agricultural, industrial or urban purposes. In the 1970s, some 3,000 wells in the country were recorded in official reports. Documents report about 50,000 private boreholes in the 2000s. UNDP in 2014 put their number at 80,000, of which 59,000 were unregistered and 21,000 were registered (i.e., a density of 8 wells/km^2). In Lebanon, a reasonable estimation of the total number of wells is likely to be 100,000. These numbers are massive (with a total volume of 270 million cubic metres per year in 2009) compared to 842 public wells providing public water networks.

This exponential rise in private wells was largely due to the lack of, or shortcomings in, public networks for people seeking autonomy. During the war and later during the reconstruction period, informal and illegal activities escalated. Wells drilled side by side in the same aquifer affect water retention ability. The performance of these wells will depend on the thickness of the aquifer, the presence of an underground river, and the depth of the well. Even the largest Cenomanian aquifers in the altitude zone cannot be productive with a flooded karst.

With the efficiency of geospatial technologies and the integration of the eight thematic maps, local authorities and decision makers now have first-hand information on which areas are suitable for groundwater exploration. With the cadastral work process and land registration of the study area analysed and updated, it is easier to understand how these potential groundwater zones are spatially distributed in the context of registered and unregistered land and the affiliate legislation concerning private lands with well drilling. This groundwater, land registration and cadastral information are enough to further investigations and data collection.

Groundwater management as an important sustainable development has not been properly considered and has resulted in the depletion and degradation of the resource. With groundwater quality under continuous threat and unless protected, groundwater quality diminishes due to saline intrusion, pollution from urban and agricultural activities, unmanaged water waste and solid and dangerous waste disposal. To combat this, the following actions should be undertaken:

- Improve knowledge on the importance of groundwater contribution to the hydrological cycle and assess the changes to the variations of groundwater storage and level.

- Raise awareness of decision makers, water consumers and the public on the value of groundwater to promote conservation and sustainable use.

- Assess the impacts of economic progress on groundwater resources and support global collaboration for national and regional needs.

- Quantify climate change impact on groundwater resources including sea levels rise and saltwater intrusion.

In addition, to enhance groundwater efficiency and water management, several methods could be taken into consideration such as groundwater recharge, alternative sources, conservation management, construction of levees in the river channel to increase infiltration and injection of treated recycled water to form a seawater barrier. It is important to install several monitoring wells and piezometers to calibrate the prediction models and observe and analyse the fluctuation in the water table levels. At least three monitoring wells are needed to find the direction of the groundwater and perform any meaningful monitoring. Using groundwater has enhanced agricultural productivity, increased incomes and led to food security. However, greater awareness and policy and management options are needed to sustain and expand these achievements and avoid groundwater depletion or degradation.

CHAPTER ONE: INTRODUCTION

Lebanon experienced dramatic shifts in population dynamics, construction development and agriculture. This emerged during the 1960s, accompanied by intense migration from rural to urban areas, resulting in negative impacts in both environments. The effects were land degradation in the former and excessive demand for water in the latter. These and the associated lifestyle changes resulted in a significant impact on land use and resources (Masri et al., 2002).

Water is among the most critical resources for humanity and the largest available supply of freshwater lies under the Earth's surface. It's one of the essential natural commodities serving human needs and economic growth (Kumar, 2016). With the growing global demand for water, it is estimated that domestic and industrial demand will grow even faster than agricultural demand, while agriculture will remain the largest global user (UN, 2018). Groundwater is a progressively significant resource for rural and urban drinking water, agricultural irrigation, and industry, in addition to its natural ecological role of sustaining river flows and aquatic ecosystems (Foster and Cherlet, 2014).

Lebanon has always provided more water resources per person than its neighbouring countries. This is mainly due to its topography, with moderately high rainfalls (rain and snow). A large amount of these rainfalls infiltrate into its aquifers and become groundwater, while the remains evaporate or flow as surface runoff (UNDP, 2014). The total annual volume of groundwater in the country is estimated at 567 mm3.

Due to agriculture's central role in the fight against poverty in rural areas, around 60 per cent of the water supply is used for agricultural activities (MOA, 2014). More than 50 per cent of Lebanon's agricultural land is under irrigation. It was estimated in 1993 that 54.3 per cent of the land was irrigated by surface water and 45.7 per cent by groundwater (wells and springs) (Comair, 2011). Assuming that irrigation season is about six months, the total irrigation requirement is 25 m3/day/hectare. This volume will need to be considered as the estimated volume of extracted groundwater if there is no other water source for irrigation. Water management has a vital role to play in agriculture.

Compared to surface water, groundwater offers significant economic benefits per unit volume due to its ready local supply, superior drought stability and generally good quality, which means minimal treatment. Most groundwater originates directly from excess rainfall that infiltrates into the soil surface. Thus, land use has a significant effect on both groundwater quality and the pace of recharging. Of all types of substantial land-use change, the expansion of irrigated agriculture using surface water supply has the greatest effect on groundwater. It significantly increases recharge and improves water quality as excess irrigation water infiltrates deep aquifers (Foster and Cherlet, 2014).

With access to groundwater, farmers can expand and diversify their farming practices, boost domestic food and income security, and protect themselves from the impact of droughts. While the use of groundwater has considerable potential to improve future agricultural yield, food production in some regions of the world is progressively contributing to the depletion of groundwater supplies, which means that the abstraction rate exceeds the replenishment levels. Nevertheless, for groundwater to lead to sustainable agricultural intensification, it is essential to know where to invest in groundwater development and how to manage groundwater supplies sustainably (CGIAR WLE, 2017).

Groundwater is strongly connected to land use and landscape (Prabhakar et al., 2015). Massive changes in land use affecting groundwater are taking place today, as consequences of population growth and increasing and evolving food requirements. Even as the link between land use and groundwater has been recognized for a long time, it has not been thoroughly incorporated or integrated into policies and practices (IFAD, 2010).

Mostly irreversible, the anthropogenic effects on groundwater resources have significantly increased over the last 50 years due to intensive expansion of irrigated agriculture and urban water supply and a dramatic shift in land use in many aquifer recharge zones (Foster and Cherlet, 2014).

Since land-use decisions and activities can have long-lasting and, in some cases, permanent effects on groundwater, and to decide where and how much groundwater can be sustainably exploited, a common understanding of the relationship between groundwater and land is required to promote cross-sectoral dialogue on governance needs and management approaches to improve land productivity and maintain water resources.

Collecting accurate and timely information on land use is important to detect changes in land use as basis for predicting the impact on water resources (Albhaisi et al., 2013). It is also imperative to understand the extent of encroachment of recharge areas due to changes in land use/land cover. Scientific studies have described the relevance of different hydrological aspects, geomorphology, geology, slope, soil cover, drainage density, surface temperature, land use/land cover and controlling groundwater potential in any area. Yet, the extent of their effects may vary from place and time (Kumar, 2016). These can be studied using satellite images and aerial photographs that provide detailed information about a large area of the Earth's surface in a very short time (Patra, 2016). Therefore, mapping groundwater potential/recharge zones is important for planning and understanding the linkage between land and groundwater.

Researchers have used geospatial technologies for groundwater mapping by integrating thematic maps such as geology, stream density, lineament density, soil, slope and land use/land cover (Bathis, 2016). Geospatial technologies are used to collect and control Earth's location-specific data. Remote sensing and Global Navigation Satellite System collect information about terrain surface. GIS is a mapping method for establishing and analysing information.

Problem statement

Groundwater is getting more attention because of drought problems, rural water plans, irrigation projects, and other socioeconomic developments. Yet groundwater studies are riskier regardless of the extensive research and technological progress in the field, as there is no advanced method to observe water below the surface. Over the years, the increasing demand for groundwater and its growing value has contributed to the unscientific exploitation of groundwater resulting in stress conditions (Waikar et al., 2014).

The immense pressure of population growth, increased demands for water, food and fodder coupled with industrial activities have essentially contributed to drastic changes in land use purpose and patterns (Prabhakar et al., 2015). These land-use changes which led to overpumping (Ghazavi et al., 2016), uncontrolled groundwater withdrawal approaches, the absence of adequate studies and monitoring, and the increasing demand have resulted in overexploitation and continued depletion of groundwater resources in different areas of Lebanon (UNDP, 2014). Good knowledge of the hydrological processes that global changes and human activities could significantly modify is required to accurately assess the groundwater potential zone of the region (Pan et al., 2011).

The shift in land use is a major factor affecting the groundwater system. Over time, intensive human activities, including industrialization, urbanization, agriculture, dam constructions, etc., have contributed to substantial and definite changes in the landscape impacting the water balance of surface and groundwater systems (Albhaisi et al., 2013) (Figure 1). The increased impermeable surface has been a significant factor that led to a decline in infiltration, resulting in a decrease in groundwater storage (Prabhakar et al., 2015). Thus, the impacts of land-use change on groundwater recharge and exploitation should be investigated (Pan et al., 2011).

Unsustainable water resource management adopted since the beginning of the mid-seventies, coupled with poor water management, has also put a strain on the country's water resources, especially groundwater. Most public and private water wells have been constructed throughout the country without proper planning and monitoring (UNDP, 2014). The lack of planned groundwater exploitation approaches led to several random bore drilling of wells failing (Venkateswaran, 2015). Unrestricted exploitation has resulted in a decline in groundwater potential, a drop in water levels and degradation of water quality (Venkateswaran, 2015).

Figure 1: Google Earth images showing the changes in land cover at Nahr Al-Jaouz River Basin, the region of Mseilha in 2013 and 2019, before and after the construction of dams

The groundwater potential of Nahr Al-Jaouz River Basin has been partially and badly exploited but could still be developed and managed to establish projects of planned groundwater exploitation and sustainable drillings. Analysis of digital elevation model data, soil permeability, lithology, geological formations, climatic data, drainage patterns, land use/land cover patterns and lineaments through geospatial technologies informs the preferred and more appropriate locations for installing wells.

The study team considered several random installed wells, many of which failed. The low positioning approaches of these wells has affected retention. Establishing a groundwater potential zone map using geospatial technologies will highlight the richness of the aquifer, determine the potential water capacity for the study area and highlight more promising areas for further groundwater exploration.

Objectives

This research aims to produce a potential groundwater zone in Nahr Al-Jaouz River Basin using geospatial technologies (remote sensing and GIS). A variety of data is used to predict the potential groundwater zones. Establishing a sustainable groundwater management method to explore this vital resource better necessitates the delineation of prospective groundwater zones.

The chosen study area is the Nahr Al-Jaouz River Basin, located north of Lebanon among the following geographic coordinates: 34° 8' – 34° 17' north latitude, 35° 39' – 36° 0' west longitude (Figure 2). It covers most of Batroûn District and is part of Al-Koura and Bcharreh District in the north and Jbayl District in the south, touching the Baalbek District in the east. This basin extends almost 200 km^2 between the sea level and 2,300 m altitude. It develops around the watercourses:

- Nahr Al-Jaouz – Ouadi Dalli – O. Tannourine – Aïn er Raha et O. Harissa, from the north side;

- Nahr Kour – Ouadi Hibbat (Bchaaleh) and Ouadi en Nib – Râs – Hadtoun, from the south side (Libanconsult, 2005).

The Nahr Al-Jaouz River Basin covers more than fifty villages on the western façade of the Lebanese mountains, particularly in the Batroun District (North Lebanon Mouhafazat) and integrates different morphological, geological, hydrological, structural, and climatic features. The study area is within the boundaries of the basins of Al-Asfour and Abou Ali from the north, Ibrahim from the East, and Al-Fidar from the south (Doumit et al., 2019).

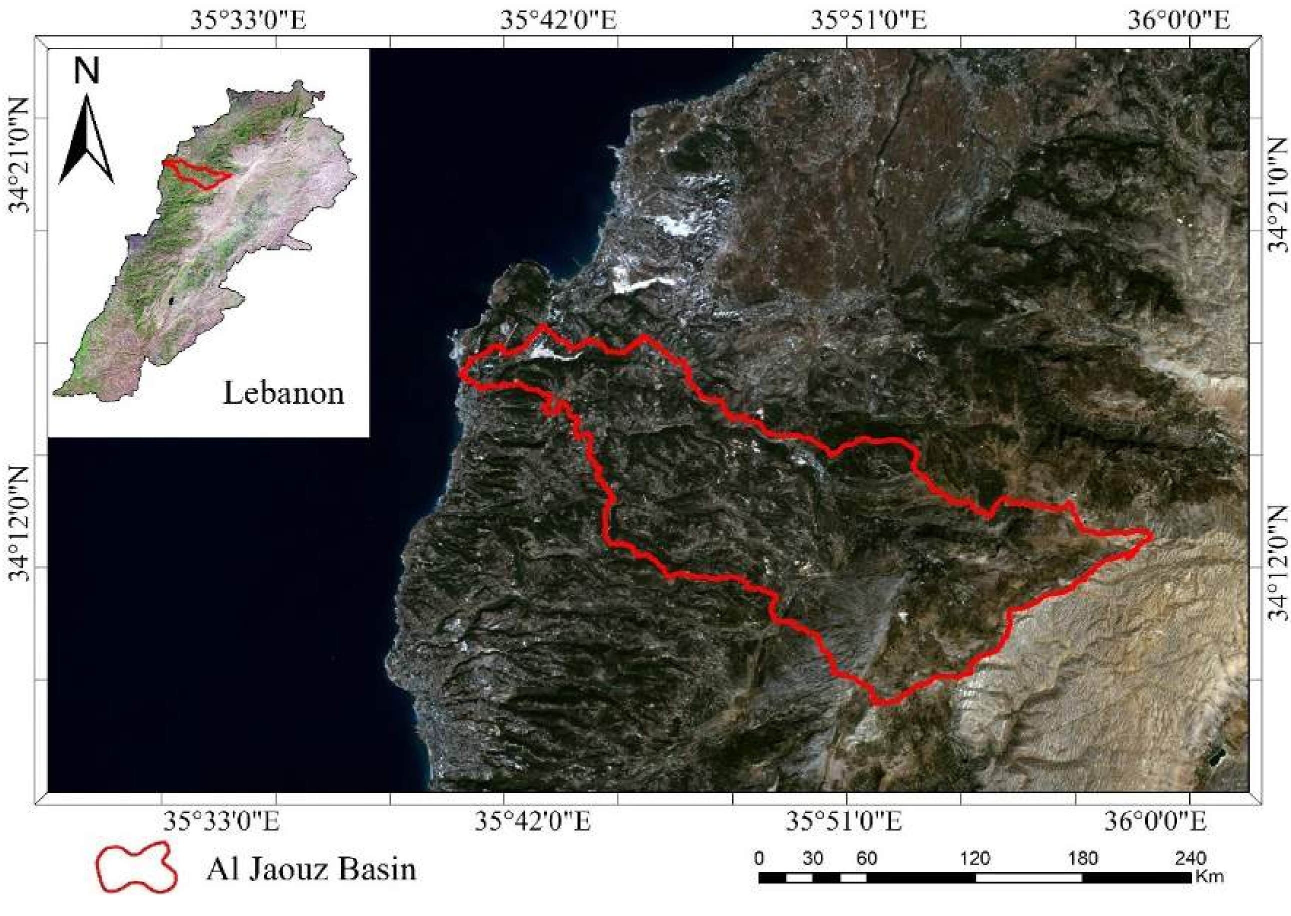

Figure 2: Location of the study area

2.1 Geology of the study area

The study area belongs to the Jurassic and the Cretaceous periods from the Secondary Era.

a. The Jurassic

Outcropping over almost 600 km^2 in the Lebanese massif, the Jurassic has more than 1,600 m thickness of very monotonous sediment: dolomites, dolomitic limestone, or strong limestone (Sanlaville, 1977).

b. The Cretaceous

After tectogenesis and the emersion localized at the end of the Jurassic period, a transgression occurred at the beginning of the Cretaceous era: sediments were deposited, in more or less marked discordance, on the eroded and karstified Jurassic (Sanlaville, 1977).

c. The Eocene

The changes in the paleogeographic conditions since the Senonian and until the end of the Early Eocene have resulted in the deposition of marly chalk sediments (Sanlaville, 1977). The Eocene limestone is also rich in a coin of foraminifera Nummulites (Walley, 1998).

d. The Vindobonian (m2a)

This is formed of sandy and reefal limestone, creating a cliff around the plateau of Hamat. Its thickness is 50 m. The Vindobonian lies discordant on the straightened layer of the middle and late Cretaceous (Sanlaville, 1977).

e. The Quaternary

The Quaternary period was marked by more than 50 glacial and interglacial climate cycles.

It is divided into two epochs: the Pleistocene, 12.6 million years to 11,000 years before present (BP) which has known long ice ages (glaciations), separated by shorter warm periods (interglacial periods); and the Holocene, the current interglacial period which began about 11,000 years BP (Elias et al., 2013).

The Quaternary is represented by the recent alluvium and deposits (q0) and the alluvium and terraces of the middle quaternary (q1). In the regions of Laqlouq, Douma, Harissa and around Qarn Niha, the lower terraces of major rivers, the slope scree, large landslides, and the avalanche cones line the foothills and slopes and hide the underlying stratigraphy. These deposits do not exceed 30 m in thickness. As well as the karstic depressions of Foghri, Gaimoum and Rahoueh are occupied by various alluviums, which date from the Middle Quaternary (q1) and which thickness can exceed 50m. The middle and high terraces of the Msailha sector belong to the same period.

During the Middle Quaternary (q1), a big landslide from the left bank of Nahr Al Jaouz at Bsatine Al-Aossi barred the canyon of Jaouz-Kfar Hilda. A large lake was formed and the lacustrine deposits and alluvium were able to fill this depression which led to the presence of Sahl Kfar Hilda. This small plain is located at an altitude of 585 m with an area of 1.1 km^2.

The two main aquifers are those of Middle Jurassic limestone and dolomite (J4); and the dolomite, limestone and marly limestone of the Cenomanian-Turonian (C4-5).

Middle Jurassic Aquifer (J4)

The Middle Jurassic (J4) constitutes a large aquifer in the middle and upstream parts of the Jaouz basin. The thickness of its layers, karstification, high permeability, as well as the size of the outcrop (55 km^2), give it a first-order hydrogeological role.

The water supply to this aquifer is provided by abundant precipitation (on average 1,300 mm/year), with snowfall at altitudes (between 1,000 and 2,000 m). Also, its position downstream, from a large halo of impermeable and semi-permeable land, ensures additional volumes of water by "restoring surface water". The numerous sinkholes and the localized and diffuse losses of rivers mean that the water collected far from the aquifer is totally or partially lost in this very permeable aquifer. It should be added that the waters of karst depressions (dolines, Ouvalas, and poljés) completely infiltrate the karst's interior.

The Middle Jurassic aquifer (J4) is manifested by the famous karstic resurgence of Dalli-Ghaouaouit (Kfar Hilda) and by around thirty small and medium springs, the most important of which are those of Houb (Nabaa el Korsi, Nabaa el Karm, Mar Sarkis), from Tannourine el Faouqa (Houaïlifate), Aïn er Raha and Nabaa ez Zahlé (Tannourine and Tahta) (Figure 3).

Cenomanian (C4) And Turonian (C5) Aquifers

This is the largest aquifer in the study area. It is divided into two parts: (1) Jord Tannourine's Cenomanian (C4) in the east, and (2) Cenomano-Turonian (C4-5) on the western half (Figure 4). The thickness of the carbonate layers (dolomites, limestones, marl limestones, etc.) exceeds 500 m in the high mountains and 750 m in the low mountains.

