MOBILISATION DES EAUX SOUTERRAINES POUR L'ALIMENTATION EN EAU POTABLE A ZAHLÉ – LIBAN

AIDE À LA DÉCISION

COOPERATION ENTRE

- LA MÉTROPOLE MONTPELLIER MÉDITERRANÉE
- LE DÉPARTEMENT DE L'HERAULT
- LA RÉGION OCCITANIE
- L'AGENCE DE L'EAU RHÔNE MÉDITERRANÉE ET CORSE ET
- L'ÉTABLISSEMENT DES EAUX DE LA BEKAA

Groundwater Vulnerabilité assessment

Zahlé Municipalité

Mark Saadeh, Hydraugeologist -KREDO

Under the supervision of UPLOAD

CPIE APIEU Territoires de MONTPELLIER

842 RUE DE LA VIEILLE POSTE,

MAS DE COSTEBELLE,

34000 MONTPELLIER

Téléphone : 04 67 13 83 15

Courriel : apieumtp@educ-envir.org

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1. Introduction

KREDO has been commissioned to consult on a project funded by a French cooperation led by NGO APIEU, the Bekaa Water Establishment (BWE), and UPLoAD Consultants.

The project aims at addressing Zahleh's water issues through conjunctive use, which generally consists of harmoniously combining the use of both surface water and groundwater in order to minimize the undesirable physical, environmental and economic effects. It is based on a "permeable city" approach through which the project will;

- Promote a culture of positive "environment change making" through water saving activities
- Avoid rain waters to get polluted and transform them into a clean and useful resource that can contribute either to groundwater recharge (through indirect and nature based processes relying mainly in ecosystemic restoration) and/or to alleviate groundwater extractions (through developing alternative to private wells or network-provided domestic water).

With this objective in mind, the tasks of the report are manifold, but they namely include:

1. Mapping of groundwater vulnerability of different geological formations,
2. Analysis of contamination risks of private as well as public wells,
3. Providing an analysis of groundwater pollution risks related to pollution sources.

A desk study of literature review of articles and reports in tandem with site visits of Zahle Caza was undertaken by KREDO for the preparation of this report.

Data on groundwater quality and quantity was compiled from previous studies, and updated with some recent data obtained through the Bekaa Water Establishment. Groundwater quantity and quality was evaluated on a basin/aquifer level. The vulnerability of aquifers in terms of contamination and water balance was also evaluated on said level. Recommendations were then presented.

The following major references were just some of the few that were reviewed and integrated into this report. They include but are not limited to:

- Litani Water Quality Management Project (BAMAS) by DAI in 2005
- Litani River Basin Management System (LRBMS) by IRG in 2012
- Integrated Management of Groundwater in Zahleh caza by Kehdy in 2013
- Assessment of Groundwater Resources of Lebanon by UNDP in 2014
- Hydrogeological study in Zahleh cazas by UNICEF/ELARD in 2017
- Groundwater diagnostics of Zahle groundwater by El Hakim (APIEU project) in 2018

In light of the major aforementioned references, the data and analyses they present, digress on several key issues namely, number of licensed and unlicensed wells, well yields, spring discharges, levels and extent of groundwater contamination, depth to water table etc.

As such, any such data referenced in this report is treated with a certain level of uncertainty in light of the scarce corroborative data provided by official offices such as the Bekaa Water Establishment (**BWE**) and the Litani River Authority (**LRA**), two major public entities operating within the Litani river basin. To be noticed however, access allowed to unpublished data produced by BWE through the present project.

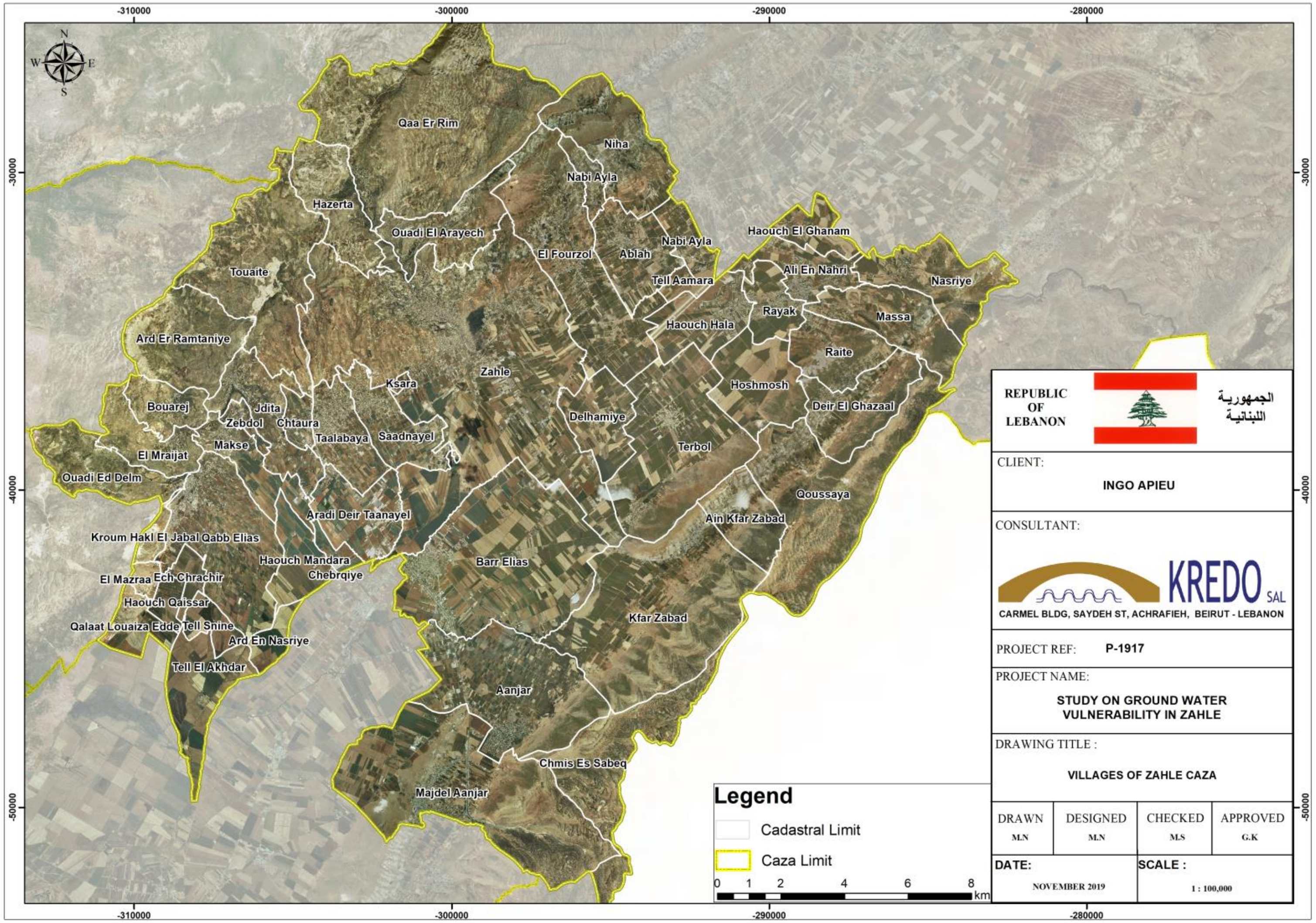

Figure 1: Study area - Zahle Caza and cadastral limits (KREDO)

2. Climate

Groundwater recharge is impacted by the hydrologic cycle namely through precipitation (rain and snow) evapotranspiration, infiltration, and surface runoff.