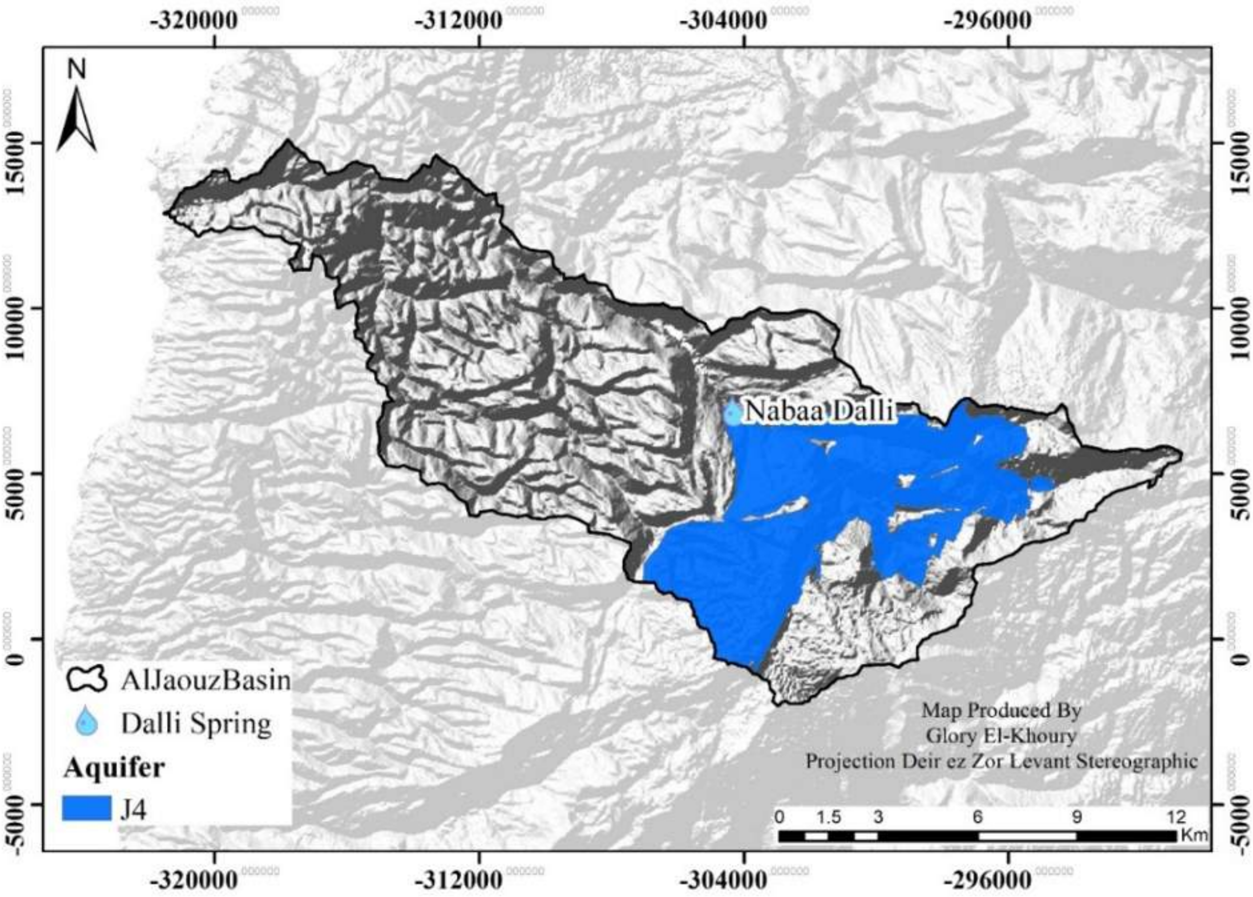

Figure 3: Middle Jurassic (J4) aquifer of Nahr Al-Jaouz River Basin

Cenomanian Aquifer of Jord Tannourine (C4)
The Cenomanian (C4) majestically outcrops at Jord Tannourine (east of the map). It forms part of Lebanon's high peaks, extending to Makmel and Qornet es Saouda in the north, the Jabals Sannine and Knaïssé in the south and the Yammouneh region in the east. The region is well-watered. Precipitation, mostly in the form of snow, averages 1,800 mm per year.

Regarding the study area, the thick layers of the Cenomanian (C4) plunge with a kind of flexure or significant dip. The direction of the dip is east and southeast. The infiltrated water flows towards the interior of the massif. It does not flow out to the west, hence the almost total absence of essential sources at the foot of Jord Tannourine's edge escarpment. The small springs of Jdid (Harissa) and Chaaïya (Zaaroura) spring from the contact of the lower Cenomanian with the green marls of the Albian (springs of discharge). Their flow rates do not exceed 5 l/s on average.

The most important Cenomanian spring of Jord Tannourine (in high mountains) remains the spring of Rahoueh (altitude 2,160 m, water temperature 5.2°C, flood flow, 200 l/s, sorting flow: 5 l/s, average flow: 40 l/s). This is a spring of discharge in a rather synclinal bottom. It springs from a large cave with a meridian direction and 950m length. The cave is crossed by a meandering stream, which took advantage of the marly and marl-limestone beds at the base of the Upper Cenomanian (C4c), for 16 laterally drain waters of the syncline, and flow towards the vast polje of Sahlet er Rahoueh. Given its altitude and water quality, the Rahoueh spring is captured for the drinking water supply of Tannourine el Faouqa and its hamlets.

The Cenomano-Turonian (c4-5) Aquifer in the western half of the Jaouz Basin
It rests on a waterproof sole formed by the green marls of the Albian (C3) and the different layers of the Lower Cretaceous (C1-2). The thickness of the carbonate beds as well as karstification, result in high permeability and a very high infiltration index. The precipitated water on this aquifer leaves the surface and sinks deeply to form underground reserves behind

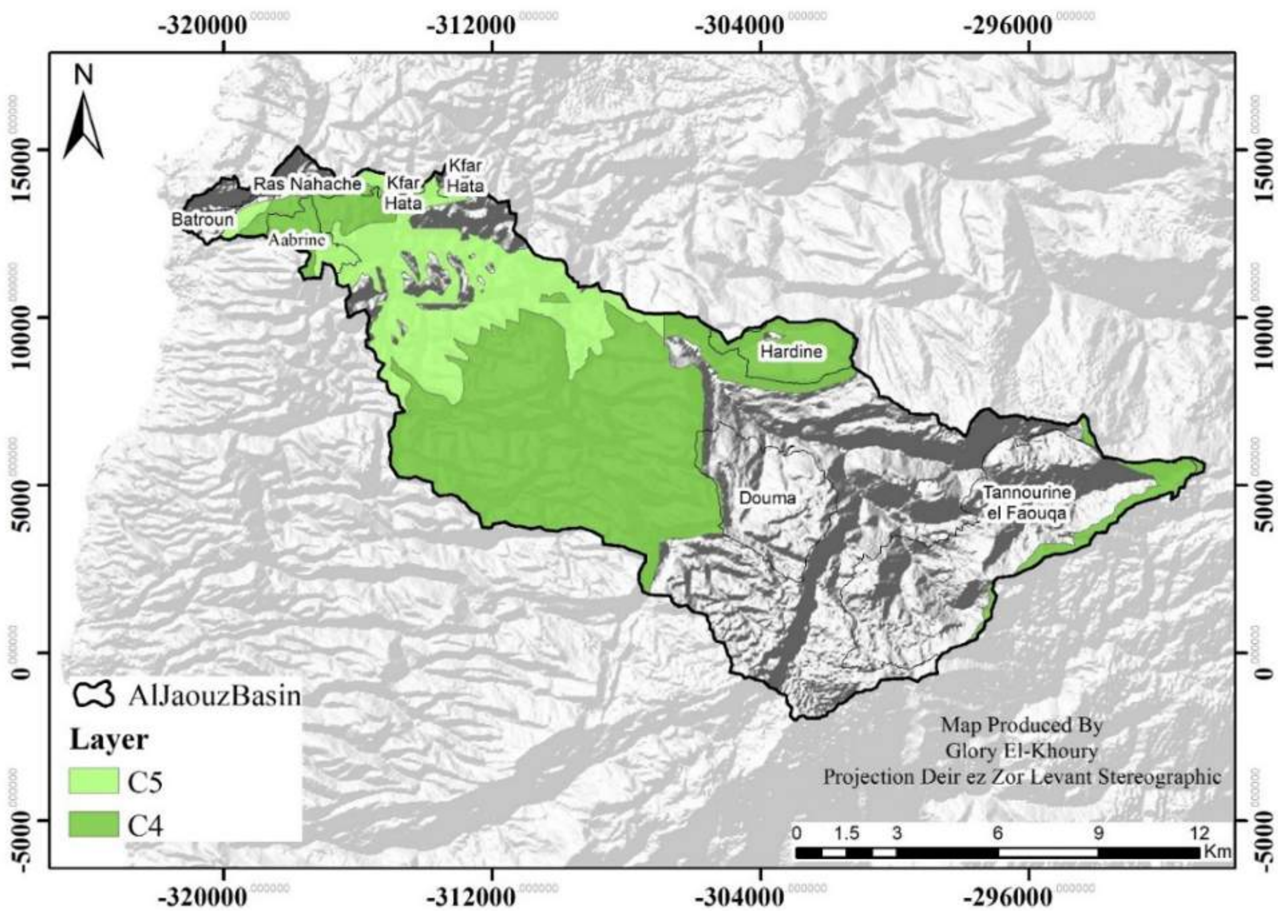

Figure 4: Cenomanian (C4) and Turonian (C5) aquifers of Nahr Al-Jaouz River Basin

the famous anticline with an impermeable core of Smar Jbaïl-Aabrine-Kfar Hata. The groundwater, which can leak westward along the large faults, contributes to the nourishment of many coastal and submarine sources of the Batroun coast.

The large east-west faults direct the groundwater at depth to the west, i.e., towards the drowned areas of this karst massif. Curiously, this groundwater does not manifest anywhere west of the study area. No large spring is reported over a large area. This deprives the low and medium mountains of Batroun and parts of the district of Koura of an accessible, exploitable resource (Libanconsult, 2005).

2.2 Soil of the study area

Lebanon's soils are generally calcareous, except for sandy soils created by basal strata. Lebanon has a diverse landscape of sloping and steep ground (FAO, 2009). Most of Lebanon's soils are very shallow, particularly in mountainous areas, with just a few metres of depth. Many soils originate from transported materials deposited by water or gravity. They vary greatly in consistency and productivity and are usually Mediterranean in nature. Besides the sandy soils, lithology has diversified soil properties, most of which are base-saturated calcareous soils. The most commonly known soils are Terra-Rossa and Rendzina, which account for around 70 per cent of Lebanon's soil. Its mountainous terrain mostly mainly characterizes Lebanon, and the soils are discontinuous, young, fragile and vulnerable to erosion with truncated mantle and visible rock outcrops (MOA, 2001).

Referring to the World Reference Base for soil resources and after digitizing the soil map of Nahr Al-Jaouz River Basin, the study team identified nine main types of soil distributed across the basin and defined by qualifiers depending on their texture, diagnostic horizons, properties or materials, chemical characteristics, qualifiers describing

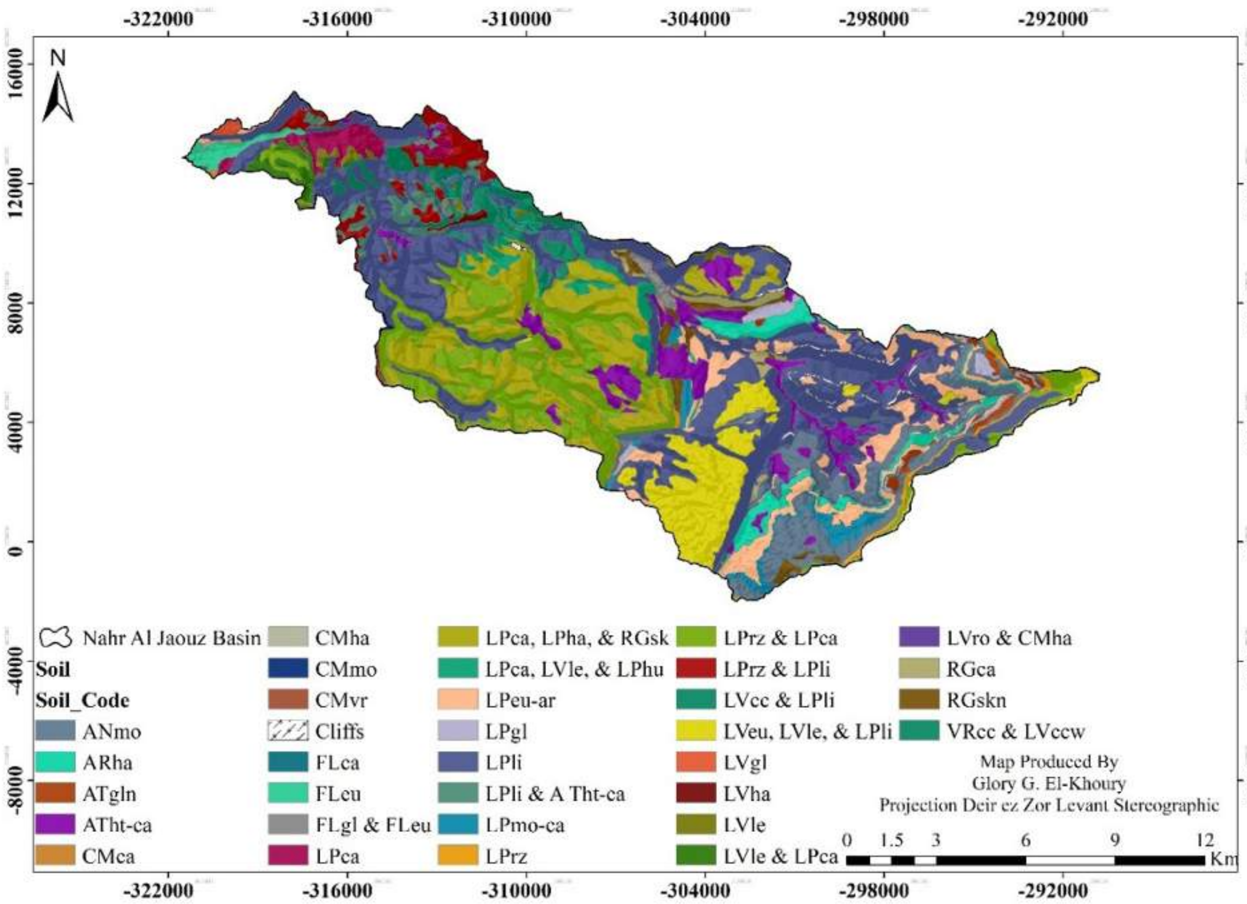

Figure 5: Soil map of Nahr Al-Jaouz River Basin

physical characteristics, qualifiers describing surface characteristics, qualifiers describing textural characteristics, including coarse fragments and qualifiers describing colour.

The main soil types across the Nahr Al-Jaouz River Basin are:

a. Leptosols are free-draining and very shallow soils, overlaying on continuous rock with 25 cm thickness from the soil surface to the hard rock or very high calcareous material. These are also extremely stony and/or gravelly.

b. Cambisols are young soils with beginnings of subsurface soil development. The parent material transformation is clear from the structure formation and the brownish discolouration signifies the rising percentage of clay material and the decrease in carbonate material. Cambisols are used intensively and are generally suitable for agricultural land. Most cambisols develop in areas with excess precipitation and terrain slope that permit runoff discharge of excess water. Also, Cambisols are medium-textured and have good structural stability, high porosity, good water holding capacity and internal drainage.

c. Fluvisols are genetically young soils in alluvial deposits. These soils occur in river sediments, lacustrine, and marine deposits.

d. Regosols are soils with very weak developed minerals in unconsolidated materials. They are not particularly shallow or rich in gravel, sand or fluvic materials. Regosols are prone to erosion in sloping terrain due to the low coherence of the matrix material. They are sensitive to drought because of their low water holding capacity and high permeability.

e. Luvisols are soils with high clay content in the subsoil than in the topsoil due to the pedogenetic processes, especially of the clay migration. Most Luvisols are well drained with a wide variety of unconsolidated materials. Still, Luvisols in depression areas with shallow groundwater may develop gleyic soil properties in and below the argic horizon.

f. Anthrosols include soils that have been deeply changed by human activities such as adding organic materials or domestic waste, irrigation and agriculture. Hortic Anthrosols are well-drained, particularly those near higher-ground villages; some have formed from wetland soils and have minimal internal drainage.

g. Vertisols are hard, churning clay soils with a high percentage of swelling clay. When they dry out, these soils form deep, large cracks from the surface downward, which occurs in most years. During the dry season, vertisols become very hard and very sticky during the wet season. If properly handled, Vertisols are productive soils. Infiltration of water with surface mulch or fine tilth in dry Vertisols is initially rapid. However, the water infiltration rate becomes almost negligible once the soil surface is thoroughly wet and cracks have closed. Vertisols flood easily if the rains continue at this point. Vertisols with considerable shrink/swell capacity are measured with the highest infiltration rates but preserve a relatively fine class of structure. The data on the water holding capacity of Vertisols varies widely, which can be due to the complex pore space dynamics.

h. Arenosols consist of sandy soils, either developed in residual sands from in situ weathered sediments or rock rich in quartz, or soils formed in newly deposited sands such as deserts dunes and beach lands. They originate from translocated materials of sandy texture. Some Arenosols occur in relatively small areas with extremely weathered siliceous rock. Also, they occur in a wide range of habitats and their potential for use in agriculture varies accordingly. The common feature of all Arenosols is their coarse texture, which usually has high permeability and low water and nutrient storage capability.

i. Andosols are soils that develop in volcanic ejecta in almost any climate region. Even so, Andosols may occur in materials rich in silicate due to acid weathering under pre-humid and humid climates. They have good potential for agriculture. In general, Andosols are usually fertile soils, especially those containing intermediate or basic volcanic ash, that have not been subjected to excessive leaching. Exceptions to this rule are some types of Andosols that are highly hydrated, dried out firmly, for example after deforestation. The soil surface material of such type crumbles to become hard granules easily removed by surface run-off water (FAO, 2006).

2.3 Climate of the study area

Located between 33˚22′ and 34˚40′ north latitude, Lebanon lies between the temperate and the tropical regions. It has a typical Mediterranean climate as it sits in the middle of the eastern shore of the Mediterranean Sea.

The study area is located on the northern borders of high subtropical pressures (subsidiary branch of Hadley's cell), near the great deserts of Arabian and African Sahara. It is influenced by the Mediterranean Sea and the Jet stream. In summer, the influence of high subtropical pressures (present at altitude) prevents airflow and causes absolute drought from June to September. At the surface (sea level), the entire eastern Mediterranean is under low thermal pressure. During the rainy season from October to May, the region is subjected, at altitude, to a westerly circulation of air masses (temperate influences) materialized by the subtropical Jet Stream while a low-pressure area covers the Mediterranean. This flow is zonal (rapid circulation of the Jet, 150 to 500 km/h) or undulating (slow circulation of the jet, speed <150 km/h), with alternating periods of good and disturbed weather (Traboulsi, 2014).

Precipitations are concentrated in the rainy months with more than 50 per cent of the overall annual total during the winter months of December, January and February. The total annual rainfall is about 600 mm on the coast and increases to more than 1,800 mm on the mountain peaks of Mount Lebanon (Traboulsi, 2010). Such spatial variation is compounded by annual rainfall fluctuations with local variations related to topography. On a monthly scale, the transition period months (at the beginning and end of the rainy season) have the highest variability levels, specifically when rainfalls are more important for vegetation (Doumit et al., 2019).

Summer is the warmest season in the study area, with the summer drought enhanced by high temperatures. High heat frequency and intensity are also experienced during spring and fall peaks along the coast linked to the weather patterns of Khamsin, a hot, dry, dusty wind caused by Saharan depressions in the spring and by Egyptian-Sudanese depressed thalweg in the fall (Traboulsi, 2014).

2.3.1 Precipitations

Two main characteristics must be emphasized. First, precipitations are heavy throughout the region, while regional or local variations occur depending on altitude, exposure or latitudes. On the other hand,

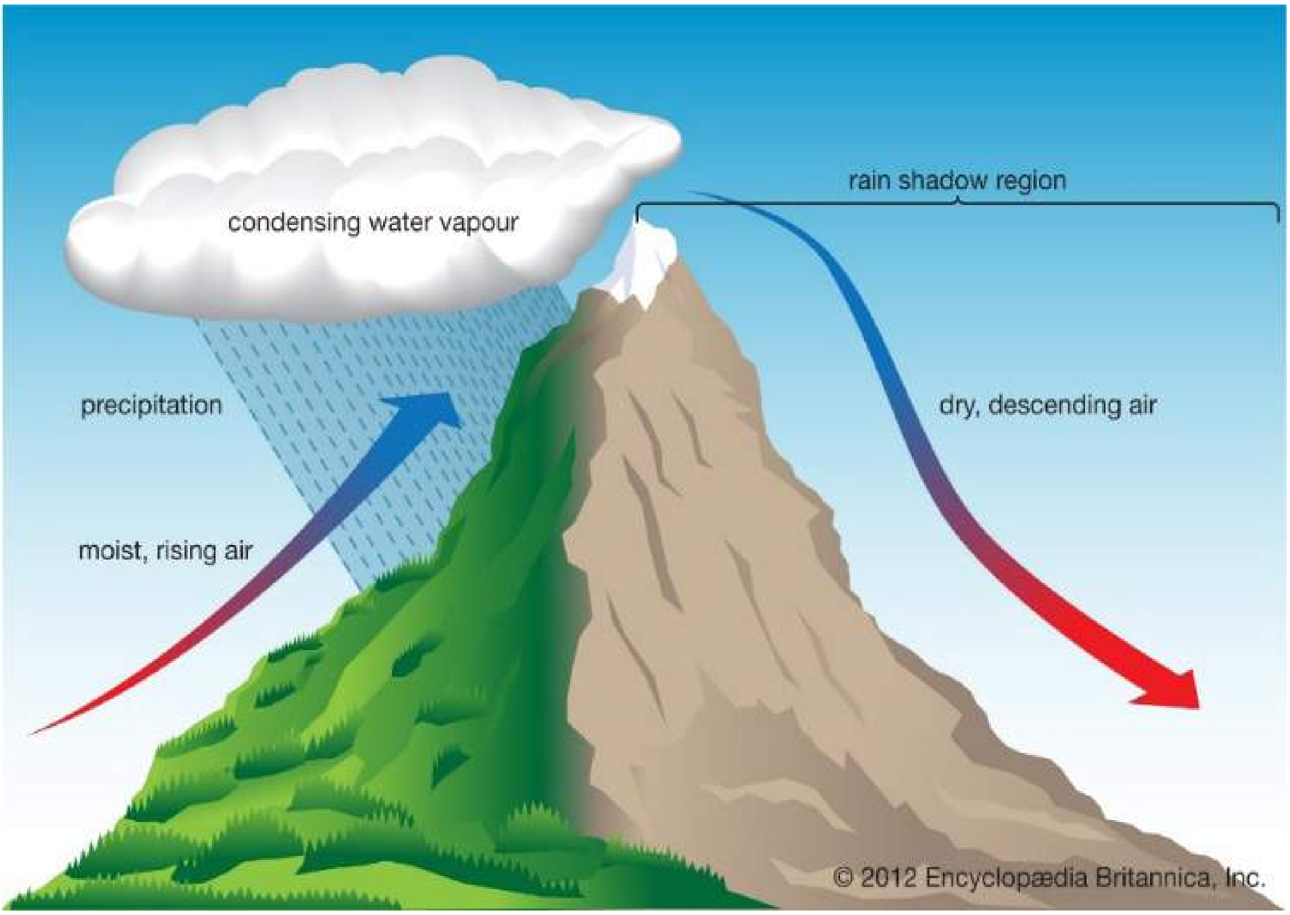

Figure 6: Orographic System

the regime is typically Mediterranean, with marked summer drought, high rainfall variability and sudden, frequent shower (Sanlaville, 1977). Lebanon's rugged topography gives it a specific orographic precipitation type. The orographic effect is caused by the rising of air masses on the windward front slope to the west (Figure 6). The humid air from the Mediterranean Sea rises upland along with the Mount Lebanon chain, acting as a shield all across the coast. The rising air mass condenses, triggering coastal thunderstorms. The shadow of the rain appears as the air descends to the east on the leeward side of the mountain. Descending air is drier due to the heavy rainfall on the windward side of the mountain. Lower rainfall rates are recorded inland on the rain shadow side of Mount Lebanon. The topographic complexity of mountain areas throughout the country induces high spatial variation of precipitations (Jomaa et al., 2019).

Climate studies in Lebanon lack climate data. Rainfall data in the country has many limitations and their reliability is sometimes problematic. The oldest observations date back a hundred years (Traboulsi, 2010). Since remote sensing is a different approach to rainfall analysis that captures variations on a temporal and spatial scale relative to gauges (Jomaa et al., 2019), the study team used the CHIRPS (The Climate Hazards Group Infrared Precipitation with Stations) datasets for the Nahr Al-Jaouz River Basin. It extends previous approaches to 'smart' interpolation methods and high resolution, long-term record precipitation estimates based on infrared Cold Cloud Duration (CCD) observations. The yearly precipitation curves at Nahr Al-Jaouz River Basin show two yearly peak-precipitation rates, 2012 and 2019 with 1,210.13 mm and 1,270.2 mm, respectively. Years 2014 and 2017 had minimal precipitation rate with 645.91 mm and 619.23 mm (Figure 7).

The rainy season does not really begin until mid-October and lasts until mid-April, but rainfall mainly occurs from December to February. These three months generally receive 60 to 70 per cent of the total annual, with a net maximum in January of 20 to 27 per cent of the total annual.

The dry season is very long. The absolute maximum precipitation of July, August and September is 5.7

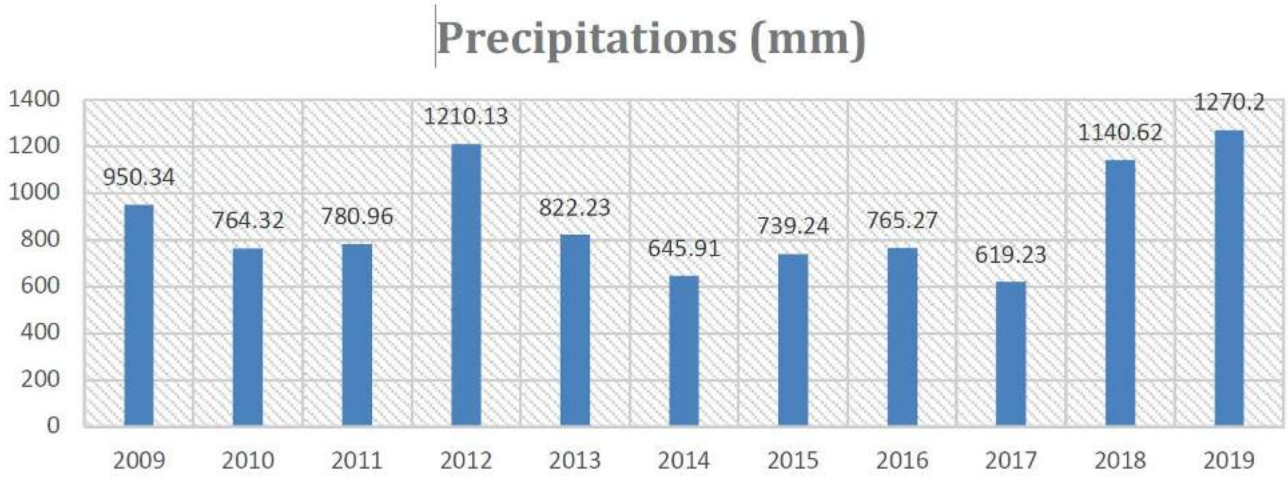

Figure 7: Yearly mean precipitation

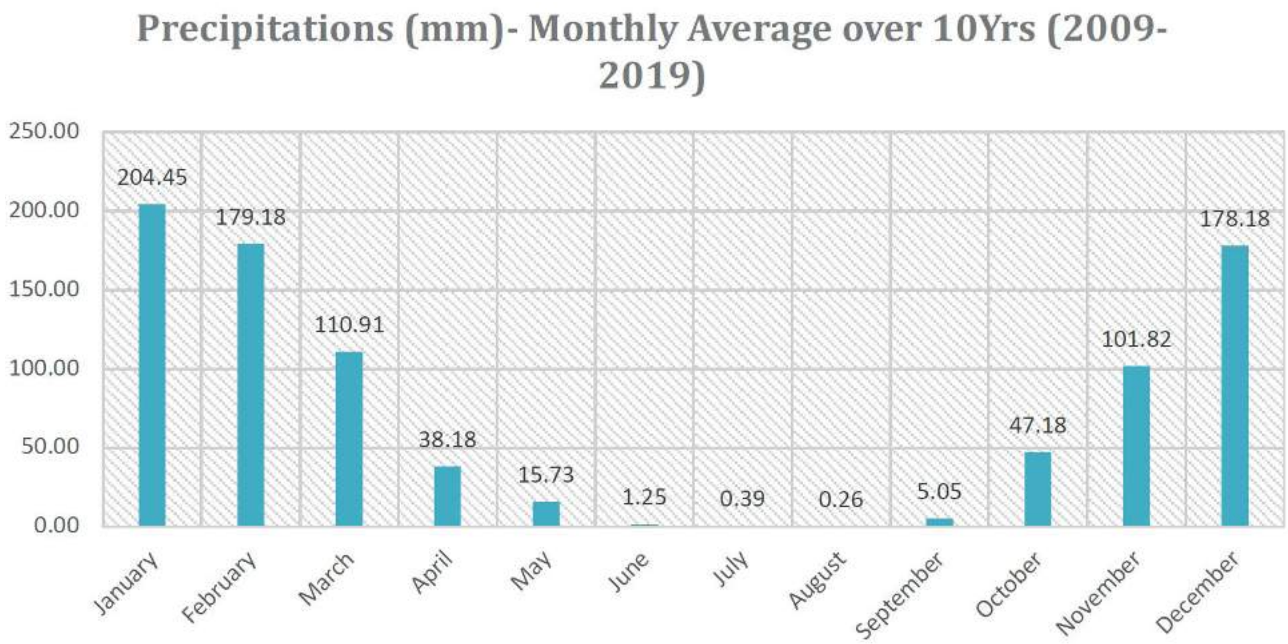

Figure 8: Monthly average precipitations over 10 years

mm. May and June have more with 15.73 mm in May and 1.25 mm in June (Figure 8). During these five months, from May to September, even if fog or clouds form between 600 and 1,200 m altitude, the country experiences a beautiful weather with an incredible and exhausting fixity (Sanlaville, 1977).

At Nahr Al-Jaouz River Basin, the peak-precipitation rate of the rainy season is in January, with a monthly highest rate of 204.45 mm over the mountain area, where precipitation rate is the highest and Mount- Lebanon receives the most precipitation toward westward slope. Rainfall distribution in February is similar to January with 179.18 mm monthly high rate. In March precipitation begins to decrease from a high rate of 110.91 mm to 38.18 mm for April and 15.73 mm for May.

Summer always remains remarkably dry with 1.25 mm for June, 0.39 mm for July, and 0.26 mm for August. In early fall and late spring, rainfall follows the topographic effect, which is the period of no rain all over Lebanon.

In September, precipitations are insignificant with 5.05 mm. November shows the first precipitations signifying the beginning of the rainy season with 47.18 mm, and continue to increase in December with 178.18 mm. In general, the rain falls in sudden thunderstorms interspersed with lightning. The morphological effect of this precipitation is significant in a country where the slopes are steep and the vegetation cover is discontinuous (Sanlaville, 1977). The distribution and variability of precipitation requires water management.

2.3.2 Temperature

The climate in Lebanon is affected by several combining geographical factors, which leads to a striking climatic originality that persists, like all Mediterranean region, in its summer drought coupled with high temperatures and the warmth of the rainy season (Bolle et al., 2002). Due to the proximity of the sea, the protective role of the mountain range and the large predominance of western winds, temperatures are mild, relatively high and low in contrast (Sanlaville, 1977). Since climate studies in Lebanon lack data, the study of temperatures in the study area was based on the FLDAS (Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System). The FLDAS is a custom instance of the NASA Land Information System. Its datasets include a collection of simulated land surface parameters from the Noah 3.6.1 model. The data are in 0.10˚ resolution from January 1982 until the present (https://disc.gsfc.nasa.gov/).

At the coastal area of Nahr Al-Jaouz River Basin, the yearly mean temperature varies between 18°C and 20°C. It decreases with the elevation following a thermal gradient of 0.6°C every 100 m. Around 1,000 and 1,500 m, mean temperature varies between 14°C and 16°C, 1,500 and 2,000 m the temperature registers a mean varying between 12°C and 14°C, and at more than >2,000 m the temperature is between 10°C and 12°C (Figure 9). There was some contrast of temperatures at the coastal area and the annual amplitude is relatively low with 14°C.

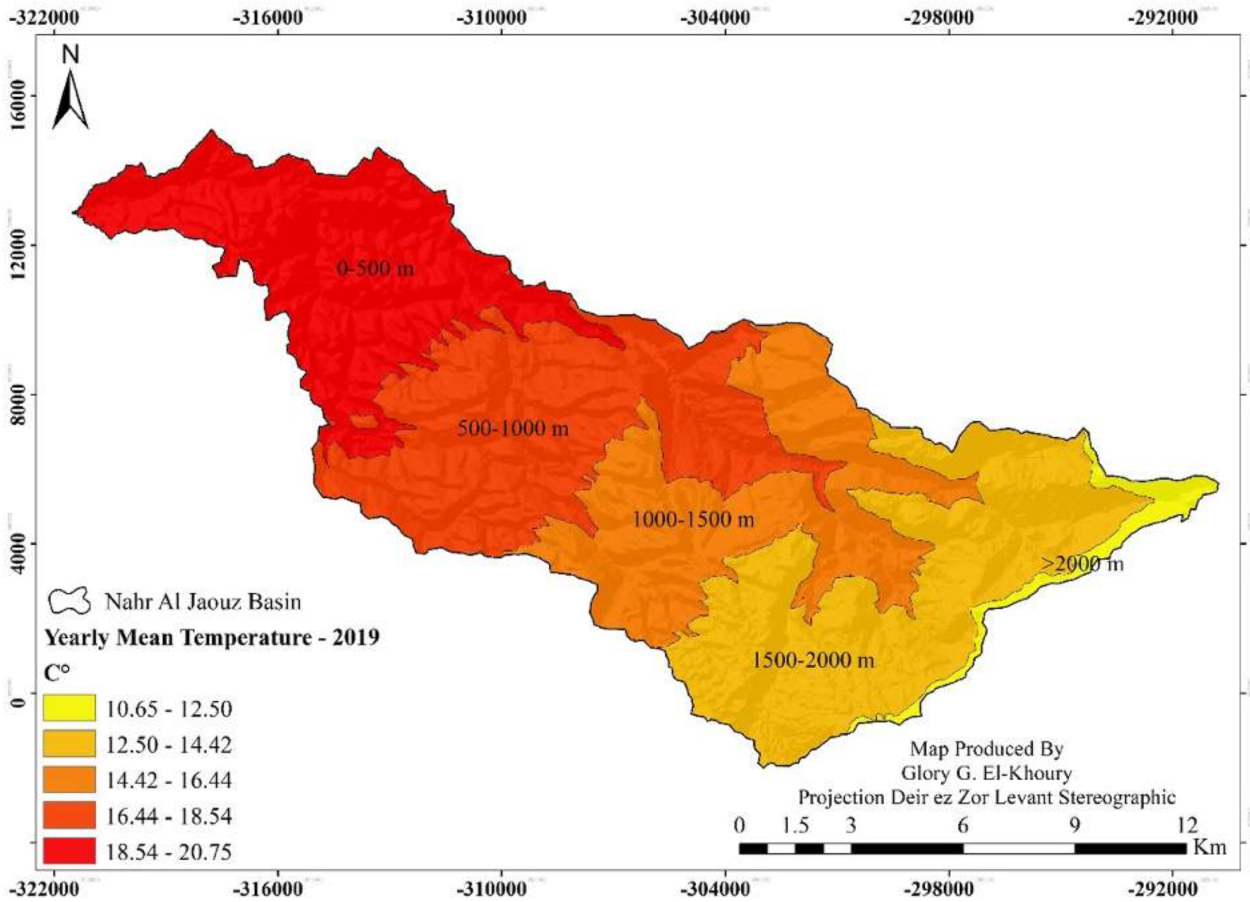

Figure 9: Yearly mean temperature at Nahr Al-Jaouz Basin-20

January is the coldest month, with 8°C as monthly mean, 14°C as maximal monthly mean, and 2°C as minimal monthly mean. The highest average temperatures in 2019 in the study area were observed in July and August with 21°C mean, and 27°C maximal monthly mean (Table 1).

The summer drought is strengthened by high temperatures. Although summer is considered to be the hottest season in the region, the frequency and intensity of high temperatures are also experienced in spring and autumn due to the khasim (Traboulsi, 2014).

Autumn at Nahr Al-Jaouz River Basin is relatively warmer than spring, where temperatures registered 21°C in September, 19°C in October, and 16°C in November, while in March the average is around 9°C, 12°C in April, and 19°C in May (Table 1 and Figure 10).

	Temperature (°C)		
	Monthly mean	Maximum monthly mean	Minimum monthly mean
January	8	14	2
February	8	14	3
March	9	14	3
April	12	17	6
May	19	24	15
June	21	26	16
July	22	27	17
August	22	27	18
September	21	26	16
October	19	24	14
November	16	22	11
December	10	16	5

Table 1 Temperature distribution over 2019 in the Nahr Al-Jaouz Basin

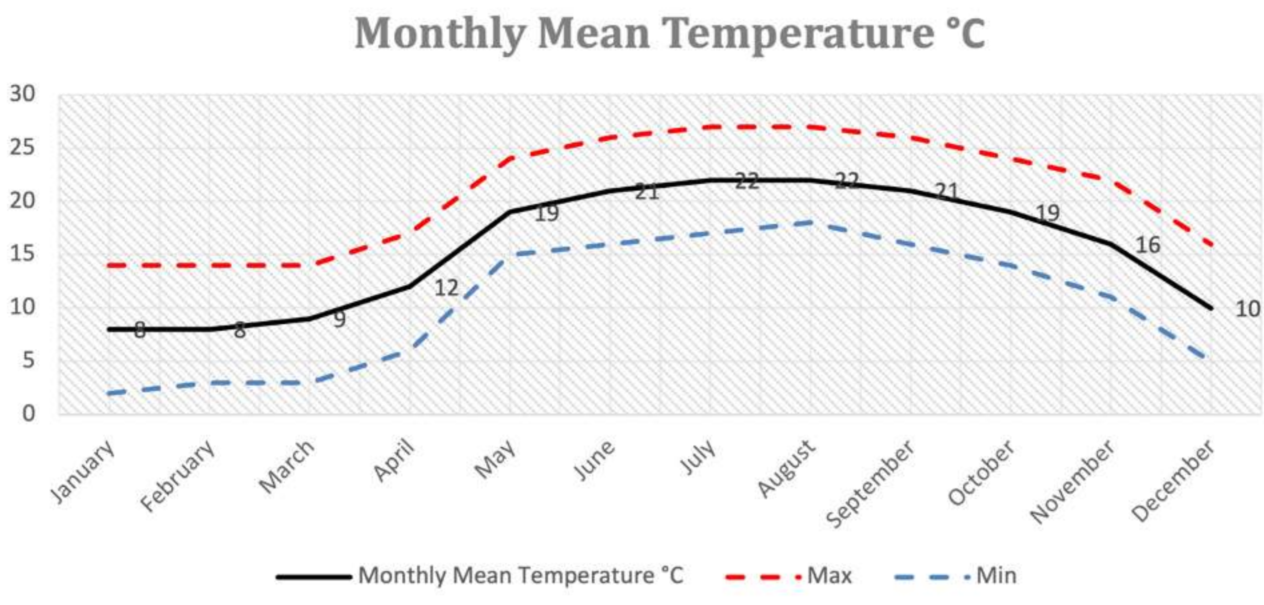

Figure 10: Monthly mean temperature, 2019

In the present study, the groundwater potential zone mapping of Nahr Al-Jaouz River Basin was carried out by integrating remote sensing data and conventional maps, including soil sheets (scale 1/50,000) provided by the National Center for Remote Sensing. The first step was to convert the conventional maps into digital format by scanning in TIFF format and then geo-referenced into Deir ez Zor Levant Stereographic. Remote sensing data were used directly for thematic map generation because of their digital-ready format. Eight different themes of data were prepared: geology, soil, lineament density, stream density, lineament and stream intersection density, slope, rainfall, and land use and land cover. Each thematic map was then reclassified using the Reclassify tool of Spatial Analyst in GIS ArcMap 10.4 software.

3.1. Geological map

Geological features are responsible in controlling the permeability and the porosity of an aquifer material and are thus known as indicators of hydrological characteristics (Benjmel et al., 2020), where geology plays a significant role in the occurrence of groundwater in any area (Kumar et al., 2016). The geology of an area is a significant criterion as it can augment or reduce the extent of runoff water percolation to aquifer rocks. The permeable features facilitate water infiltration, through the subsurface flows. In comparison, impermeable rock promotes surface runoff (Benjmel et al., 2020).

Lithological formation map

Geological map with a scale of 1/20,000 was digitized and the geological formations were extracted as vectors then converted into raster carried out by using GIS ArcMap 10.4.

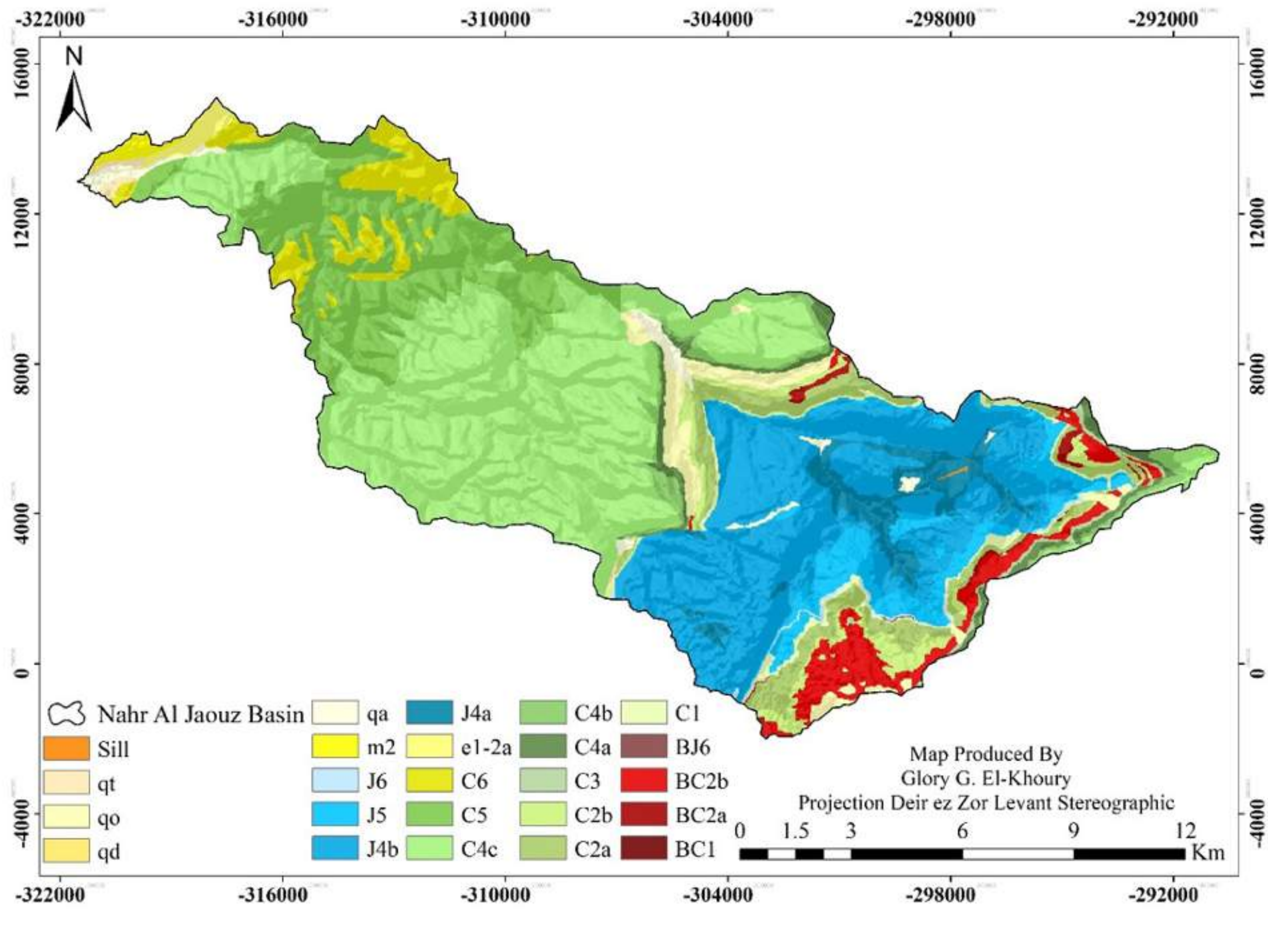

Figure 11: Lithological map of Nahr Al-Jaouz River Basin

Reclassification

The geological map was classified into class 1 for impermeable formations, class 2 for semi-permeable formations, and class 3 for permeable formations (Figure 12, Table 2 and Table 3). The permeable formations are potential locations in groundwater infiltration relative to impermeable formations. The numerical values are set depending on the capability of infiltration of each geological feature, which ranges from low to high.