Land use and land cover have a significant impact on infiltration, and runoff, whereas climatic conditions can impact both precipitation and evapotranspiration.

Despite the low resolution of available climate models relative to the size of Lebanon, climate projections show an overall increase in temperatures and a decrease in precipitation (Karmalkar, McSweeney, New, & Lizcano, 2003). Moreover, projections predict changes not only in the quantity of precipitation, but also in the period during which this precipitation falls.

The number of days with maximum daily temperatures higher than 35 °C will increase, and successive dry days will increase causing a seasonal prolongation of dry periods (Karmalkar et al., 2003; MoE/UNDP/GEF, 2016).

In Zahle Caza, there is only one meteorological station with recent and consistent data found in Tel Al Amara, managed by the Lebanese Agricultural Research Institute (**LARI**).

Comparing average temperatures recorded at Tel Al Amara station between the two periods of 1953-1973 and 1998-2011, there is an obvious increase of 1◦C in average temperature, from 14.1 ◦C to 15.1 ◦C (Kehdy, 2013). Average monthly evaporation values were slightly higher for the period of 1998-2011 compared to the period of 1953-1973 (Kehdy, 2013).

For example, for the month of July, average evaporation was around 325 mm for 1998-2011 period compared to 250 mm for 1953-1973 period (Kehdy, 2013). The increase in evaporation would lead to the increase in water required for irrigation. This in turn would add more stress on groundwater aquifers, since water for irrigation in Zahle Caza is supplied abundantly by wells.

Average yearly precipitation over the of 1998-2016 recorded at Tel Al Amara station is at the low end of the spectrum with a paltry 571 mm compared to the rest of the country.

Average monthly precipitations are presented in Table 1 below.

Table 1: Average monthly precipitation in mm 1998-2016 - Tel Al Amara

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Monthly Average	130.71	119.89	68.37	32.91	9.90	0.04	0.39	0.19	2.71	25.69	61.63	118.86

Precipitation in the form of snow is not consistently and accurately measured in meteorological stations around the country leading to high uncertainties in any attempts at accurate water balance models. The decrease in precipitation and the prolongation of dry and warmer periods is expected to impact the extent of snow cover and its residence time, thus infiltration and subsequent recharge of aquifers.

3. Geology

The major geological structures of the Zahleh area are Mount Lebanon to the west, the Bekaa valley in the middle, and the Anti-Lebanon mountain range to the east. The two mountain ranges are formally two very large NNE-SSW trending anticlines separated by the Bekaa valley syncline. They have; however, been further broken up and disrupted by a series of major and minor faults through the ages.

The longest fault in Lebanon which also runs along the western flank of the Bekaa and about 4 km away from Zahle city is the well known Yammouneh fault (Figure 2). It originated in the Miocene epoch, around 10 to 12 million years ago, as the boundary between the Arabian Plate and the Levantine part of the African Plate.

The left lateral, strike slip Yammouneh fault has led to the movement of the Bekaa valley around 50 km northwards with respect to Mount Lebanon. The slip rate is estimated at 4.0 to 5.5 mm per year, with a major earthquake recurrence interval of around 1,000 years.

Evidence suggests that the fault has not moved for many thousands of years, and it is not clear whether it is currently classified as dead or dormant. No major earthquakes have occurred since the earthquake of 1202 that struck Syria.

As for aquifers in the Bekaa, it is fair to assume that the general flow of groundwater in the upper Litani river basin is from the snow covered peaks of the leeward Lebanon mountain chain as well as the and windward slope of the anti-Lebanon mountain chain towards the middle Bekaa syncline attested by the majority of dips (or inclinations) of geological formations (minute **T** shapes found on geological maps of Dubertret).

The following figure demonstrates the sheer number of faults crisscrossing just north to the city of Zahleh including the longest being the Yammouneh (all in red). Normally, fault lines are favorable sites for drilling water wells since they often behave as conduits or channels for groundwater flows.

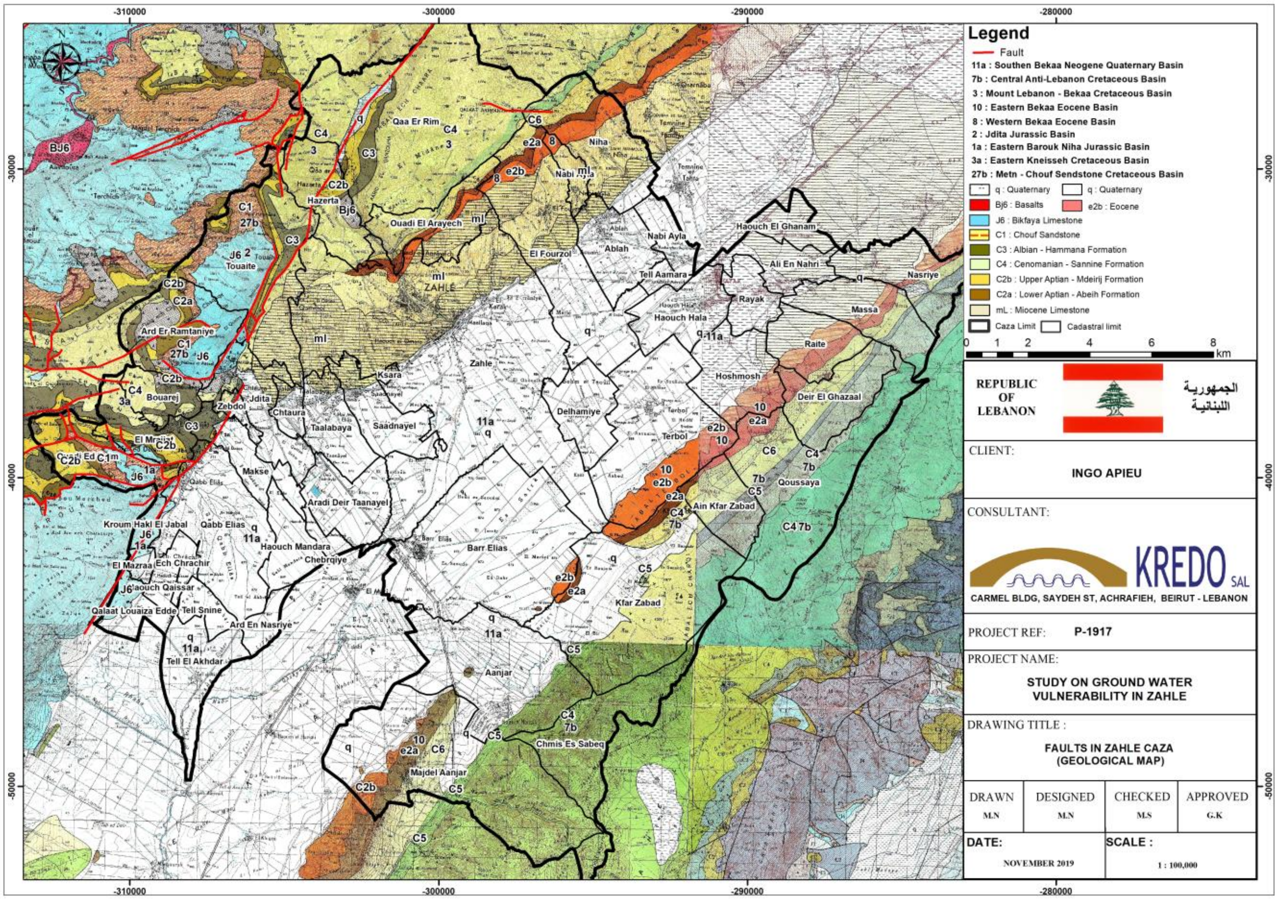

Figure 2: Minor and major faults north of the city of Zahleh (KREDO)

As for the geologic formations in **Zahle Caza,** they are listed and described below in a stratigraphic order from youngest to oldest formations (Saadeh, 2008).