Era	Period	Epoch	Stage/Age	Symbol	Permeability
Cenozoic	Quaternary	-	-	qo	Permeable
		-	-	qt	Semi-Permeable
		-	-	qa	Semi-Permeable
		-	-	qd	Impermeable
	Neogene	Miocene	-	m2	Permeable
	Paleogene	Eocene	-	e1-2a	Impermeable
Mesozoic	Cretaceous	Upper Cretaceous	Senonian	C6	Impermeable
		Mid-Cretaceous	Turonian	C5	Permeable
			Cenomanian	C4c	Permeable
				C4b	Impermeable
				C4a	Permeable
			Albian	C3	Impermeable
		Lower Cretaceous	Aptian	C2b	Permeable
				C2a	Semi-Permeable
				BC2b	Impermeable
				BC2a	Impermeable
			Neocomian	C1	Semi-Permeable
				BC1	Impermeable
	Jurassic	Upper Jurassic	Kimmeridgian	J6	Permeable
				BJ6	Impermeable
			Oxfordian	J5	Impermeable
		Mid-Jurassic	Callovian	J4b	Permeable
				J4a	Permeable
				sill	

Figure 11: Lithological map of Nahr Al-Jaouz River Basin

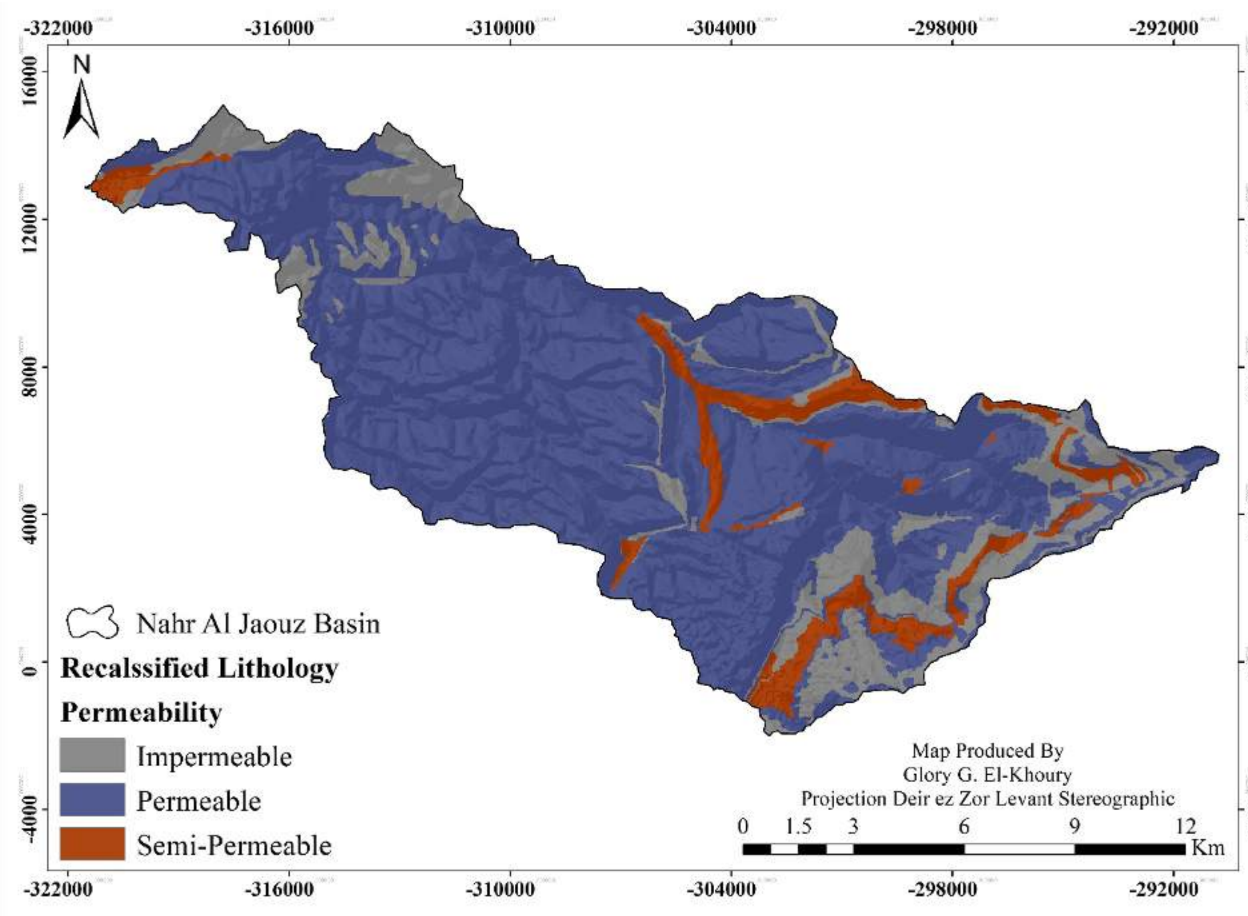

Figure 12: Reclassified geology

Class	Permeability	Groundwater prospect	Area (per cent)
1	Impermeable	Low	16
2	Semi-Impermeable	Moderate	8
3	Permeable	High	77

Table 3 Geology classes

3.2 Soil map

Soil is an essential component in delineating the groundwater prospect areas. The soil is distinguished by physiography, climate, and geology and plays a major part in groundwater recharge and runoff. The area's water retention capability relies on the soil type and permeability (Kumar et al., 2016).

Soil formations

The soil map was prepared using 1/50,000 scale soil sheets of Tripoli, Batroun, Jbeil, and Qartaba, and converted into digital format. The soil formations were extracted as vectors by digitizing and then converted into raster by the rasterization algorithm in GIS ArcMap 10.4.

Reclassification

The soil map was classified into three as in Table 4: Class 1 for impermeable soil formations, Class 2 for semi-permeable soil formations and Class 3 for permeable soil formations. The permeable formations are the potential locations for groundwater infiltration relative to impermeable formations. Depending on the capacity of infiltration, the values of each soil feature range from low to high. Figure 13 shows the reclassified soil permeability.

Class	Permeability	Groundwater prospect	Area (per cent)
1	Impermeable	Low	11
2	Semi-Impermeable	Moderate	22
3	Permeable	High	67

Table 4 Soil classes

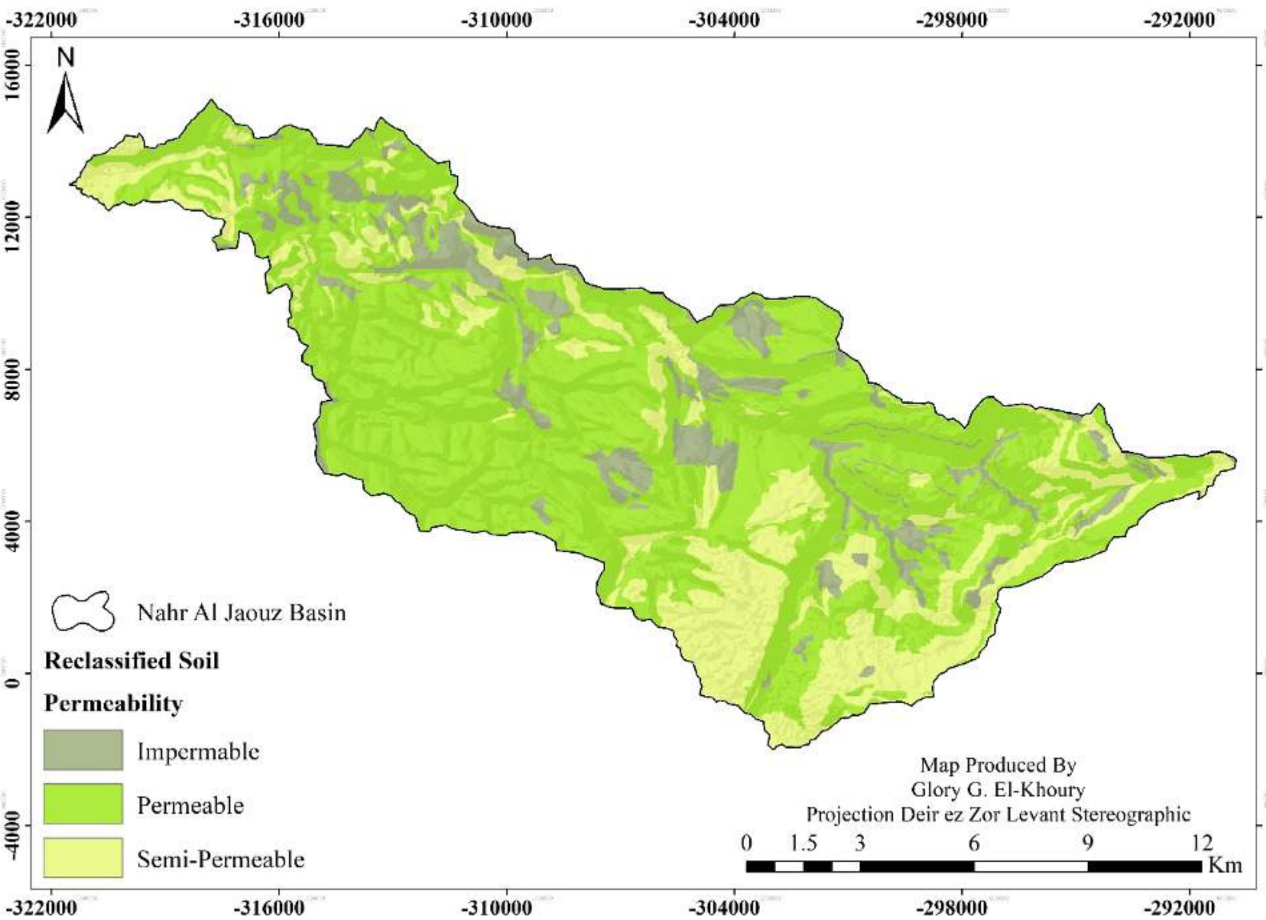

Figure 13: Reclassified soil map

3.3 Remote sensing

Remotely sensed data with optical, multispectral, multitemporal and broad synoptic coverage are very useful methods for identifying groundwater indicators (Khodaei et al., 2011). They are used for the qualitative assessment of groundwater supplies through the extraction and analysis of surface morphology and their hydrological properties. In addition, it offers better observations and a more comprehensive study of the different geomorphic units, landforms and line characteristics that regulate subsurface water conditions (Abdalla, 2012). This study used remote sensing data for the lineament extraction, preparing the land use/land cover map, calculating the slope, generating the stream features and preparing the rainfall map.

3.3.1 Lineament extraction

The mapping of lineaments or linear structural segments on the Earth's surface has always been a significant aspect of structural geological studies. They expose the architecture of the underlying rocks developed as a result of different tectonic movements over the geological history of an area (Javhar et al., 2019). Lineaments are long, linear, straight features enhanced by the permeability of the terrain (Suganthi et al., 2013) which geologically speaking, are typically faults, joints, or limits between stratigraphic formations (Kocal et al., 2004).

The lineament study aims to enhance the awareness of the linkage between the fracture systems and surface water penetration, controlling the water movement and infiltration. The existence of groundwater is governed and controlled by the occurrence of fracture, joints, lineaments and degree of weathering. Major lineament zones provide better targets for groundwater recharge than joints due to their larger widths, longer lengths, and acting as ducts and better interconnections with other fractures (Abdalla, 2012). Sentinel-2A (S2A) satellite images from the USGS earth explorer website, which was acquired on 7 November 2019, were used in this study. The LINE module of the PCI Geomatica software was used for automatic lineament extraction (Javhar et al., 2019).

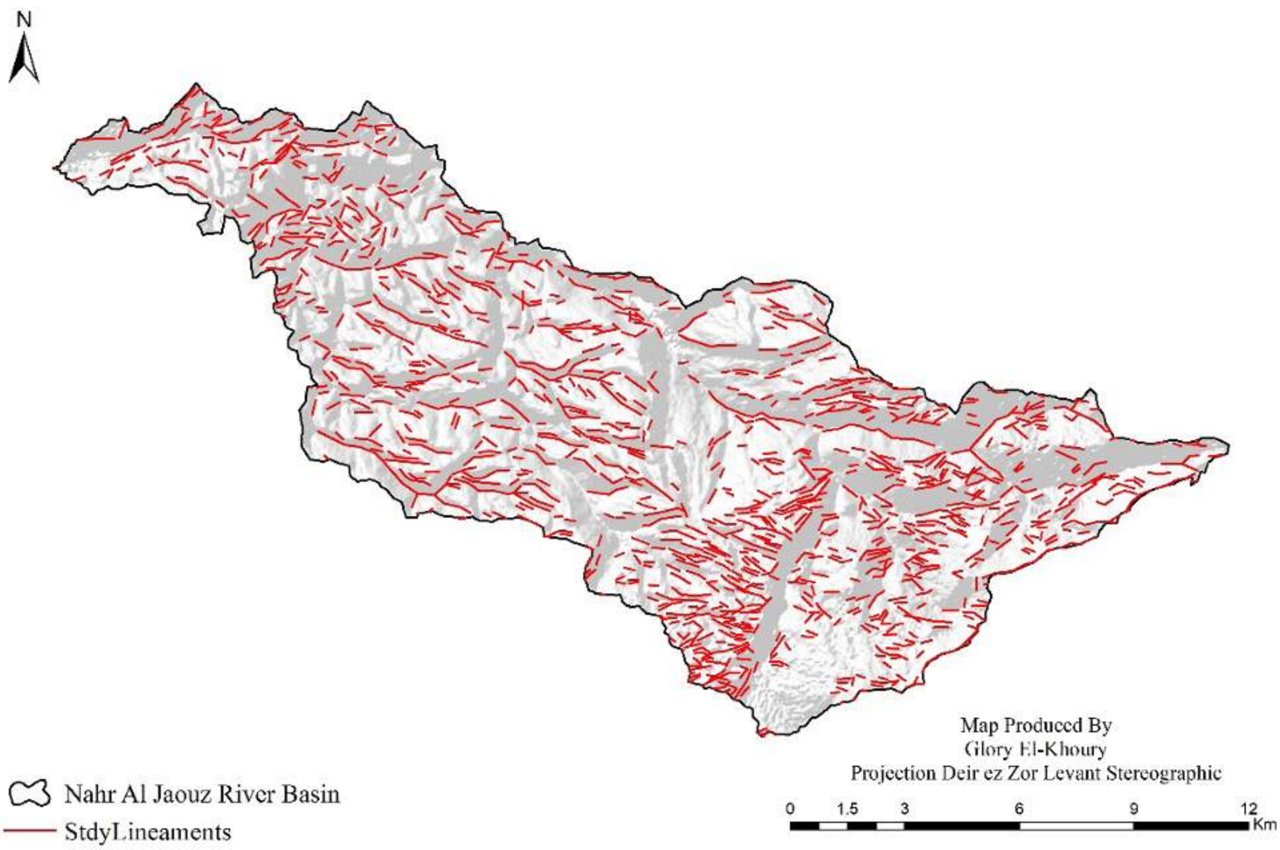

Figure 14: Lineaments of Nahr Al-Jaouz Basin

The prominent directions of the Nahr Al-Jaouz River Basin lineaments are northwest-southeast (NW-SE) and northeast-southwest (NE-SW), as shown in Figure 15. Directional analysis has been carried out to describe better the occurrence of lineament in the study area. Lineaments have been identified throughout the area. Figure 16 shows that the major lineaments are located southeast of Nahr Al-Jaouz River Basin at elevations 1,500 to 2,000 m.

Lineament density

The lineament density of the study area was calculated by using the Line Density tool from the GIS ArcMap 10.4 software. A lineament density map is a quantitative measure of the length of a linear feature expressed in kilometre per kilometre squared (km/km^2) (Waikar et al., 2014). The density of lineaments in a given area has a direct impact on the existence of groundwater in that area.

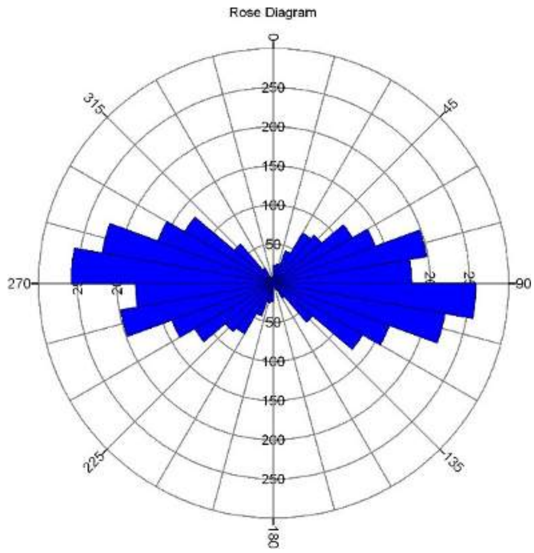

Figure 15: Rose diagram of lineaments

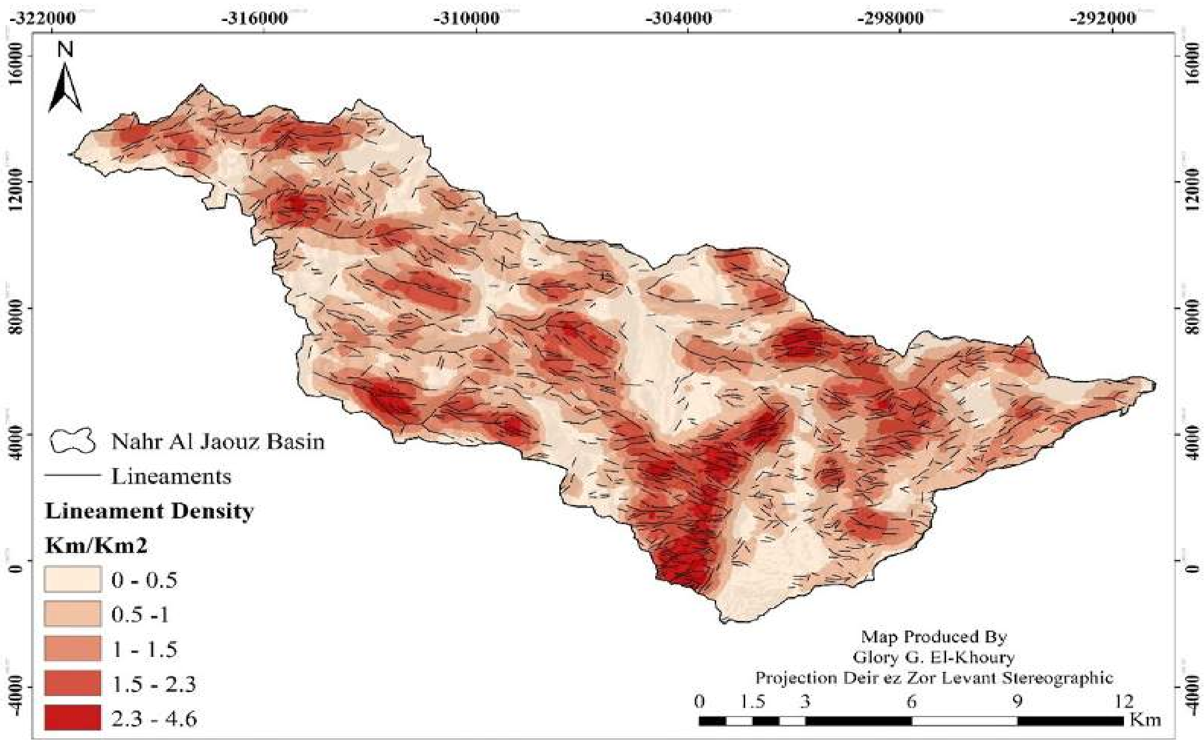

Figure 16: Lineament density map of Nahr Al-Jaouz River Basin

Class	km/km^2	Lineament Density Categories	Area per cent
1	0.5 – 0	Very Low	24
2	0.99 – 0.5	Low	36
3	1.56 – 0.99	Moderate	23
4	2.35 – 1.56	High	14
5	4.83 – 2.35	Very High	3

Table 5 Lineament density classes

Reclassification

The Lineament Density map was categorized into five: Class 1 for very low density, Class 2 for low density, Class 3 for moderate density, Class 4 for high density and Class 5 for very high density. The high lineament density is therefore a potential location for groundwater infiltration relative to the low lineament density region. The numerical values depend on the relative runoff infiltration capacity, which can range from very low to very high density and their importance for groundwater potential is determined by these values (Table 5).

3.3.2 Land use/land cover

Land use/cover mapping is one of the most significant applications of remote sensing. Land cover plays a major role in the development of groundwater sources, controlling many hydrogeological processes, such as infiltration, evapotranspiration and surface runoff. The surface cover provides roughness to the surface and decreases discharge thereby increasing infiltration. Infiltration in forest areas will increase and runoff will be reduced, while infiltration rates in barren and urban areas will decrease (Waikar et al., 2014).

The land use/land cover map of Nahr Al-Jaouz River Basin was generated using cloud free Landsat 8 images from 2013 to 2019 acquired between June and August (summer months). Each spectral band of Landsat data was converted to reflectance values using Radiometric Calibration. Then a Pan Sharp algorithm to enhance the spatial resolution of the images was applied, using the multispectral images as low resolution with 30 m and the panchromatic band as high resolution with 15 m. Converted reflectance values of Red (band 4) and Near Infrared (NIR) (band 5) are used to apply the Soil Adjusted Vegetation Index (SAVI).

$$SAVI = ((NIR – RED)/(NIR + RED + 0.5)) * (1.5)$$

The photosynthetic activity of vegetation depends on and may be limited by water availability, temperature, and radiation, among other factors. Usually the summer months are dry, and under such condition, the supply of surface water can be limited, which can decrease the photosynthetic activity. Nevertheless, the presence of groundwater enables groundwater-dependent vegetation.

In many regions around the world, vegetation indices derived from remote sensing data have been used to classify groundwater-dependent vegetations due to their ability to access water from sources other than precipitation. Eamus et al. (2006) defined the criteria for identifying groundwater-dependent vegetations (GDV), such as the probability of GDV remaining green and physiologically active even during dry periods and presenting minor seasonal changes in the leaf area index. Vegetation indices, such as Normalized Difference Vegetation Index (NDVI), are capable of capturing vegetation greenness and seasonal variation, which are used to determine the likelihood of GDV (Páscoa et al., 2020).

In the study, the SAVI index was used instead of NDVI because in areas where vegetative cover is low, SAVI corrects the NDVI for soil brightness. SAVI, derived from Landsat Surface Reflectance, is measured as a ratio of the R and NIR values with a soil brightness correction factor (L) specified as 0.5 to accommodate most forms of land cover.

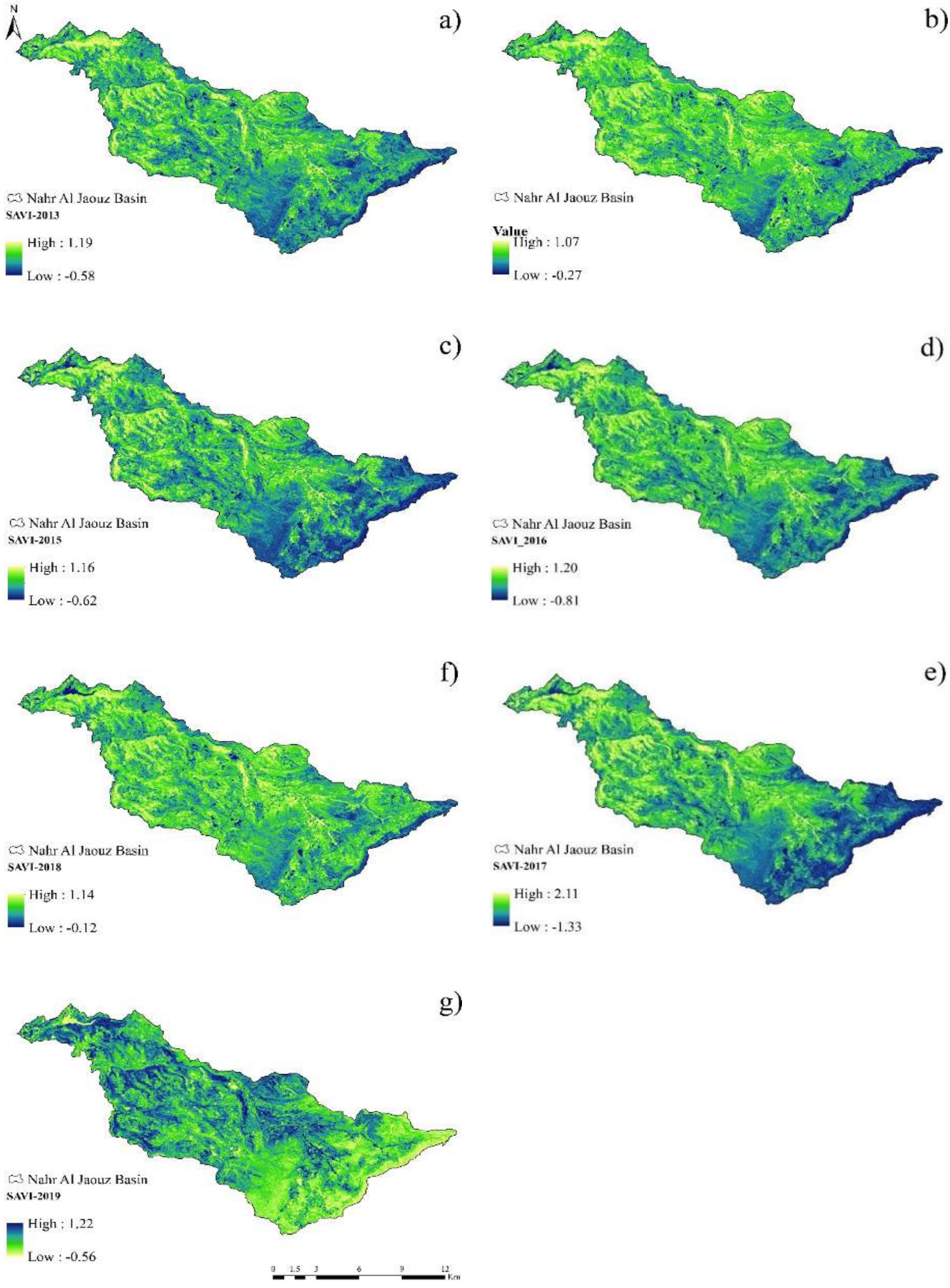

Figure 17: SAVI values of Nahr Al-Jaouz River Basin, 2013 to 2019

SAVI values for vegetated land areas (Figure 17) range from 0.4 to 1, with values greater than 0.4 indicating dense vegetation. Values less than 0.4 suggest no vegetation, e.g. barren areas or rock built up. And values below zero indicate water bodies. SAVI values are then categorized into five land cover classes: dense vegetation (forest), low-dense vegetation, sparse vegetation or grassland, barren and built-up areas, and water bodies.

Land use/land cover of the study area has been analysed using unsupervised classification, which shows five classes: dense vegetation, low-dense vegetation, grassland, water bodies, and built-up and barren. Built-up and barren have the same spectral signature so they have been merged into one class. It was necessary to correct this in order to show more important layers and separate the built-up from the barren areas. For that, vector data was extracted and the classes by attributes were modified depending on the Google Earth imagery. The vector layers were converted into a raster with 30 m spatial resolution as the output cell. These were then categorized using the reclassify tool Spatial Analyst ArcMap 10.4, into seven classes (Table 6 and Figure 18).

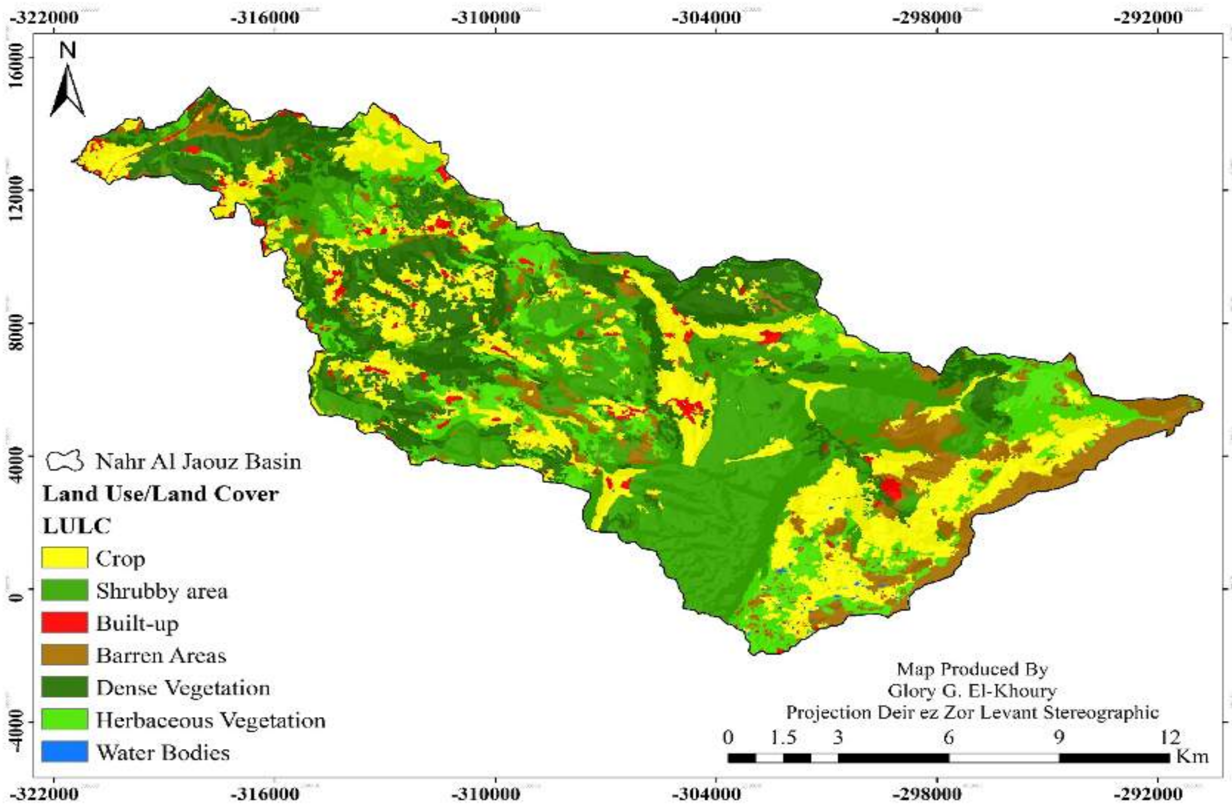

Figure 18: Land use/land cover graph of the study area

Classes	LU/LC	Area (per cent)
1	Built-up	2
2	Barren areas	10
3	Herbaceous vegetation	13
4	Scrubland	30
5	Dense vegetation	21
6	Water bodies	1
7	Crop	23

Table 6 Land use/land cover map of Nahr Al-Jaouz River Basin

Table 6 shows that 30 per cent of the basin is covered by scrubland and a good percentage of 23 per cent of crop land. Dense vegetation covers 21 per cent and 13 per cent are covered by herbaceous vegetation, which leaves 10 per cent for barren areas, 2 per cent for the built-up area, and 1 per cent for water bodies. That shows how Nahr Al-Jaouz River Basin is an agricultural vocational zone which demands more access to water.

3.4 Slope map

Slope is a key criteria of the steepness of the earth's surface. It provides useful information on the nature of the regional geological and geodynamic processes. The slope is one of the factors governing water penetration into the subsurface; hence an indicator of suitability for the prospect of groundwater (Venkateswaran et al., 2015).

Increased slope contributes to high surface soil runoff and erosion (Bathis et al., 2016), allowing less residence time for rainwater to infiltrate (Venkateswaran et al., 2015). The surface's gentle, nearly level slope allows water to flow very slowly and provides enough time to penetrate the soil (Bathis et al., 2016).

The slope map was generated from the SRTM Digital Elevation Model of 30 m spatial resolution image using ArcMap 10.4 slope algorithm of the spatial analyst tools, with an output measurement in percentage. The slope value of the study area ranges from 10 to 67 per cent (Figure 19).

The result shows that the highest slope values lie in the study area's valleys where there is major runoff circulation.

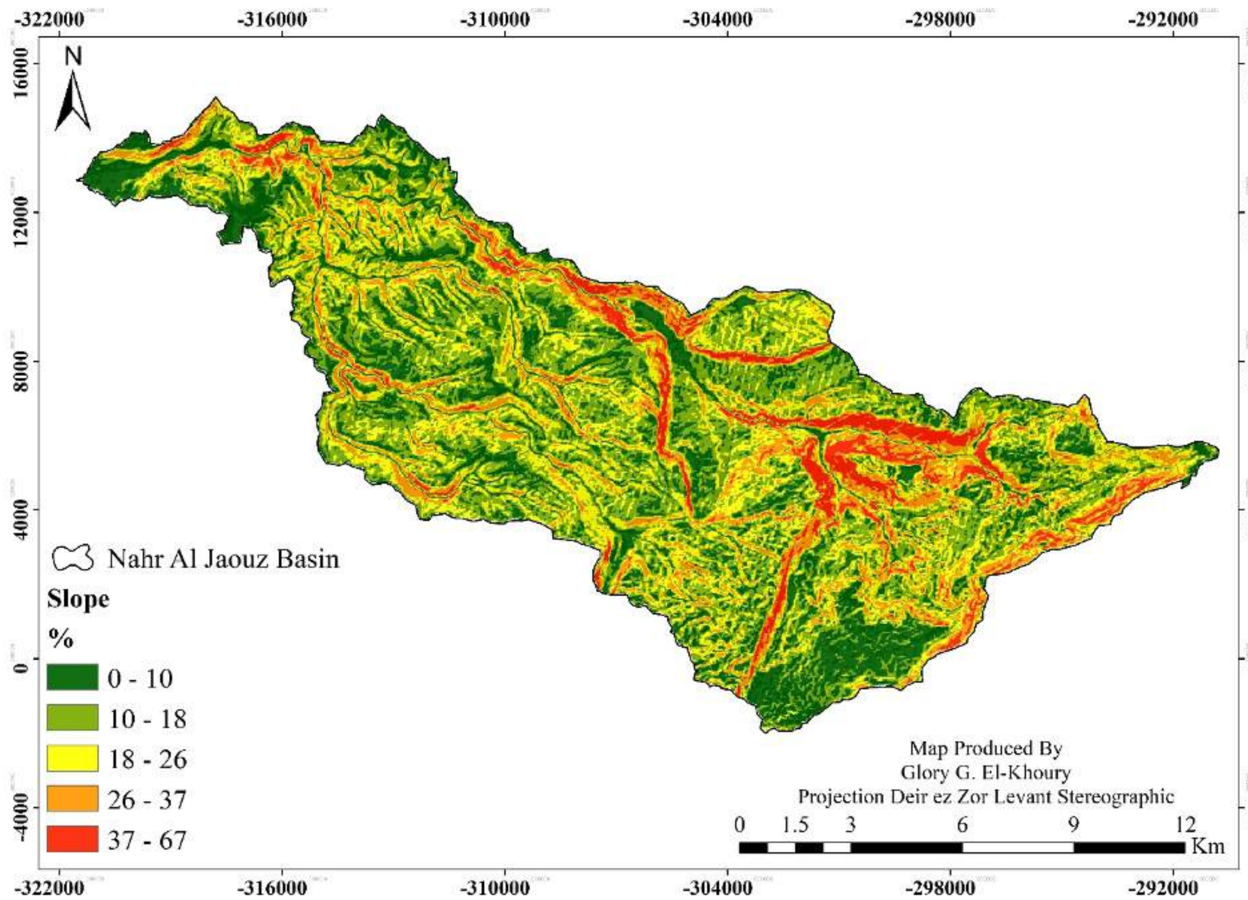

Figure 19: Slope map of Nahr Al-Jaoz Basin

Class	Percentage	Slope category	Groundwater prospect	Area (per cent)
5	0-10	Nearly level	Very High	22
4	10-18	Very gently sloping	High	33
3	18-26	Gently sloping	Moderate	25
2	26-37	Moderately sloping	Low	14
1	37-67	Extremely Sloping	Very Low	6

Table 7 Slope gradient and category of Nahr Al-Jaouz Basin

Reclassification

The slope map was categorized into five classes: Class 1 for extremely sloping value, Class 2 for moderately sloping value, Class 3 for gently sloping value, Class 4 for very gently sloping value, and Class 5 for nearly level sloping value. The very low slope value is a potential for groundwater because it provides adequate time for water to infiltrate into the sub-surface relative to the very high slope value indicating a steeper slope which promotes a high runoff. The values depend on the corresponding runoff infiltration capability, which ranges from Very low to Very high (Table 7) and is important for groundwater potential.

3.5 Stream map

The delineation of the Nahr Al-Jaouz River Basin stream network from the DEM requires identifying a threshold area. The threshold area reflects the minimum support area needed to drain to a point where water will flow in a concentrated manner and form a channel. Depending on this threshold area, various drainage networks could be obtained. The density of stream networks reduces as the threshold value increases. A drainage network with the main streams will be created using a high threshold area value (Doumit, 2017).
A threshold of 100 was used in the study. Cells with a flow accumulation value of 0 correspond to the ridges. To delineate the drainage network, a threshold is selected and all cells higher than 100 are classified as part of the stream network.

Stream density

Stream density (D) is the total length of the permanent and temporal streams and rivers divided by a unit size of area (A):

$$\mathrm{D} = \frac{\sum_{1}^{n} L}{A}$$

Where L is the length and 'n' is the number of rivers (Horton, 1945).

Stream density is regarded as one of the indirect recharge potential indicators (Khodaei et al., 2011), reflecting both surface and subsurface formation characteristics. More stream density means higher runoff (Venkateswaran et al., 2015). The stream density is inversely proportional to the infiltration rate that relies on the permeability of the bedrock. Permeable deposits are characterized by high infiltration rates which result in low runoff, being unable to flow over long distances or cutting more channels which, compared to impermeable deposits, show low stream density (Gaber et al., 2020). Stream density map of Nahr al Jaouz River Basin was prepared using line density tool in ArcMap 10.4 software (Figure 20).

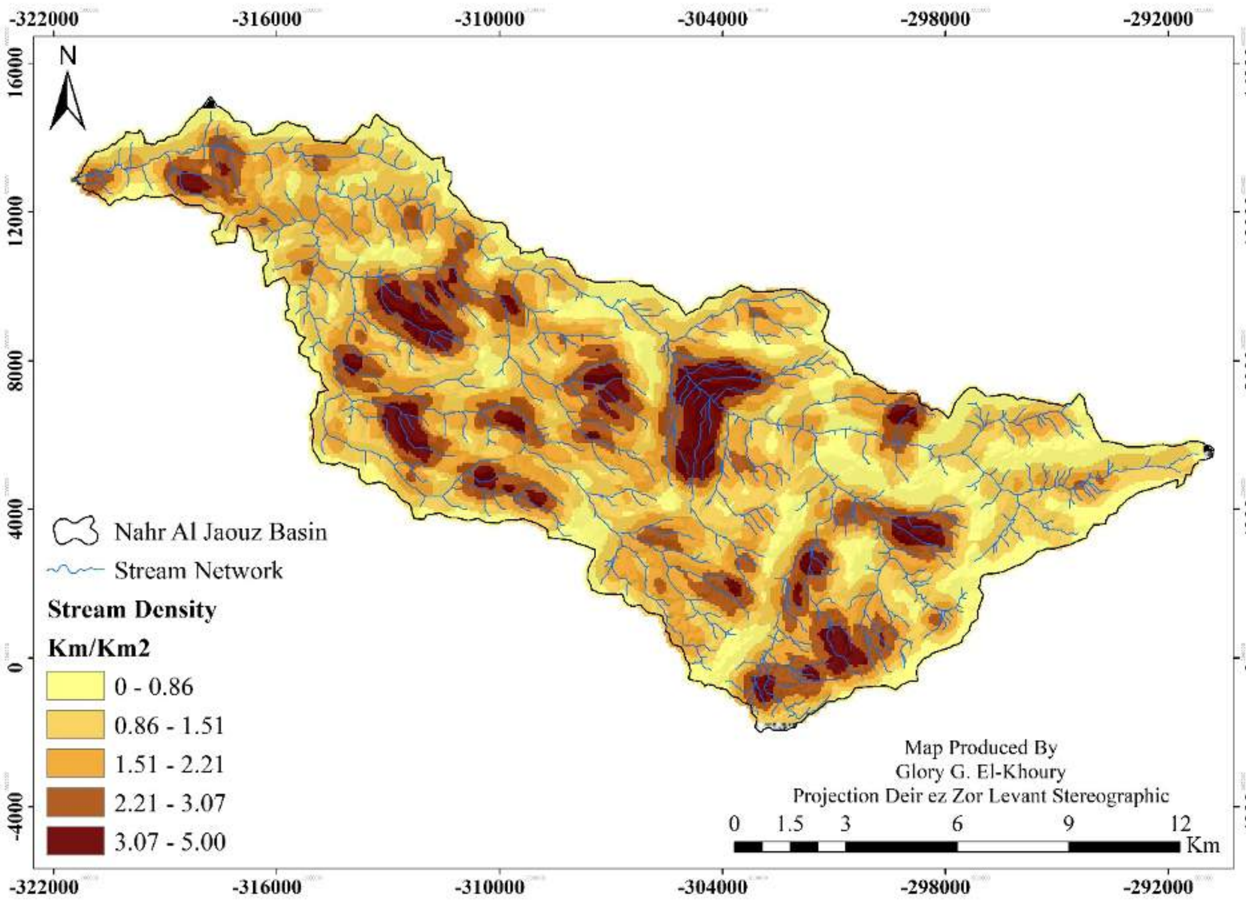

Figure 20: Stream density map of Nahr Al-Jaouz River Basin

Classes	Stream Density (km/km²)	Groundwater prospect	Area (per cent)
5	0-0.86	Very High	21
4	0.86-1.51	High	32
3	1.51-2.21	Moderate	25
2	2.21-3.08	Low	14
1	3.08-5.00	Very Low	7

The Nahr al Jaouz Basin's stream density varies from 0.86 km/km² to 5 km/km².