- **Quaternary period** is the most recent geological period, and is mainly comprised of eolian and fluvial deposits that have accumulated over the past 2 million years. It has a thickness of a few hundred meters and designated as **q** on various geological maps.
- **Tertiary period** has several stratigraphic units that date back to 2 to 65 million years ago. The Tertiary geological period includes the following stratigraphic formations of various lithologies.
    - **Neogene period** consists of the following formations:
        - **Pliocene (p)** is composed of mostly sand, and has a thickness of around 100 m.
        - **Miocene (m_l)** has miscellaneous compositions, and a thickness of around 200 m.
    - **Paleogene period** consists of the Eocene (**e**) formations and generally considered an aquifer with some local exceptions:

    - **Ecocene (e_{2b})** has a thickness of around 200 m, and is made of marly limestone.
    - **Ecocene (e_{2a})** has a thickness of around 200 m, and is made of marly to chalky limestone.

- **Cretaceous period** is an extensive geological period dating back between 65 to 135 million years ago. It includes the following lithological units:
    - **C_6** from the Senonian epoch, such as the Chekka formation has a thickness of less than 500 m, and is made up of white marly chalks with black chert (hard, dark, opaque rock composed of silica) nodules.
    - **C_5** from the Turonian epoch, has a thickness of less than 200 m, and is composed of marly limestone with brown chert nodules.
    - **C_4** from the Cenomanian epoch, such as Sannine formation.
        - **C_{4C}** has a thickness of around 300 m and contains dolomitic limestone.
        - **C_{4B}** has a thickness of around 150 m and contains green marly limestone.
        - **C_{4A}** has a thickness of around 300 m and contains dolomitic limestone.
    - **C_3** Albian locally known as the Hammana formation has a thickness of around 200 m. Its lithology is mainly an amalgam of limestone, marl, sandstone, and basalt.
    - **C_2b** Upper Aptian consists of two formations
        - **C_2b_2** is composed of marl and sandstone and some basalt, and has a thickness of around 35 m.
        - **C_2b_1** is composed of limestone cliff, and has a thickness of around 50 m.
    - **C_2a** Lower Aptian has a thickness of around 150 m and is composed of limestone, marl, sandstone, and basalt. It is normally rich in amber and has a blue core.
    - **C_1** Neocomian formation has a thickness of around 300 m, and is mainly sandstone. It often contains basalt intrusions.

- **Jurassic** is the oldest geological period in Lebanon and Zahleh and alike. It dates back between 135 to 195 million years ago. The only stratigraphic unit present in Zahle Caza is the following:
    - **J_6** Kimmeridgian, or locally known Bikfaya limestone formation, composed of massive dolomitic limestone, with brown chert nodules. Its thickness is around 100 m. Note that the **BJ_6** Jurassic formation simply indicates basaltic (lava) intrusions into the original J_6 formation.

From the following figure, it is pertinent to note that the geological formations underlying the greater part of Zahleh city are predominantly of the Quaternary (q) and the Miocene (m) and are both designated aquifers, and in this particular case unconfined, meaning that the water table in an aquifer system has no overlying impervious rock layer (aquitard) separating it from the atmosphere, and as such unconfined aquifers are often subject to

And as such, these aforementioned unconfined aquifers underlying Zahleh (q and m) are often highly vulnerable to surface point and non-point sources of contamination as well as to groundwater depletions through over-pumping of wells.

As a side note, the apparent incoherence in geological designations, formation colors etc often employed by various sources namely journals, maps or other materials, is in no small part attributed to the absence of a governing body such as a geological society or syndicate prevalent in other countries.

Even the seminal geological maps of Lebanon prepared by Dubertret circa 1950s, have subtle discrepancies when it comes to designations and the use of colors when it comes to the same geological formations. Be it as it may, alterations in such maps and figures, however slight, constitute copyright infringement.