Table 8 Stream density values and categories of Nahr Al-Jaouz River Basin

Reclassification

The stream density map is classified into five: Class 1 for very high, Class 2 for high, Class 3 for moderate, Class 4 for low and Class 5 for very low. High stream density means a very low potential location for groundwater infiltration relative to the very low stream density area. The given numerical values depend on the relative runoff infiltration capability, which ranges from very low to very high density, and gives significance to their groundwater potential (Table 8).

3.6 Stream-Lineament intersection

Stream network and lineaments intersection reveal areas of high groundwater potential, where surface runoffs can quickly reach the subsurface aquifer at such locations, increasing the infiltration rates and serving the storage zones (El Hage et al., 2020).

Stream-Lineament intersection density

The Stream-Lineament intersection density map was calculated using ArcMap 10.4. First, an intersection algorithm was generated between the extracted lineament features and the stream network of Nahr Al-Jaouz River Basin using the geoprocessing tool. Then a kernel density was applied for the intersection points using the Spatial Analyst tool. The values underwent Natural Breaks classification (Table 9, Figure 21).

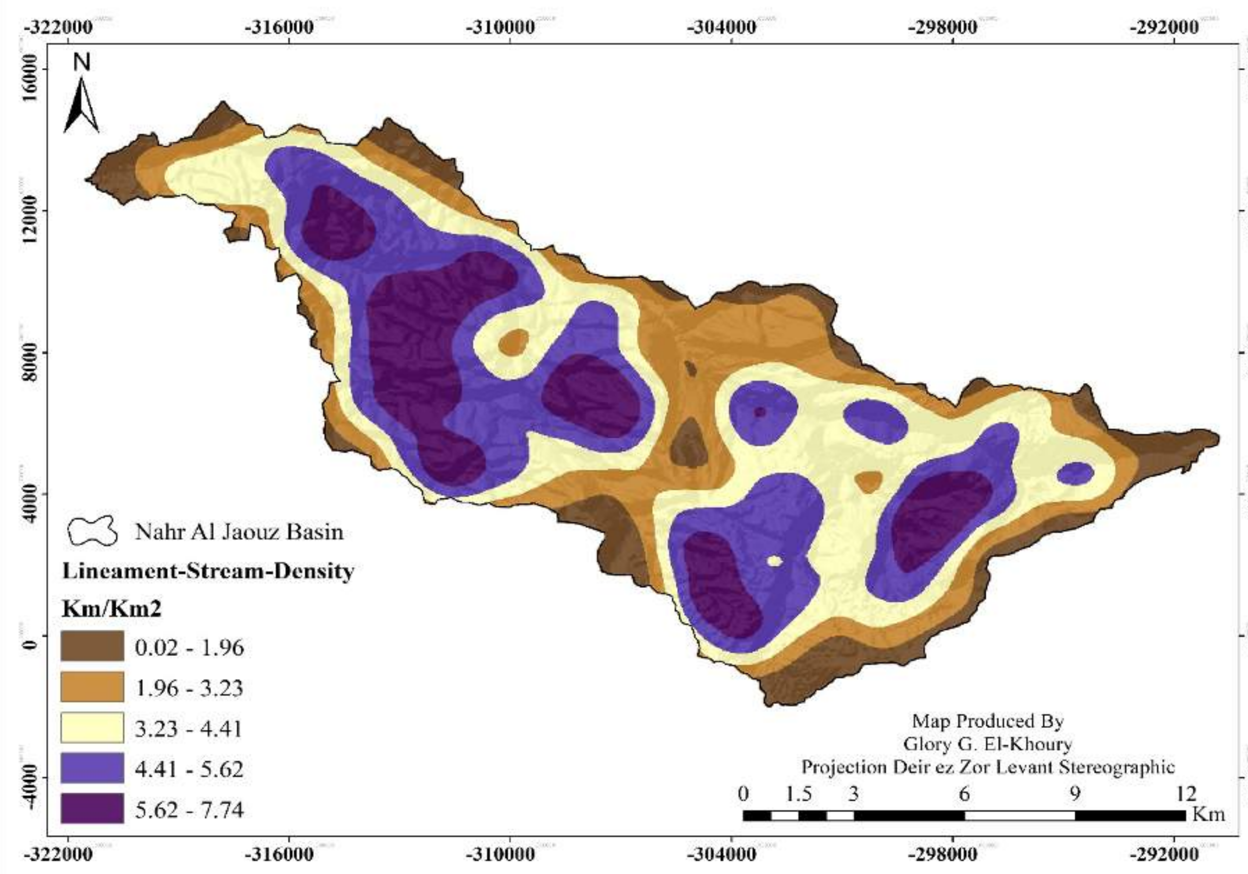

Figure 21: Stream-Lineament intersection density map

ClasseS	Stream-Lineament intersection density (km/km²)	Groundwater prospect	Area (per cent)
1	**0.02-1.96**	Very Low	12
2	**1.96-3.23**	Low	20
3	**3.23-4.41**	Moderate	27
4	**4.41-5.62**	High	25
5	**5.62-7.74**	Very High	16

Table 9 Stream-Lineaments intersection density categories

Reclassification

The Stream-Lineament intersection density map was reclassified into five: Class 1 for very low, Class 2 for low, Class 3 for moderate, Class 4 for high and Class 5 for very high. The very low density has a low potential for groundwater recharge relative to the very high density, which serves the infiltration by increasing the rate and enhancing the aquifer storage. Each value relies on corresponding infiltration capability, which ranges from very low to very high density, and gives significance to groundwater recharge (Table 9).

3.7 Rainfall map

Rainfall is the most significant factor influencing the groundwater potential of any region and is the primary source of water in the hydrological cycle (Bathis et al., 2016).

The Climate Hazards Group Infrared Precipitation with Stations V2.0 Data

Annual rainfall data of Nahr Al-Jaouz Basin were collected from the CHRIPS (The Climate Hazards Group Infrared Precipitation with Stations) datasets monthly time series from 2009 to 2019, with a spatial resolution of 0.05˚. The rainfall map was prepared using a Kriging interpolation method in ArcMap 10.4. The annual rainfall ranges from 793 mm to 1,398 mm over 10 years and the values were then categorized for each year (Figure 22).

Reclassification

The rainfall maps were classified into five: Class 1 for very low precipitations, Class 2 for low precipitations, Class 3 for moderate precipitations, Class 4 for high precipitations and Class 5 for very high precipitations. Very high precipitation is a significant potential for groundwater relative to very low precipitation areas. Each numerical value is given depending on the relative precipitation quantity which ranges from very low to very high and is important for groundwater potential (Table 10).

Classes	Precipitation (mm)	Categories
1	793 - 871	Very Low
2	871 - 911	Low
3	911 - 973	Moderate
4	973 - 1,286	High
5	1,398 - 1,286	Very High

Table 10 Reclassified precipitations values

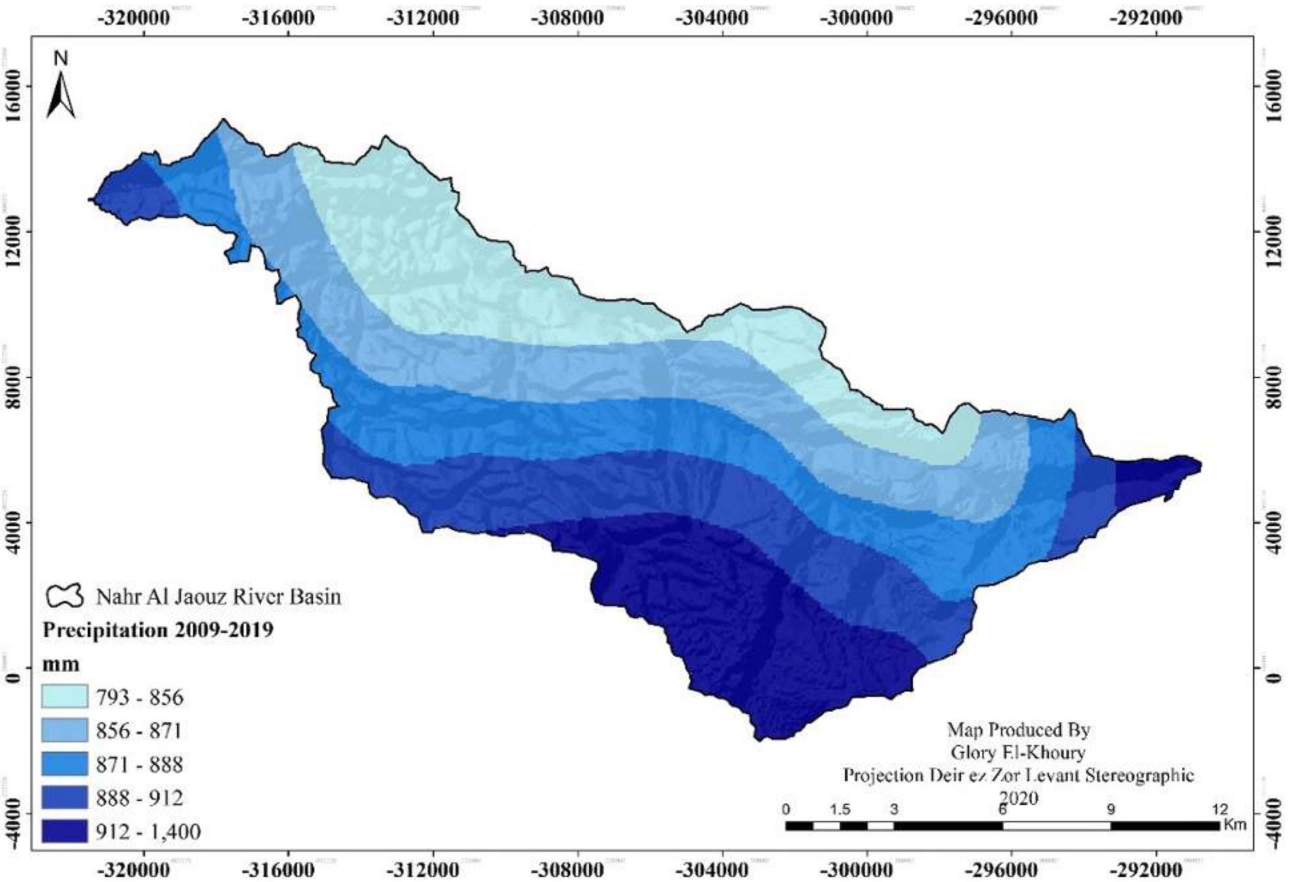

Figure 22: Precipitation map of Nahr Al-Jaouz River Basin

3.8 Groundwater potential map

The groundwater potential zone map was prepared by overlaying all the thematic layers and their corresponding classes in the weighted overlay method using the spatial analysis tool in ArcMap 10.4. All the thematic layers such as geology, lineaments, slope, soil, stream density, stream and lineaments intersection density, were converted into raster format with a 30 m spatial resolution. Each was assigned a weight value according to the influence of different parameters. For weight assigning, lineament-stream intersect density, lineament density and geology were given a higher weight, whereas stream density, land use/land cover, slope and rainfall were given the same weight, and soil the lower weight. Each sub variable was assigned a value, where the maximum value is given to the feature with the highest groundwater potential and the minimum given to the lowest groundwater potential (Table 11).

Parameter	Classes	Groundwater Prospect	Values	Weight (per cent)
Geology	Impermeable Semi-permeable Permeable	Low Moderate High	1 2 3	15
Soil	Impermeable Semi-permeable Permeable	Low Moderate High	1 2 3	5
Stream density (km/km²)	0-0.86 0.86-1.51 1.51-2.21 2.21-3.08 3.08-5.00	Very High High Moderate Low Very Low	5 4 3 2 1	10
Lineament density (km/km²)	0-0.5 0.5-0.99 0.99-1.56 1.56-2.35 2.35-4.83	Very Low Low Moderate High Very High	1 2 3 4 5	15
Lineament-Stream intersect density (km/km²)	0.02-1.96 1.96-3.23 3.23-4.41 4.41-5.62 5.62-7.74	Very Low Low Moderate High Very High	1 2 3 4 5	25
Rainfall (mm)	793-871 871-911 911-973 973-1,286 1,286-1,398	Very Low Low Moderate High Very High	1 2 3 4 5	10
Slope (per cent)	0-10 10-18 18-26 26-37 37-67	Very High High Moderate Low Very Low	5 4 3 2 1	10
LU/LC	Built-up Barren areas Herbaceous vegetation Scrubland Dense vegetation Water bodies Crop	Very Low Low Moderate High Very High Very High Very High	1 2 3 4 5 5 5	10

Table 11 Values and weight for different parameter of groundwater potential zone of Nahr Al-Jaouz River Basin

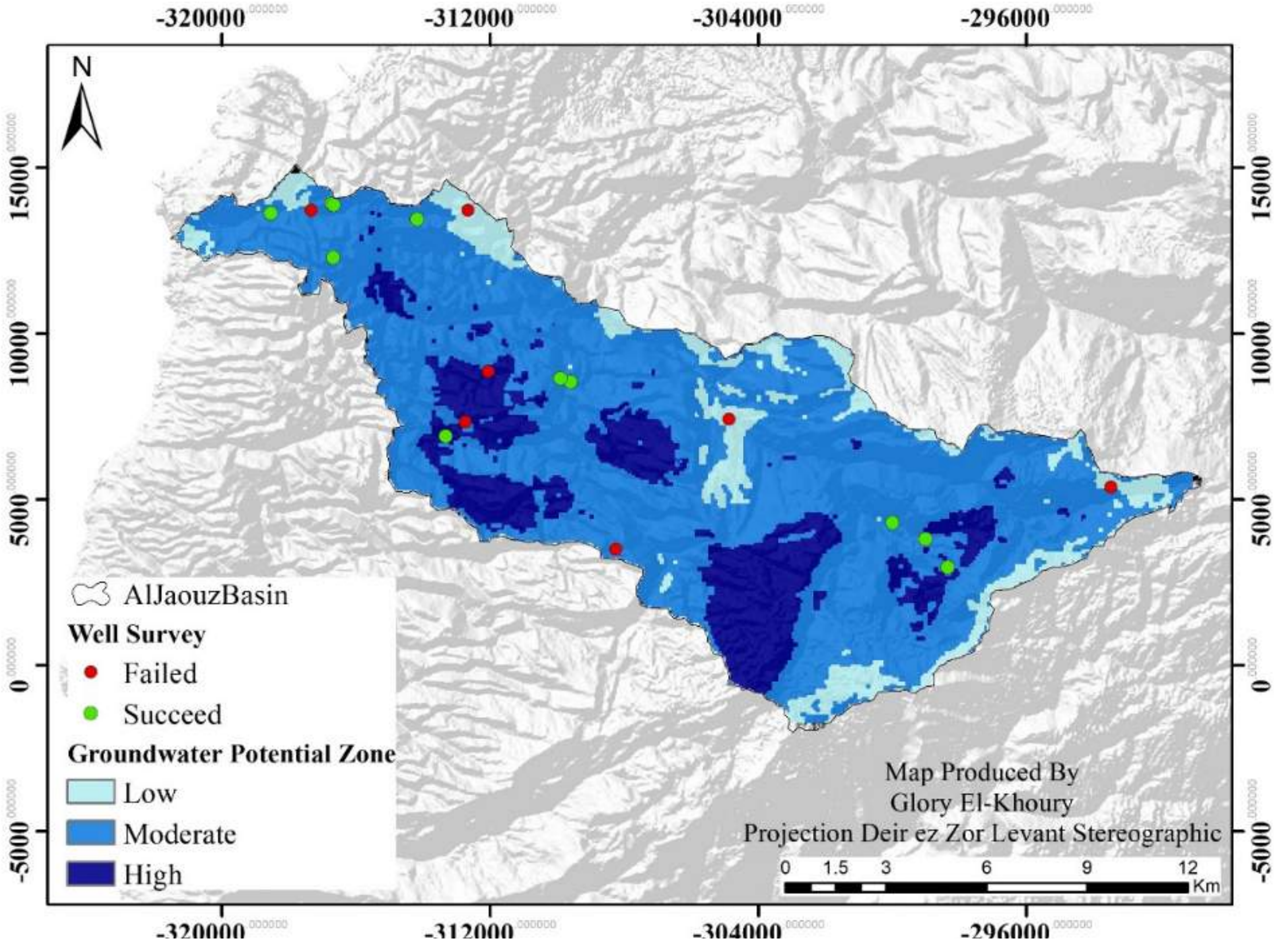

Figure 23: Groundwater potential zone of Nahr Al-Jaouz Basin

Category of groundwater potential	Area (per cent)
Low	10.79
Moderate	70.01
High	19.20

Table 12 Groundwater potential categories of the study area

Table 12 shows that 70 per cent of the total area of Nahr Al-Jaouz River Basin has moderate groundwater potential, 20 per cent with high potential and 11 per cent low potential. The results obtained from the Groundwater Potential Zone model were validated based on the list of wells from the Ministry of Energy and Water. After collecting the data from the Ministry, it was necessary to do a survey campaign for the wells in the study area. Each location of the wells was collected via GPS points based on the stereographic projection of Deir ez Zor, and each well was assigned to an ID. Referring to the drilling reports from the Ministry of Water and Energy, Table 13 shows the region where wells were drilled, the X and Y, the depth in metres, the discharge in litres per second, and whether the drilling work has failed or succeeded.

Region	Well ID	X	Y	Comment	Depth (m)	Discharge (L/S)
Abrin	W1	-316678.082	12288.876	Succeed	450	8
Assia	W2	-309599.809	8549.515	Succeed	650	11
Wata Houb	W3	-299998.098	4301.743	Succeed	141	8.5-10
Ijdaabrin	W4	-314179.378	13449.435	Succeed	430	10
Tannourin-Faouqa (Kherhel)	W5	-298350.678	2962.786	Succeed	300	6.25
Chobtine	W6	-313327.649	6904.206	Succeed	504	5
Hamat 1 (Ras Nhach)	W7	-316723.87	13917.887	Succeed	90	6.6-10
Hamat 2 (Ras Nhach)	W8	-316657.632	13884.332	Succeed	115	6
Helta	W9	-309899.554	8649.088	Succeed	690	Not equipped
Houb	W10	-299012.75	3806.385	Succeed	141	8.5-10
Mseilha	W11	-318536	13630	Succeed	75	Not equipped
Hamat	W12	-317337.8819	13710.78574	Failed		
Kfarhelda	W13	-304880.2484	7408.803847	Failed		
Zein	W14	-312750	7325	Failed		
Sourat	W15	-312060	8860	Failed		
Btaaboura	W16	-312660	13715	Failed		
Ram	W17	-308250.792	3491.784	Failed		
Al-Markaz Tannourine	W18	-293489.175	5374.731	Failed		

Table 13 Ministry of Energy and Water survey at Nahr Al-Jaouz River Basin

When analysing the result of the applied model of groundwater potential zone and the reports of wells, we noted that three wells that failed are located in the low groundwater potential zone, one in the high potential zone, and two in the moderate zone. The successful wells are located either in the high potential zone or in the moderate potential zone (Figure 23).

3.9 Land status and groundwater zoning

3.9.1 Land registration

Since the independence, the creation of the Lebanese State and the implementation of its sovereignty have faced persistent obstacles, if not long-lasting disturbances. This culminated between 1975 and 1990 during the civil war, as internal forces supplemented by international interventions almost sidelined the state. These difficulties illustrate how the state mapped its territory and the different steps of the effort. The French authorities began the creation of a land registry based on cadastral zones during the French mandate but left the project unfinished. The Lebanese State has not completed it since 1943. Therefore, some areas have never been delineated, while others have never been validated or officially registered for land parcel surveys (Verdei et al., 2019). The map (Figure 24) below shows that some regions are still subject to conflicts. This is the consequence of the different actors involved in this process with contradictory logics: public administrations (judiciary, army), landlords, societies, etc.

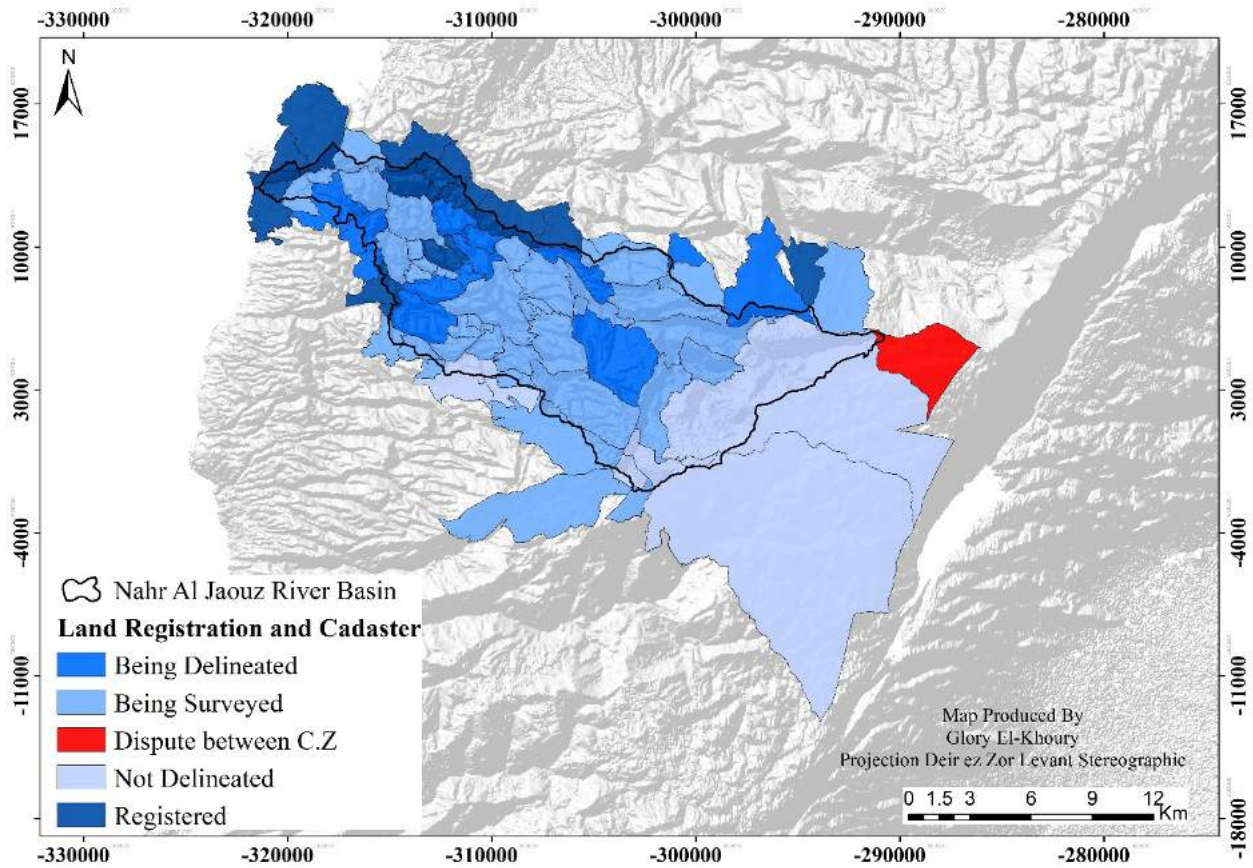

Figure 24: Land registration and cadastre of Nahr Al-Jaouz River Basin (Atlas of Lebanon)

3.9.2 Access to land information

Figure 24 and Figure 25 show the cadastral work processes in years 2003 and 1965, respectively, where only 11 regions were registered in 1965 and 14 in 2003. To update, it was necessary to collect data from the Directorate of Land Registry and Cadastral. The study team was able to update the map of the land registration and cadastre as shown in Figure 24 where 29 of the 71 regions in the study area were registered. Due to the lack of data, the study team worked at one scale with the boundaries of all the region within the Nahr Al-Jaouz River Basin. Figure 26 shows a reclassified map with the registered regions as Class 1 and the others as Class 0.

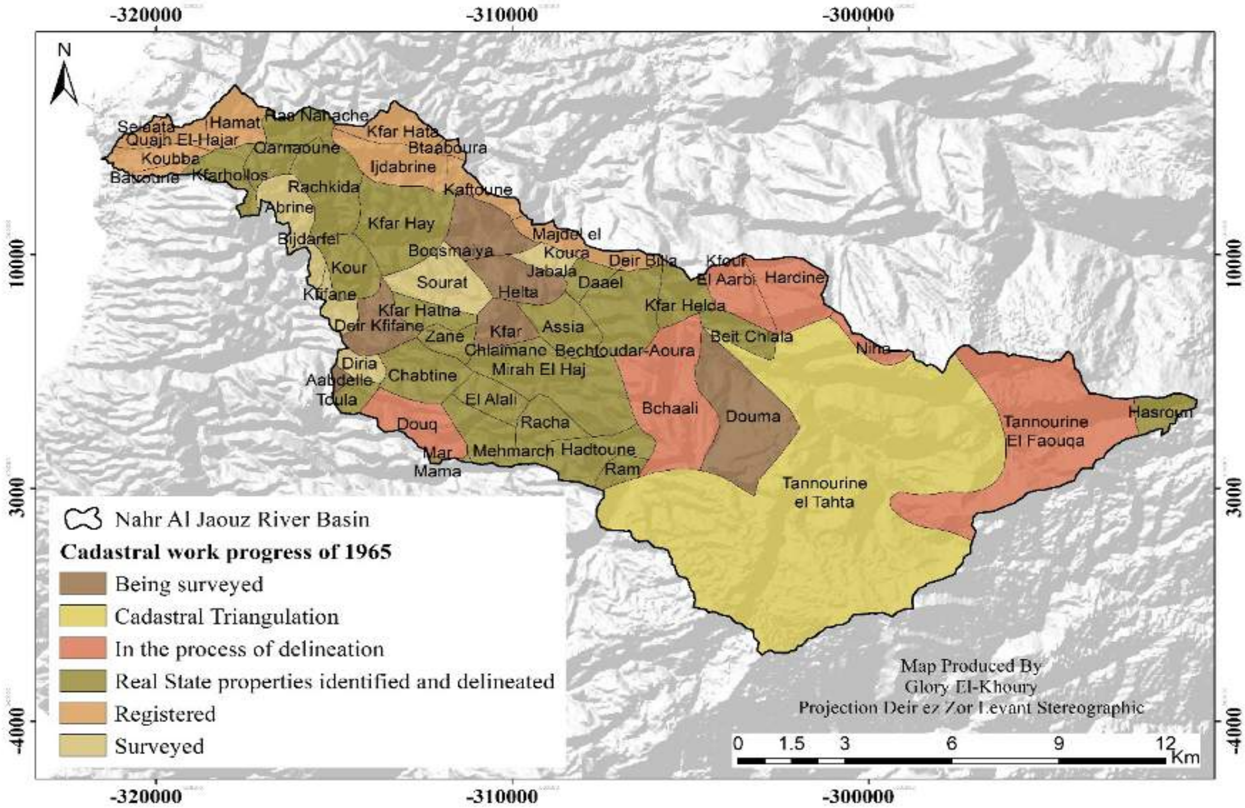

Figure 25: Cadastral work progress, Nahr Al-Jaouz River Basin, 1965

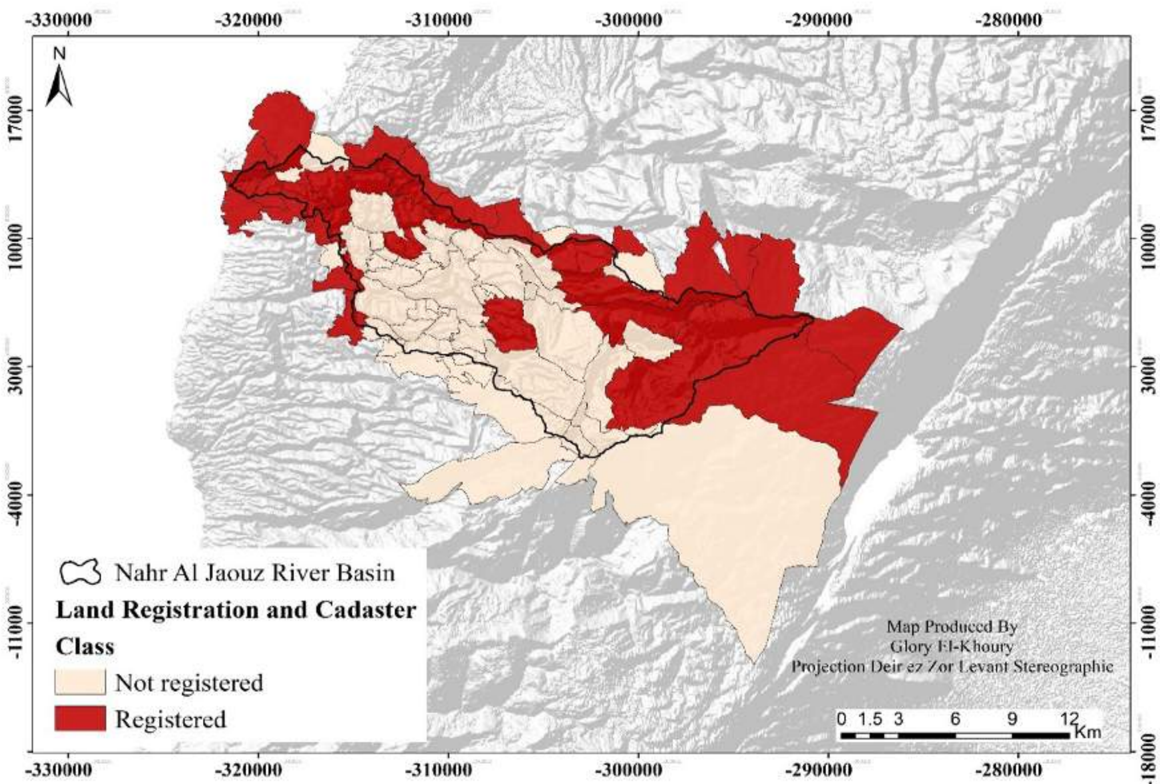

Figure 26: Classified registered land and cadaster

3.9.3 Groundwater zoning

After prospecting the groundwater potential zone of Nahr Al-Jaouz River Basin, it is important to understand how the groundwater zones are distributed spatially in the context of each region for better groundwater governance. The zonal statistics of the groundwater potential zone (Figure 27) shows that the villages with good groundwater potential (Bijdarfel, Kfar Hay, Zane, Chabtine, Douma, etc.) are located in the south and southeast of Nahr Al-Jaouz River Basin with a mean range between 3.12 and 3.99. The lowest values of groundwater potential with a mean range between 2.96 and 3.11 are located in the north and some of the coastal areas of Nahr Al-Jaouz River Basin (Batroun, Koubba, Kfar Hata, Hardine, Kfour El Aarbi, etc.) in addition to the villages of Laqlouq and Aqoura which is at south-southeast in the high mountain areas. The towns with the moderate groundwater mean values (Qarnaoun, Abrine, Bqosmaiya, Tannourine el Faouqa, etc.) ranging between 2.96 and 3.11 are dispersed in the coastal area, in the middle and high mountain areas.

The high mean of the groundwater potential covers 86 km^2 of the study area, 66 km^2 with moderate values and 41 km^2 with low values. This means that Nahr Al-Jaouz River Basin has good groundwater potential that needs further investigation to develop this resource sustainably and with good governance, since the study area is an agricultural vocational zone.

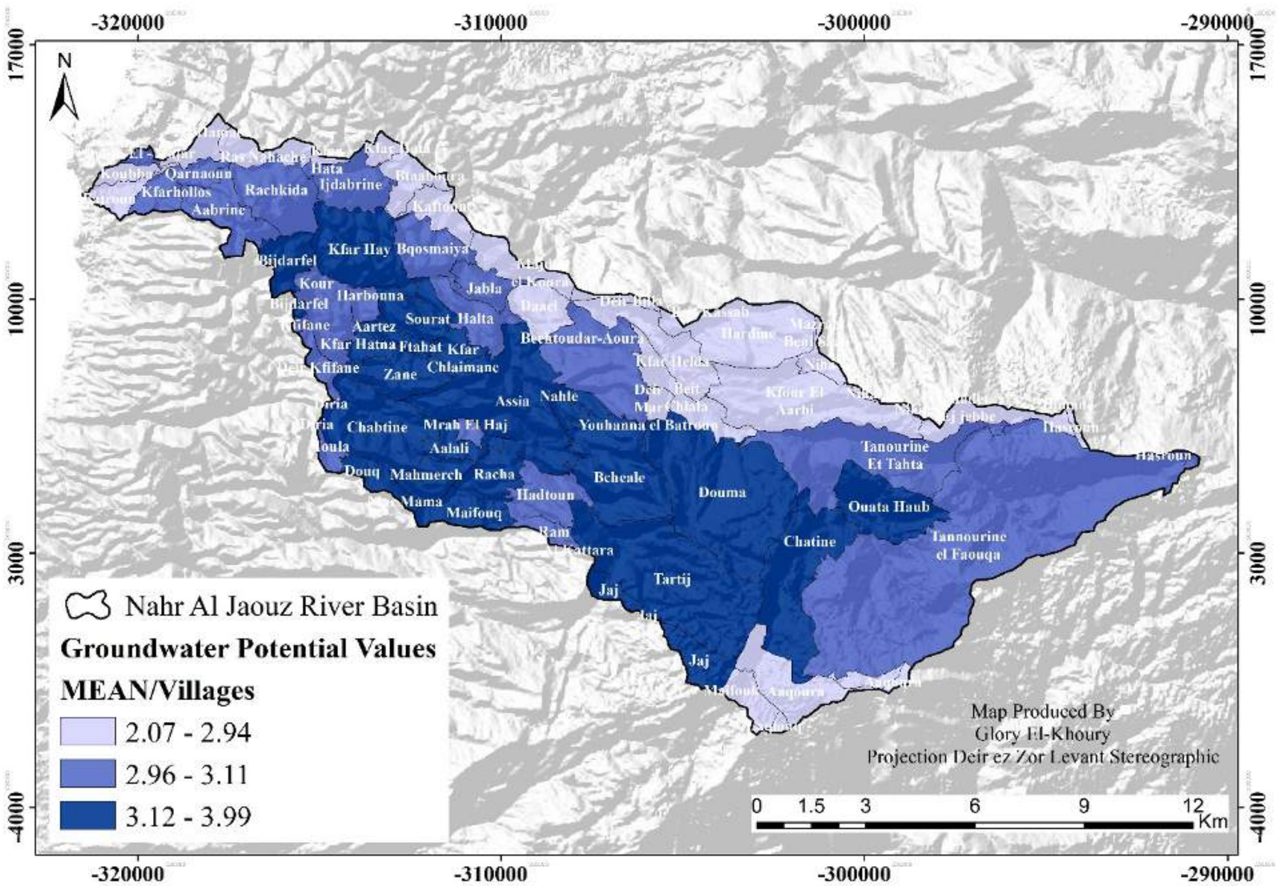

Figure 27: Zonal statistics of the groundwater potential zone

Varady and others (2013) described groundwater governance as the mechanism by which groundwater is controlled through responsibility, participation, information availability, transparency, tradition and state of law. Groundwater governance is the art of managing administrative activities and decision-making, one of which may be global within and between different jurisdictional levels.

Groundwater is a common-pool resource and is frequently used individually. However, there are cumulative effects on an aquifer that may result in catastrophic scenarios. Problems affecting groundwater can quickly escalate since most groundwater can be exploited without a good deal of monitoring criteria or standards. Negative impacts on the resource remain unnoticed and only become visible when there are already observed detrimental effects on ecological and human health due to pollution and/or excessive withdrawal.

The intensive use of groundwater resources in Lebanon dates back to the late 1950s. Improved pumping installations also encouraged groundwater use for urban, industrial or agricultural purposes. In the 1970s, official reports recorded about 3,000 wells in the country. Later, documents noted about 50,000 private boreholes in the 2000s. UNDP in 2014 put their number at 80,000 of which 59,000 were unregistered (i.e., a density of 8 wells/km^2). With the impressive rise in drilling caused by the drought of 2014, 100,000 is likely to be a reasonable estimate of the total number of wells in Lebanon. Compared to the 842 public wells supplying public water networks, this number is massive (with a total volume in 2009 of 270 million cubic metres per year).

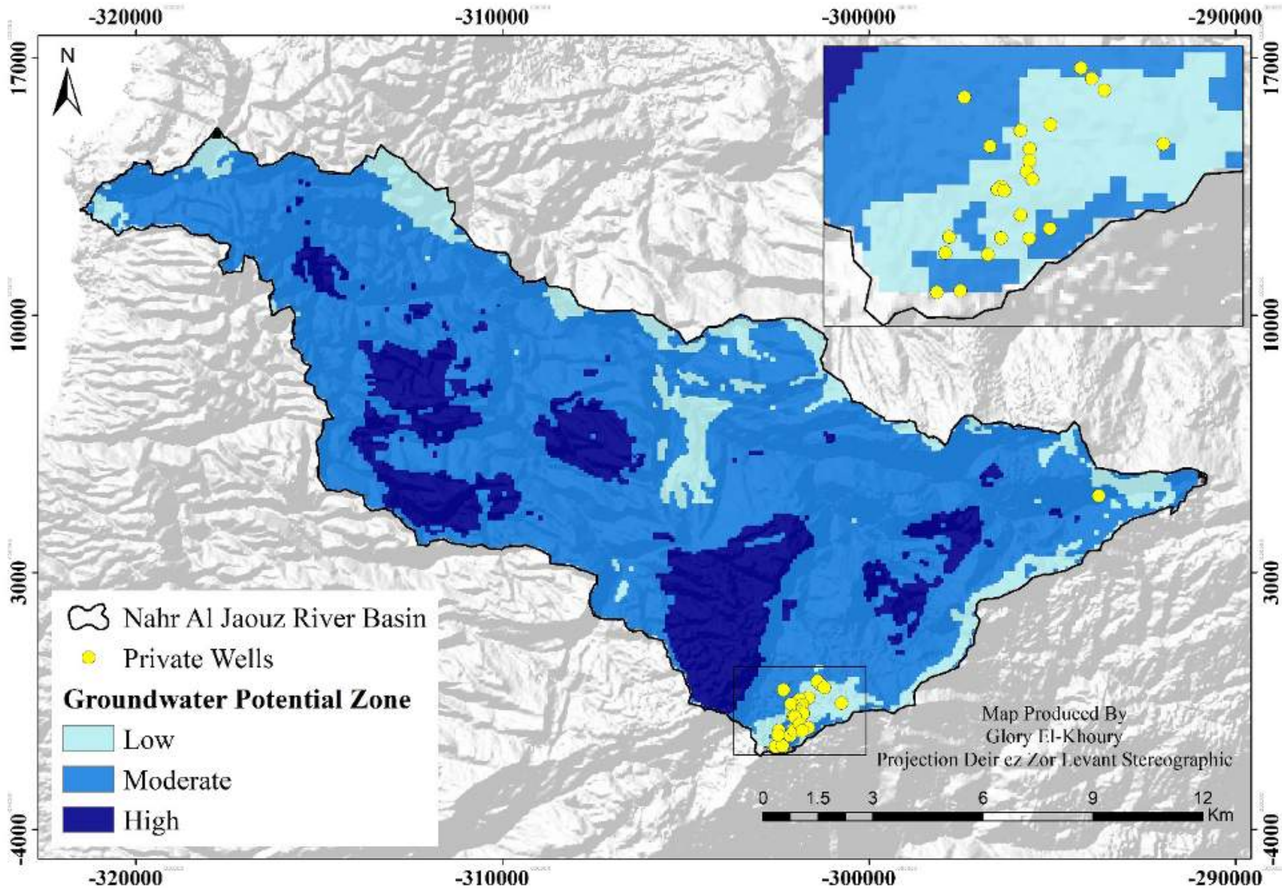

Figure 28: Private wells location at the mountain region of Nahr Al-Jaouz River Basin

This exponential rise in private wells is mainly due to the lack of, or shortcomings in, public networks for people seeking autonomy. During the war and later during the reconstruction period, informal and illegal activities escalated. In the study area, some private wells are located at the mountain regions (Tannourine el Fawqa, Aqoura, Laqlouq), where the groundwater prospect model has shown a low value, and well density varies from 1 to 6 well/0.25 km^2 (Figure 29).