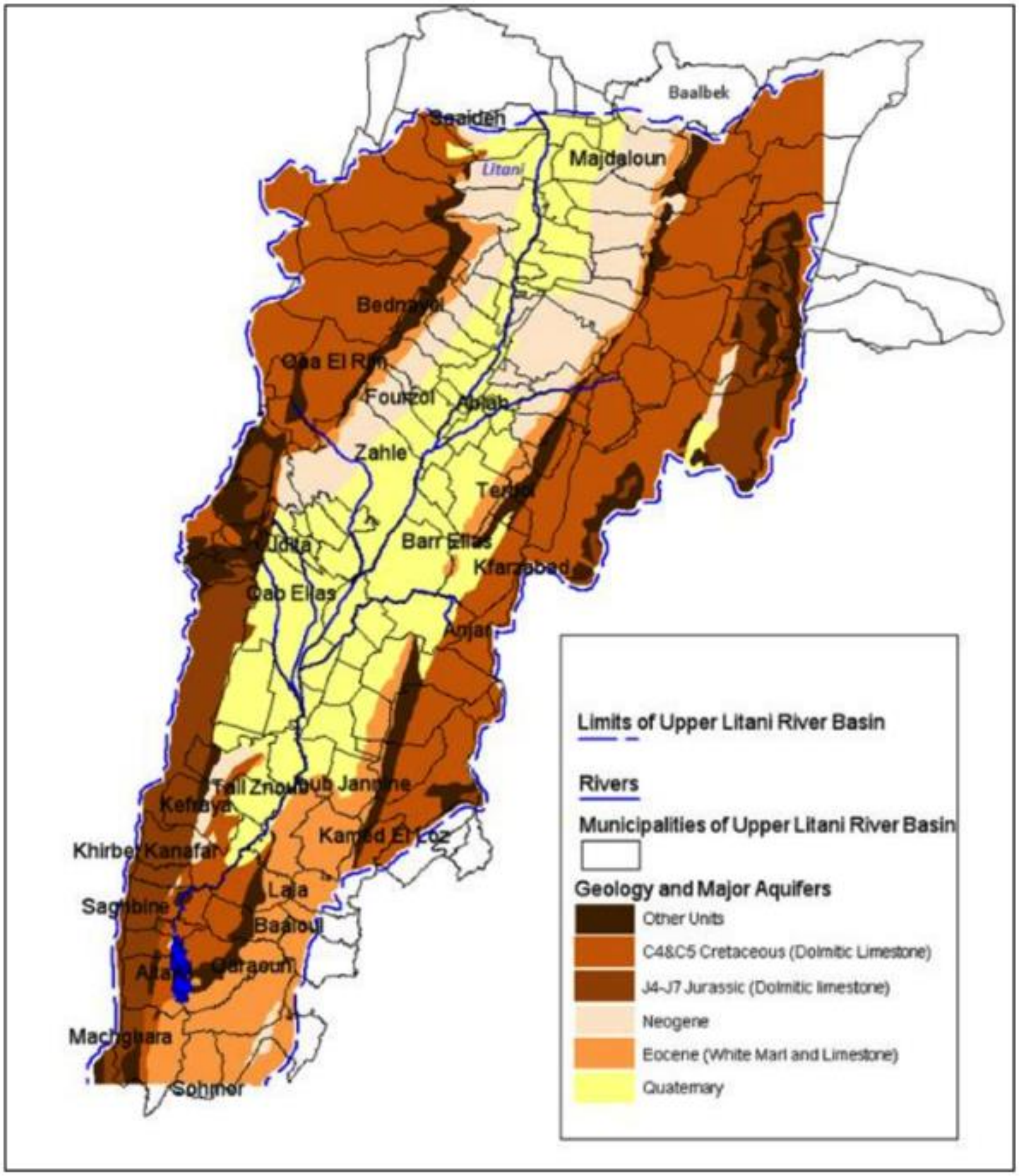

Figure 3: Aquifers of the Upper Litani River Basin (USAID-LRBMS, 2012)

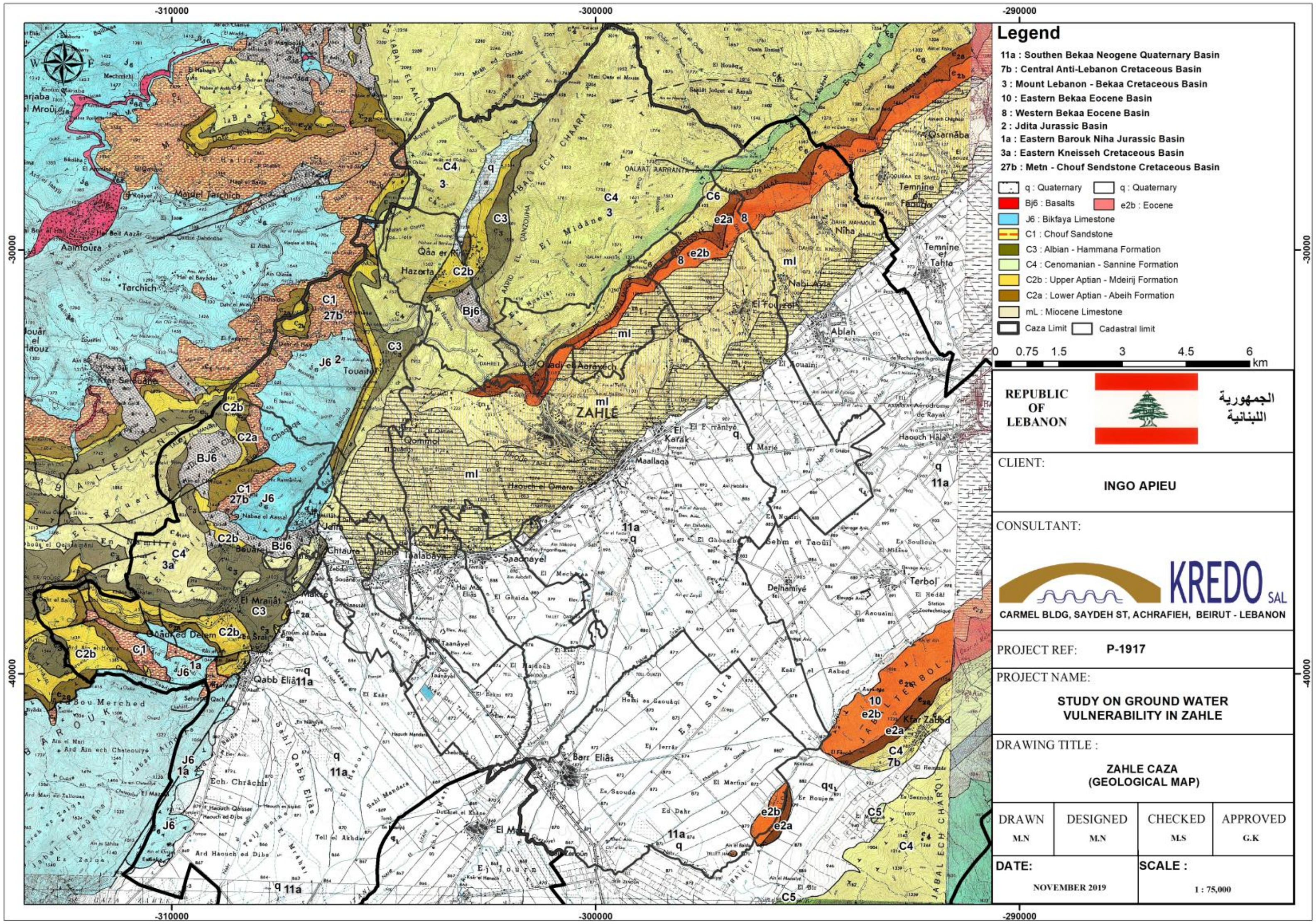

Figure 4: Geologic map of Zahle Caza (KREDO)

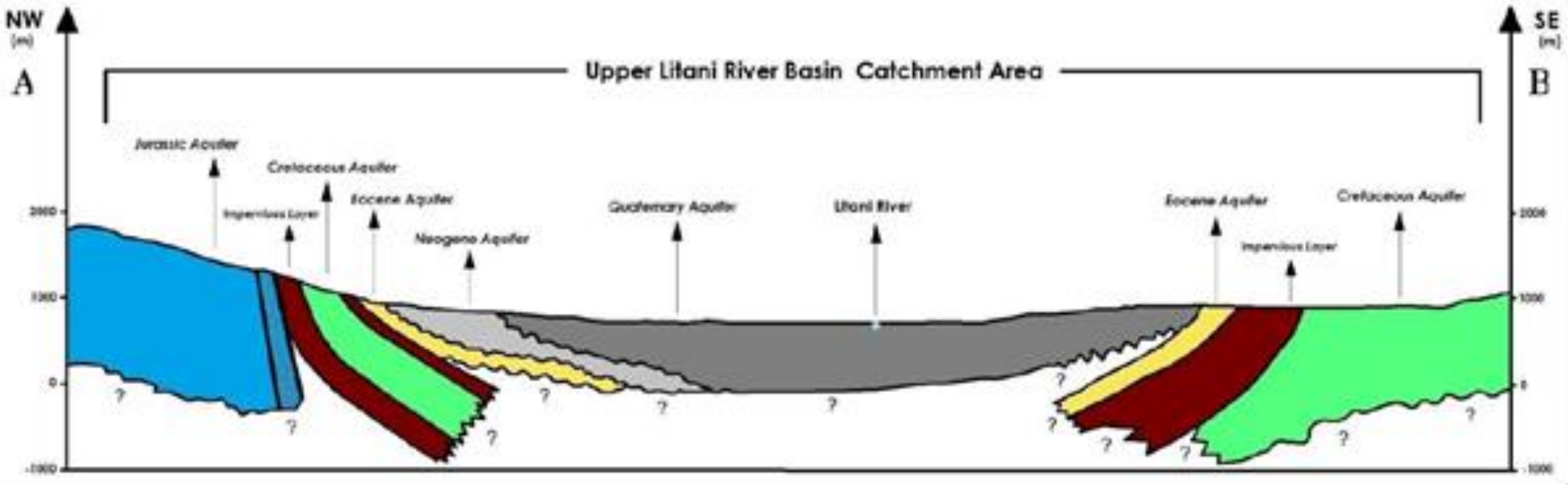

Figure 5: Typical geologic cross-section of the Bekaa Valley (LRBMS, 2013)

In the above cross section, the city of Zahleh rests predominantly on the Neogene aquifer formation (specifically designated as ml on Dubertret geological maps) and as such, is highly susceptible to contamination from point as well as non-point surficial sources.

4. Hydrogeology

From a hydrogeological perspective, the formations described in the previous section can be either of two types, an aquifer or an aquitard.

It is worth noting that other terms such as aquifuge and aquiclude are falling into disuse. By definition, aquifers are formations capable of supplying economic or viable quantities of water to wells and springs. Whereas aquitards cannot supply water in economic quantities.

Table 2 summarizes general hydrogeological characteristics of the formations present in Zahle Caza *(Saadeh, 2008)*. As a rule of thumb, aquifers that outcrop at the surface are categorized as unconfined and as such, are highly susceptible to contamination from surficial sources, as opposed to confined aquifers, which are deeper and often better shielded from contamination.

Table 2: Hydrogeological characteristics of formations in Zahle Caza

Designation		Aquifer/Aquitard	Typical Yield (L/s)	Hydraulic Conductivity (m/s)	Transmissivity (m^2/d)
Quaternary (q)		Aquifer	5 – 30	10^{-7} – $5x10^{-5}$	
Neogene	**Pliocene (p)**	Aquitard			
	Miocene (m$_1$)	Aquifer	10-30	10^{-7} – $5x10^{-5}$	
Eocene	**e$_{2b}$**	Aquifer in general	Up to 30	5x10-5 – 1.5x10-4	~10-4 to 10-2
	e$_{2a}$	Aquifer in general	Up to 30	$5x10^{-5}$ – $1.5x10^{-4}$	
Cretaceous	**C$_6$**	Aquitard			
	C$_5$	Aquifer	~ 40 - 50	$5x10^{-4}$ to 10^{-3}	~10^{-2} to 1
	C$_4$ a &c			$5x10^{-4}$ to 10^{-3}	
	C$_{4b}$	Aquitard		$1.5x10^{-4}$ – $3x10^{-4}$	
	C$_3$	Aquitard			
	C$_{2b}$	Aquifer	Up to 25	$5x10^{-4}$ to 10^{-3}	~2.3 x 10^{-6} to 3.2 x 10^{-6}
	C$_{2a}$	Aquitard			
	C$_1$	Aquifer	Max yield of 10	10^{-7} – $5x10^{-5}$	~10^{-5} to 10^{-4}
Jurassic	**J$_6$**	Aquifer	Max yield of 50	$5x10^{-4}$ to 10^{-3}	~10^{-2} to 1

Based on the following (UNDP, 2014) study , nine arbitrary aquifer basins were delineated in the Zahle Caza with groundwater flow indications pointing towards the Bekaa syncline emanating from the Lebanon and Anti-Lebanon mountain ranges. It is generally understood that an aquifer basin or system often comprise one or more adjoining aquifer formations.

For example, the arbitrarily designated Southern Bekaa Neogene/ Quaternary Basin (**11a**) which underlies Zahleh metropolitan, is in fact an amalgam of several different geological formations, mainly the quaternary (q) and miocene (ml), both of which happen to be unconfined aquifers with an estimated outcropping area of 228 square kilometers.

As such, this very same aquifer basin (11a), being unconfined in nature, is highly vulnerable to pollution from point as well as non-point surficial sources including raw sewage, fertigation, landfills just to name a few.

Another important basin is the so called Mount Lebanon-Bekaa Cretaceous basin (designated **3**) which adjoins the 11a basin and is a source of myriad springs namely Qaa El Rim from the mountain slope north of Zahleh. Said basin (**3**) owes its groundwater abundance to the major aquifer, locally known as Sannine formation and designated as **C_4**.

Table 3 below lists **nine basins (productive basins/aquifers only)** according to UNDP study of 2014 (executive summary only, www.pseau.org) delineated in black.

Table 3: Groundwater basins in Zahle Caza

Basin Name and Code	**Major Stratigraphic units of aquifer**	**Outcropping area (km^2)** (UNICEF & ELARD, 2017) [1]
Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary (q) / Miocene (ml)	228.4
Central Anti-Lebanon Cretaceous Basin (7b)	C_5-C_4	64.6
Mount Lebanon – Bekaa Cretaceous Basin (3)	C_5-C_4	35.2
Eastern Bekaa Eocene Basin (10)	Eocene e_{2b} – e_{2a}	18.4
Western Bekaa Eocene Basin (8)	Eocene e_{2b} – e_{2a}	9.86
Jdita Jurassic Basin (2)	J_6	8.5
Eastern Ba rouk Niha Jurassic Basin (1a)	J_6	4.7

[1] It is worth noting that there is a 60 km^2 discrepancy between the area of Zahle Caza and the total outcropping area of groundwater basins.

Eastern Kneisseh Cretaceous Basin (3a)	C_5-C_4	3.35
Metn- Chouf Sandstone Cretaceous Basin (27b)	C_1	3.1