Lebanon is distinguished by its water wealth represented by rivers, springs, lakes, wells, groundwater and water basins. Hence, the need for a modern law to regulate this vital facility for the Lebanese state. Whereas the legislation governing this sector is long-standing, mostly going back to 1943, some to the Ottoman occupation of Lebanon. Others date back to the French mandate in 1920, with the issuance of a series of legal legislation, the most prominent of which was Decision No. 144 of 10 June 1925, related to public domain. Decision No. 320 of 26 May 1926, relating to public property and its preservation, and a Real Estate Law issued according to Decision No. 3339 of 12 November 1930.

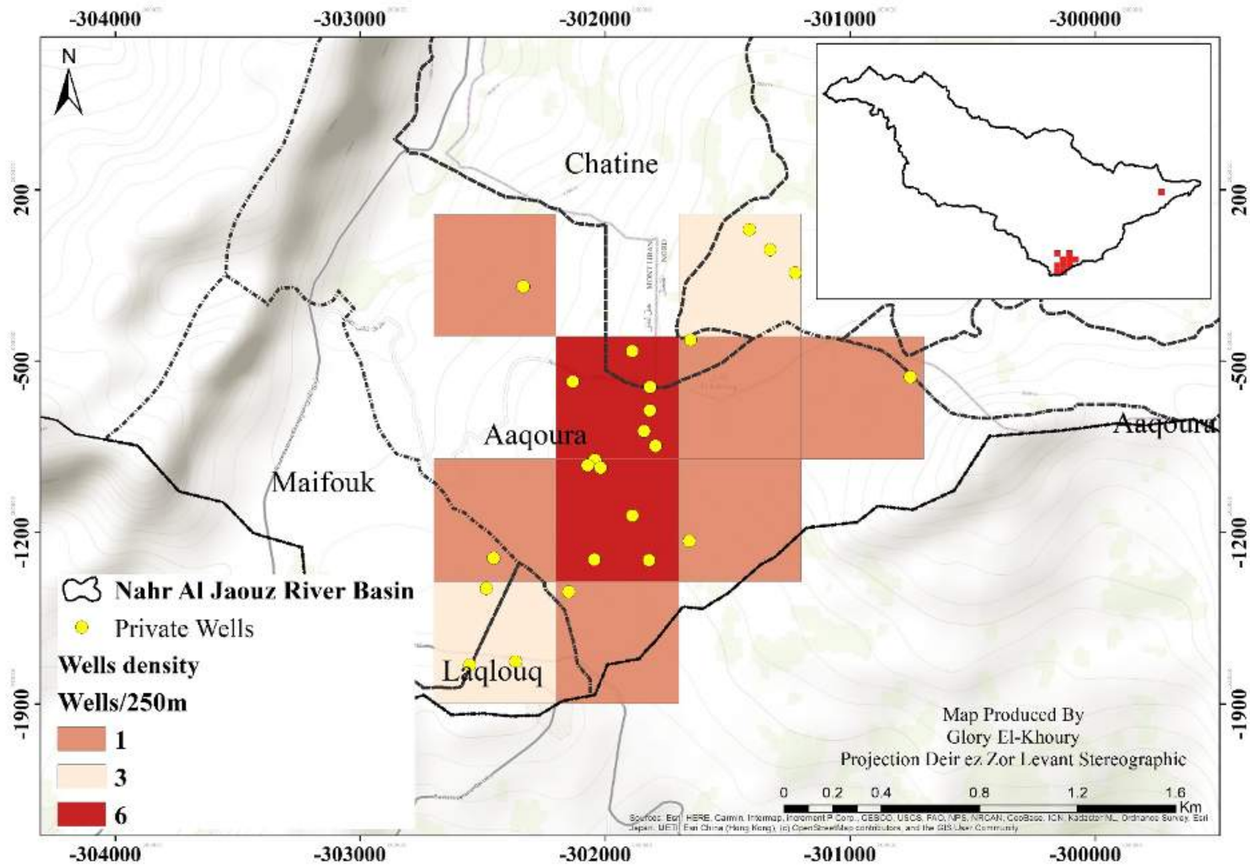

Figure 29: Private wells density

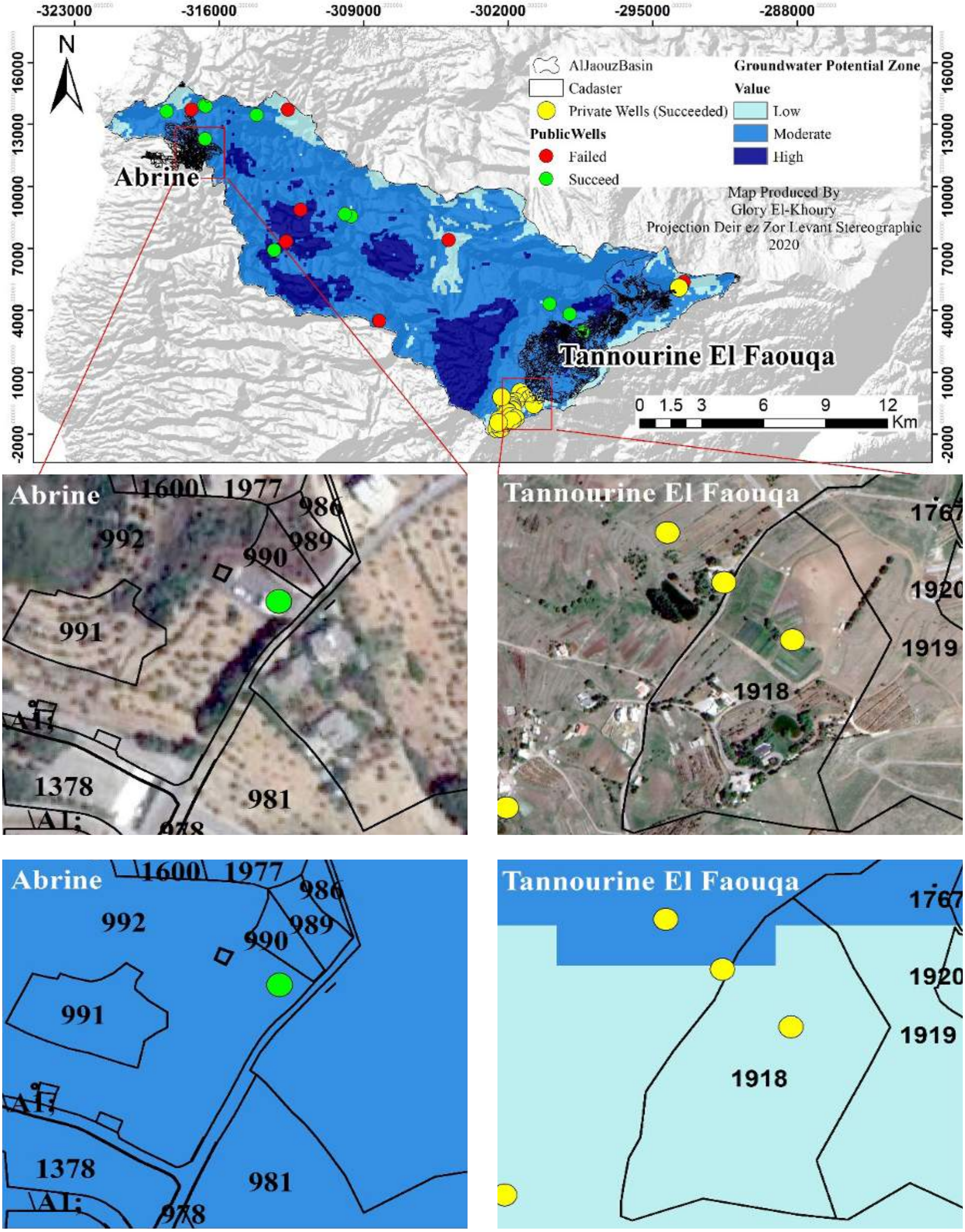

Figure 30: Location of private and public wells

In addition, after the declaration of independence, several legislations were issued to regulate this sector. However, due to the development of legal and scientific concepts and means of using water, these legislations have become insufficient. This called for a modern water law that considers new developments, and the urgency to preserve this main resource and meet the needs of Lebanese society.

The Ministry of Energy and Water, in cooperation with the competent departments, embarked on a Water Law project which took more than ten years to prepare, and the bill was referred to the House of Representatives for consideration and approval. Whereas, Water Law No. 77 in 2018 was marred by many gaps that made its implementation almost impossible, Law No. 192 of 16 October 2020 was prepared in cooperation and coordination with the ministries and all concerned departments to fill the gaps and ensure consistency between the articles of the Water Law.

Article 5 of Law No. 192 states that every person legally benefiting from any water resource has the right to benefit from it in a way that does not harm these resources or the interests of others and shall bear the same duties imposed with regard to the preservation of these resources and protect it from drain and pollution. Exploiting groundwater resources without prior permission from the competent authority is prohibited. Article 8 of the same law states that water is a public domain and cannot be acquired, owned or disposed of in any way, taking into consideration the provisions of Decision No. 144/S of 10 June 1925 and Decision No. 320 of 26 May 1926.

Public ownership of water includes water in all its natural states, its geological sites, its attachments and public enterprises designated or necessary to manage it. This covers:

- groundwater, including freshwater springs undersea, off the Lebanese shores;

- springs and wells drilling, irrigation springs and other sources of water intended for the public;

- possible sanctuary of the surrounding areas that are not intended for its direct protection.

Article 10 of Law No. 192 states that groundwater, regardless of depth, is subject to a special regime in terms of protection and control. No one is allowed to extract groundwater by digging artesian wells or by any other means without obtaining permission or a prior license from the Ministry of Energy and Water, within specified conditions under the provisions of this law (see http://www.legallaw.ul.edu.lb/Law).

The regulation of water exploration and use of water came under Decree No. 14438 of 2 May 1970. Article 2 states that work related to exploration for underground or explosive water, seizing it, or drilling wells, before obtaining a license is not allowed. Article 7 gives the exemption from the permit to drill non-explosive wells on private property, provided that their depth does not exceed 150 m, subject to prior knowledge. And Article 13 states that the amount of water extracted from the well does not exceed a hundred cubic metres per day (100 m3/day). The full decree can be found at the Minister of Energy and Water portal (https://www.energyandwater.gov.lb/ar/details).

Article 13 of Law No.192, states that a water registry shall be established at the Ministry of Energy and Water, consisting of the registry of the acquired rights mentioned in Article 12 and from the general inventory of water that composes the aquatic ecosystem of the Lebanese state. The Land Registry Secretariat, the General Directorate of Urban Planning, municipalities and all public departments and public and private institutions that have restrictions and data related to water, has to provide the Water Registry with these data and information (see http://www.legallaw.ul.edu.lb/Law).

For illegal wells, the Ministry of Energy and Water sends a letter to the province police for the owner to be notified to register, or the well would be closed. They also send a letter to the Office of the Cadastre so that the land plot is marked as not conforming to the regulations. Per UNDP, three out of four wells were drilled without registration or permits. The police and municipalities regularly turn a blind eye to these illegal practices, whether or not there is bribing involved.

Ministry of Energy and Water officials do not have the right to access private property to monitor wells without the Ministry of the Interior's permission and they should be accompanied by police officers. Such control visits are officially carried out only if the administration has solid information on an unlicensed well that is intensively used for industry, processing of bottled water, or filling up of tankers; or if a complaint is filed by a neighbour seriously affected by the new well (Molle et al., 2017).

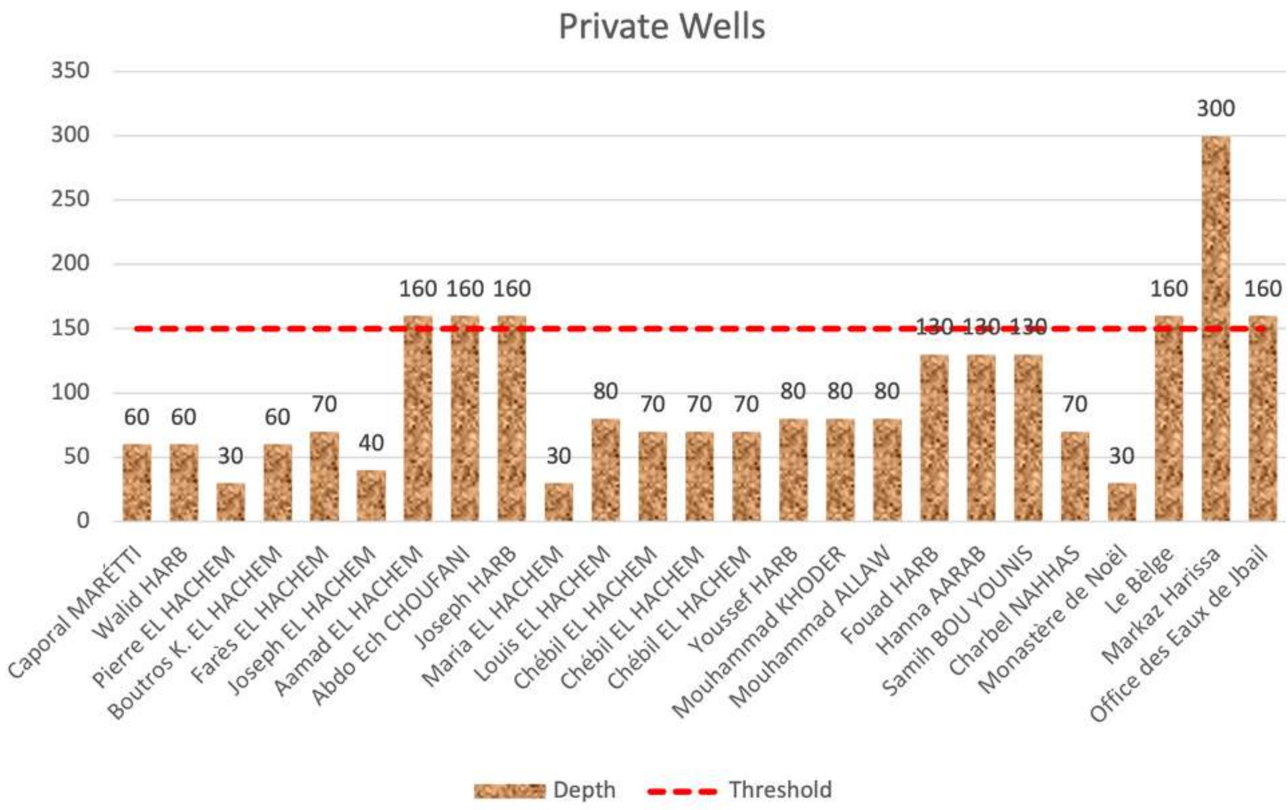

Figure 31: Depth of private wells in Nahr Al-Jaouz Basin

In Figure 30, the images to the right shows an example of the location of private wells in the Tannourine El Faouqa region, where two private wells are located in a private land specified with parcel number 1918. Majority of this parcel is located in a low groundwater potential area. Also, to the left of Figure 30 there is an example of a public well drilled by the Ministry of Energy and Water located in the region of Abrine on parcel number 992, which is a moderate groundwater potential zone.

Due to the lack of data and the unfinished cadastral work process, it was difficult to determine if other private wells, specifically the illegal ones, are located on private or public land. The graph below shows the depth of the private wells located in the low groundwater prospect zone in Nahr Al-Jaouz River Basin.

As shown in Figure 31, there are six wells exceeding the threshold depth limit. The wells drilled side by side in the same aquifer will affect the retention ability. The performance of these wells will depend on the thickness of the aquifer, the presence of an underground river and the depth of the well. The largest Cenomanian aquifers in the altitude zone cannot be productive with a flooded karst. Groundwater governance is among the most challenging in water management. Compared to surface water, where the state usually controls the main regulating distribution points, the use of groundwater is diffused, partially invisible, and primarily guided by consumers who individually invested and would want to own this resource after having invested in accessing it (Molle et al., 2017).

One of the most important activities to take into consideration for better groundwater management is to quantify the climate change impact on groundwater (Akhbari et al., 2011). Climate change is becoming more concerning, and while it is getting a great deal of focus, its effect on groundwater is still under-exposed. Increased precipitation variability and more severe weather conditions triggered by climate change will lead to longer periods of drought and floods, directly impacting the supply of and reliance to groundwater. During long periods of drought, aquifers are prone to depletion particularly in the case of small and shallow aquifers. Climate change affects both quantity and quality of groundwater. Sea level rise can cause saltwater intrusion into coastal aquifers degrading groundwater quality and contaminating drinking water supplies.

Enhancing underground water storage is a practical step to increase freshwater supply and improve adaptation to climate change, according to the International Groundwater Resources Assessment Centre (see https://www.un-igrac.org/):

- Collect, treat, recycle and inject the wastewater into the aquifer through wells;

- Establish, maintain and improve monitoring networks in efforts to conserve groundwater quality;

- Create special protection zones around important drinking-water sources (wells and springs);

- Raise the awareness to engage the population on the importance of land-use and groundwater exploration to preserve potable groundwater quality, especially from saltwater intrusion and overuse of pesticides in agriculture, etc.

Geospatial technologies and techniques (remote sensing and GIS) were used to find areas for groundwater exploration and those that are for further investigation. Remote sensing and GIS have proven to be efficient in terms of minimizing time and labour. The study shows the integration of eight thematic maps (stream density, lineament density, geology, soil, slope, lineament and stream intersection density, land use/land cover, and rainfall) giving first-hand information to local authorities and decision-makers about the areas suitable for groundwater exploration. Weighted overlay analysis was adopted to prepare the map of potential groundwater zones. The delineated zones within the study area of Nahr Al-Jaouz River Basin were classified into: high, moderate and low groundwater potential zones.

The cadastral work process and land registration of the study area were analysed and updated to understand how these potential groundwater zones are spatially distributed in the context of registered and unregistered land, the affiliate legislation concerning private lands and the right to drill wells. Due to the lack, unavailability, and/or access to the data on land and cadastral registration, the study focused the cadastral boundaries of the regions within the study area. These groundwater, land registration and cadastral information are useful for further investigations and data collection. To improve land and groundwater governance, it is important to improve access to these information through the General Directorate of Land Registration and Cadastre who will, in turn, make data available, which may be through a digital portal for all researchers.

Groundwater management, as an important sustainable development, has not been considered properly and has resulted in the depletion and degradation of the resource. Groundwater quality is under continuous threat. Unless protected, groundwater quality deteriorates due to saline infiltration, pollution from farming and urban activities, untreated wastewater, and solid and hazardous waste disposal. The following activities should be undertaken:

- Improve knowledge on the importance of groundwater contribution to the hydrological cycle and assess the changes to the variations of groundwater storage and level;

- Raise awareness of decision-makers, water consumers and the public on the value of groundwater and promote conservation and sustainable use;

- Assess the impacts of economic progress on groundwater resources and support global collaboration for national and regional needs;

- Quantify climate change impact on groundwater resources including sea level rise and saltwater intrusion.

In addition, to improve the groundwater efficiency and water management, several methods could be taken into consideration such as: the use of groundwater recharge, alternative sources, conservation management and construction of levees in the river channel to increase infiltration and injection of treated recycled water to form a seawater barrier.

It is important to install monitoring wells and piezometers to calibrate the prediction models, and observe and analyse the fluctuation of water table levels. At least three monitoring wells are needed to find the groundwater direction and perform any meaningful field monitoring. The use of groundwater in agriculture has contributed to enhancing agricultural production, increasing incomes, and providing food security. However, more information and knowledge on groundwater resources as well as policy and management planning are needed to maintain and extend these achievements and prevent groundwater depletion or degradation (CGIAR WLE, 2017).

Despite the benefits of using groundwater on irrigated agriculture – significantly increasing the recharge rate from excess irrigation water that infiltrates into shallow aquifers – inadequate management of irrigation water can result in soil waterlogging and shallow salinization of groundwater. The implementation of cost-benefit analyses for medium and large irrigation schemes as well as the cost of maintaining irrigation systems are technical aspects of irrigation management of water supplies over time.

Farmers have historically paid high irrigation costs for the use of large pumps to draw water from deep wells, as well as the cost of pumping water. Due to heavy use of agricultural inputs, the quality of water available to farmers has gradually deteriorated. Water management strategy in Lebanon is lacking due to small-scale irrigation schemes, land degradation, and insufficient facilities. Local water management expertise is derived from unique cases of public scheme restoration using both traditional and pressurized irrigation systems. There have been a lot of experience managing irrigation through private schemes as more money has been invested in the field.

Recently, more focus has been paid to issues related to water management and enhancing the quality of water usage, such as the use of effective irrigation and water harvesting techniques. Farmers have always lacked incentives, especially from the irrigation sector. In comparison to volume-related price systems, water allocated by rotation and/or with a fixed flow rate make it difficult to enforce water-saving strategies. Further, even though water use is measured, the levies are a small percentage of the value of cash crops harvested. As a result, water prices (perceived as high in the range of prices deemed socioeconomically appropriate) have little effect on farmer behaviour.

An example of a successful opportunity was when the public sector provided irrigation equipment to farmers in the South Beqaa irrigation scheme allowing them to effectively irrigate 900 hectares of reclaimed land. This helped reduce water use per hectare from 15,000 m^3/year using furrow irrigation to 6,500 m^3/year using localized irrigation. In other regions, drip irrigation led to more than 50 per cent of water savings relative to furrow irrigation.

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