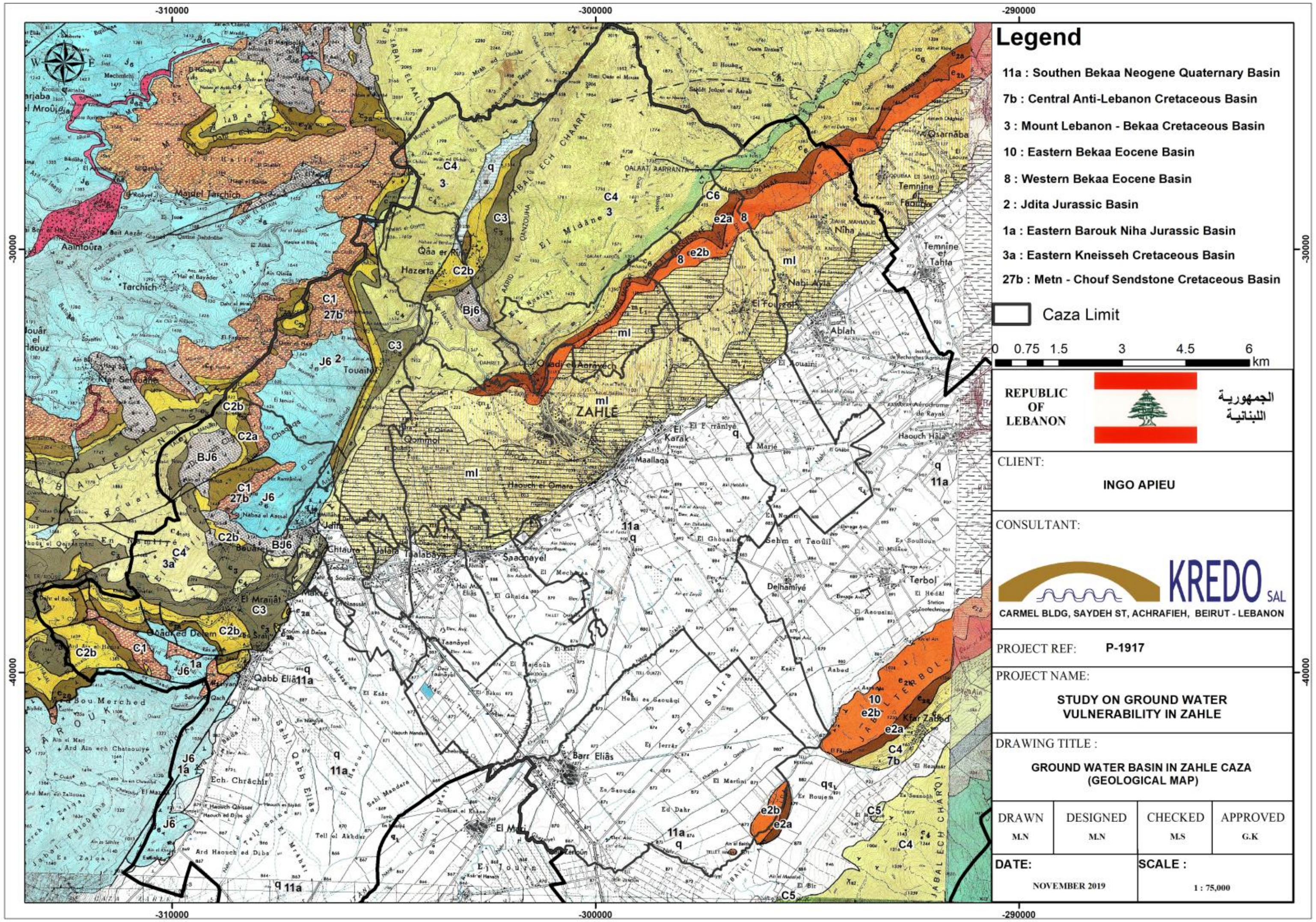

Figure 6: Groundwater basins of Zahle Caza as per the UNDP (2014) report

5. Groundwater Resources

5.1. Quantity

5.1.1. Springs

By most accounts, there are more than 200 springs of different discharge rates in Zahle Caza. Data on said flows were obtained from the following three sources:

- (El Hakim, 2018), where data was obtained from Litani River Authority (LRA) noting that the flow rates of springs are uncertain as to whether they are average values estimated from LRA or punctual site measurements. The study also referenced data collected by Bureau Technique pour le Développement (BTD) in 2012.
- (UNICEF & ELARD, 2017), where average minimum flow rates were reported without indicating the time frame over which they were calculated. Qabb Elias spring, of significant flow, was not even mentioned in said report.
- Meeting with Mr. Khalil Azar from the Bekaa Water Establishment (BWE) during the month of November 2019, where some average spring flow rates were obtained verbatim.

The table below lists the major springs with respect to their discharge and the corresponding basin they emerge from. These springs are used for both domestic and irrigational purposes.

It is worth noting that the differences in spring discharge from multiple sources is due to the lack of consistent and accurate monitoring of springs further corroborated by meetings with the Bekaa Water Establishment (BWE).

Data on the average discharge of Anjar, Chtoura, and Qabb Elias springs were obtained from the Litani River Authority (LRA). Data for Anjar and Qab Elias spring flow covered the period of 2000 till 2014, while that of Chtaura spring covered the period of 2005-2014.

Data on Berdawni spring is from a study done by Bureau Technique pour le Développement (BTD) for the Council for Development and Reconstruction (CDR) during 2009-2012. Again, all the aforementioned data requires updating.

From the following figure, it is apparent that most springs in the Municipality of Zahleh, are clustered to the north of the city emanating at or close to the Cenomanian (C_4) geological formation locally known as the Sannine and pertaining to the Cretaceous period, considered by many experts to be the major aquifer of Lebanon.

Furthermore, said aquifer (C4) being unconfined, is highly susceptible to contamination from surficial sources as well as wells alike.

Table 4: Springs in Zahle Caza - flows and groundwater basin

Spring Name	Yearly Minimum Discharge (L/s) (UNICEF & ELARD, 2017)	Average discharge (L/s) (El Hakim, 2018)	Basin	Aquifer
Anjar	970[2]	1600	Central Anti-Lebanon Central Anti-Lebanon Cretaceous Basin (7b)	C5- C4
Kfar Zabad	168		Central Anti-Lebanon Cretaceous Basin (7b)	C5- C4
Chtaura	153.5	422	Southern Bekaa Neogene / Quaternary Basin (11a)	m_l
El Kazouz	148		Eastern Kneisseh Cretaceous Basin (3a)	C5- C4
Qaa El Rim	100 – 200	337-1258	Mount Lebanon Bekaa Cretaceous Basin (3)	C5- C4
Zahle Old Spring	90	94	Southern Bekaa Neogene / Quaternary Basin (11a)	q
Al Berdawni	87.7[3]	920	Mount Lebanon Bekaa Cretaceous Basin (3)	C5- C4
Qabb Elias	83 [4]	629	Metn- Chouf Sandstone Cretaceous Basin (27b)	C1
Bhoucha	69	4[5]	Western Bekaa – Ecocene Basin (8)	Eocene e_{2b} – e_{2a}
Halabiye	25	9-100	Mount Lebanon Bekaa Cretaceous Basin (3)	C5- C4
Ain El Tine	20.8		Western Bekaa- Eocene Basin (8)	Eocene e_{2b} – e_{2a}
Nabaa Al Fouar	20.6		Eastern Bekaa Eocene Basin (10)	Eocene e_{2b} – e_{2a}

[2] Average minimum flowrate of Anjar Spring for the period of 2000-2014 is 248 L/s based on LRA data referenced in (El Hakim, 2018). This is significantly lower than the (average) minimum flowrate of 970 L/s reported in (UNICEF & ELARD, 2017).
[3] Average minimum flowrate over 2009-2012 is 120 L/s based on data from BTD study with CDR referenced in (El Hakim, 2018).
[4] Taken from (El Hakim, 2018)
[5] There is a big difference in the reported figures. According to BTD 2012 study referenced in (El Hakim, 2018), the flowrate of Bhoucha spring varies between 0 to 11 L/s, and it dries up in the summer.

Ain Al Massna	20		Mount Lebanon Bekaa Cretaceous Basin (3)	C5- C4
Ras El Ain	17.6	40 [6]	Eastern Bekaa Eocene Basin (10)	Eocene $e_{2b} - e_{2a}$
Nabaa Al Ain	13		Mount Lebanin Bekaa Cretaceous Basin (3)	C5- C4
Ain Delbe	13		Mount Lebanin Bekaa Cretaceous Basin (3)	C5- C4
Jdita	11.6		Jdita Jurassic Basin (2)	BJ6
Zoueitini	11.57	3-8[7]	Mount Lebanon Bekaa Cretaceous Basin (3)	C5- C4
Ain Er Rohbane	11		Metn- Chouf Sandstone Cretaceous Basin (27b)	C1
Ain Half Laouzi	11		Jdita Jurassic Basin (2)	J6
Ain Hazir	11		Mount Lebanon Bekaa Cretaceous Basin (3)	C5- C4
Chamsine	Currently dry due to over pumping	50	Central Anti-Lebanon Cretaceous Basin (7b)	C5- C4

[6] From Bekaa Water Establishment, Mr. Khalil Azar.
[7] According to BTD 2012 study referenced in (El Hakim, 2018), the average flow rate of this spring is 3 to 8 L/s which is less than the minimum flow rate reported in (UNICEF & ELARD, 2017).

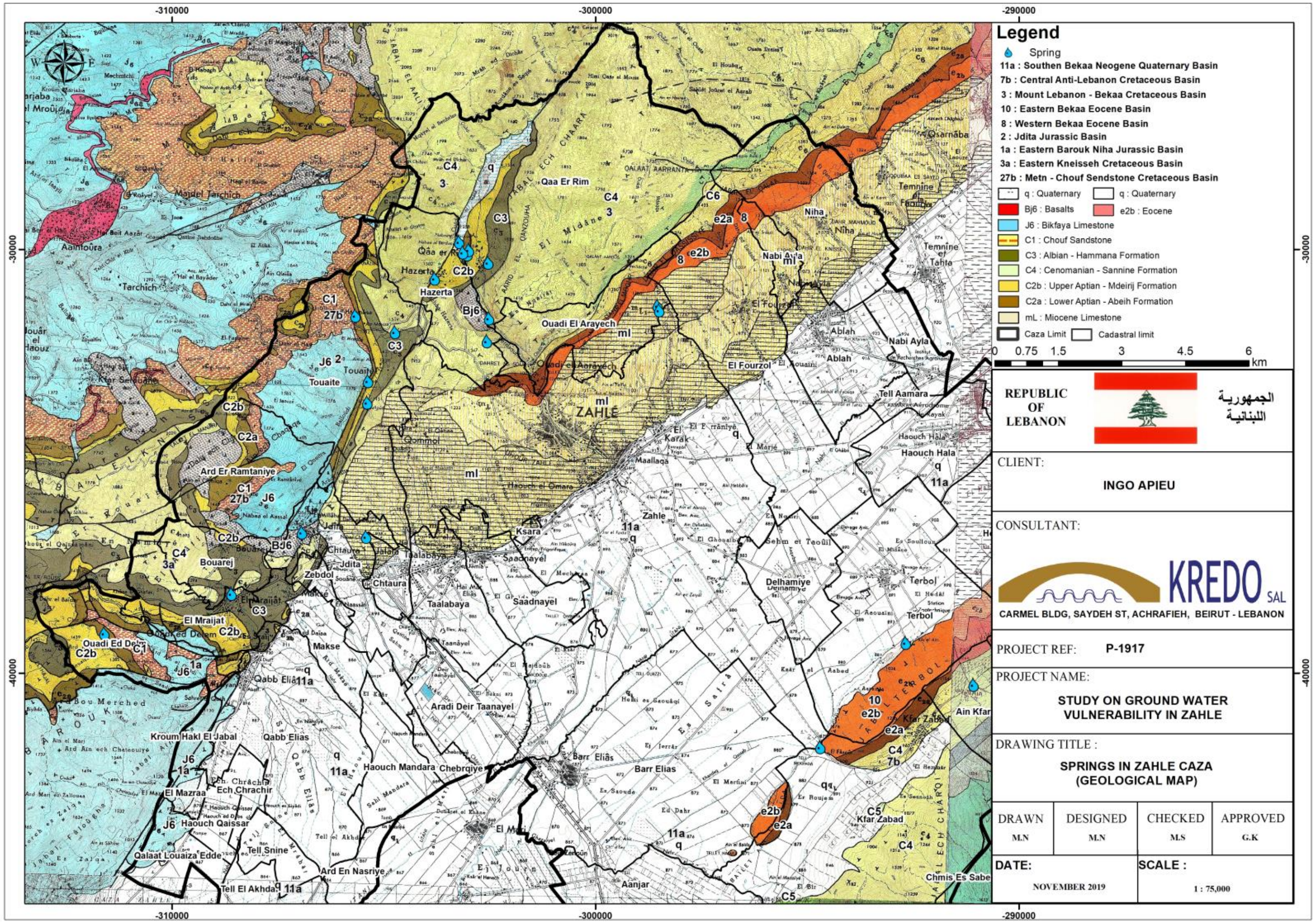

Figure 7: Major springs of Zahle Caza (KREDO)

5.1.2. Rivers

No discussion of hydrogeology is complete without mention of the overlying streams and rivers which themselves are connected to ground waters through hyporheic zones i.e. intimately connected.

In the case of Zahleh municipality, the major lotic system is the Berdawni river which passes through the center of the city of Zahleh before converging with the Litani River.

However, as the Berdawni passes through the city of Zahleh, it is lined with concrete, effectively severing the hyporheic zone, thus depriving underlying aquifers from precious surface recharge. Exactly establishing the length of the Berdawni canal through Zahleh is difficult to ascertain without actual field measurements.

Emanating from the Berdawni spring atop the Sannine (C_4) formation, on the eastern slope of the Mount Lebanon Chain, the Berdawni river runs nearly 17 km before joining the Litani and cutting through the following geological formations:

- **Quaternary (q) formation (aquifer)**
- **Miocene (m_l) formation (aquifer)**
- **Eocene (e) formation (aquifer)**
- **Senonian or Chekka (C_6) formation (aquitard)**
- **Cenomanian or Sannine (C_{4-5}) formation (aquifer)**

Different references provide a wide range of values for the discharge of the Berdawni spring and its namesake river, some examples include:

- Yearly spring minimum discharge of 87.7 L/s (UNICEF/ELARD, 2017)
- Average spring discharge of 920 L/s (El Hakim, 2018)
- 0.2 to 2.0 m^3/s for the river (LRA, 2012 to 2014)

It is also noteworthy to mention that the Berdawni river for most of its initial length runs along the well known Yammouneh fault before making a sharp 90 degree turn and meandering through the city of Zahleh, again, which for most part is unwittingly lined with concrete, thus isolating it from underlying aquifers which rely on the Berdawni for annual recharge.

5.1.3. Public Wells

Miscellaneous data pertaining to public wells was mainly compiled from the following references:

- Water and Wastewater Master Plan – Bekaa (KREDO; DAI, 2015)
- Wells listed in the UNICEF & ELARD report, 2017
- El Hakim report of 2018, based on Litani River Basin Management Support Program (LRBMS) funded by USAID
- Data verified and updated by Mr. Khalil Azar from the Bekaa Water Establishment (BWE), Head of Projects, Fall 2019.

As such, there are currently an estimated **39 public wells** in Zahle Caza used mainly for domestic and irrigational purposes. Bekaa Water Establishment is the operator of these wells as it is the only entity, legally authorized to get a power permit for pumping operations. Some wells, like in Bouwarej and Ferzol, have limited flows, and are instead managed by local water committees.

The pumping durations of most of these wells, as per the above mentioned sources, is an average of 15 hours daily. No comprehensive and regular monitoring of public wells exists, neither for quantity nor quality, as attested by BWE interviews.

Despite the installation of 15 monitoring wells in the Upper Litani River Basin under the USAID funded LRBMS project circa 2012, they seem to have fallen into disrepair due to lack of operation and maintenance funds (interview with BWE, 20.11.2019).

The Bekaa Water Establishment (BWE) declares to have installed a SCADA system for well monitoring and has submitted limited information based on their flows but excludes vital pumping durations. Therefore, based on direct discussions with BWE, the total volume of water pumped on a daily basis from the mentioned public wells in Zahle Caza is estimated to be around 55,000 m^3 with typical declared pumping durations of 15 hours.

The following, Table 5, briefly summarizes the public wells of Zahleh, with average flows easily calculated by adding the red highlighted values of column five leading to 12,044 m^3 daily, nearly a quarter of the 55,000 m^3 of water pumped from the entire caza according to the Bekaa Water Establishment (BWE).

Table 5: Public Wells of Zahle Municipality

Locality	Well_Name	Drilling Depth	Flow (L/s)	Flow (m^3/d)	Average volume pumped daily (m3)	Basin	Aquifer
Zahle	Zahle Moustadira	200	25	**2160**	1350	Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary / Neogene
Zahle - Maalaqa	Zahle Maalaqa well 3 (Red Cross)	200	20	**1728**	1080	Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary / Neogene
Zahle - Maaaqa	Zahle Maalaqa well 1(Kuwaiti Well)	200	18	**1555**	972	Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary / Neogene
Zahle - Maalaqa	Zahle Maalaqa well 2 (Sadaka Well)	125	20	**1728**	1080	Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary / Neogene
Zahle Haouch El Oumara	Zahle Yoyo well	125	17	**1469**	918	Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary / Neogene
Zahle Haouch El Oumara	Zahle Lycee well 2	125	20	**1728**	1080	Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary / Neogene
Zahle -	Zahle Lycee well 1	125	19	**1676**	1048	Southern Bekaa Neogene / Quaternary	Quaternary / Neogene

Haouch El Oumara						Basin (11a)	

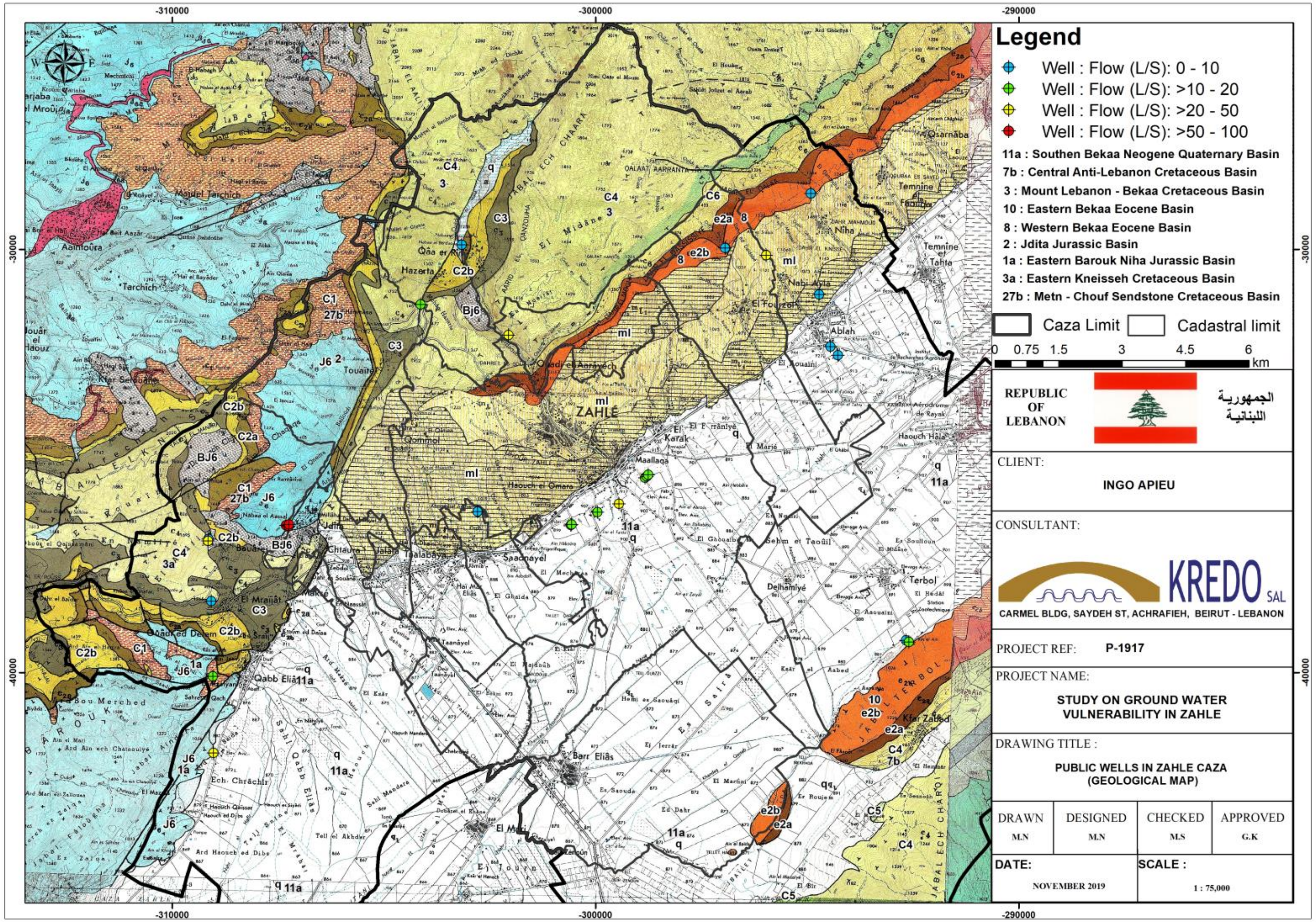

Figure 8: Public wells in Zahle Caza (KREDO)

5.1.4. Private Wells

With the exception of only one, no private wells have installed meters in Zahle (interview with BWE, 20.11.2019).

Permits for drilling private wells are issued by the Ministry of Energy and Water (Decree 14438/1970, MoEW); however, the ministry rarely follows up on the quantity or quality of water extracted once permits are granted.

Nevertheless, an estimated 40 to 50 private well permits are issued yearly within the study area (interview with BWE, 20.11.2019). BWE however is often not consulted on the subject, especially in matters regarding the safe minimum distance between existing wells (interview with BWE, 20.11.2019). According to current practices, a minimum of 300 linear meters is sometimes maintained between any two wells in the Bekaa.

No accurate data is available on the number of private wells in caza Zahleh or their respective extraction rates depths etc. since the majority of them are unlicensed.

BWE on the one hand estimates that there are between 5,000 to 6,000 such wells in Zahle caza (interview with BWE, 20.11.2019). This resonates with one study done by (UNICEF & ELARD, 2017) which estimated the number of wells at around 6,316 private wells.

UNICEF on the other hand, estimates that 1,579 of the above mentioned private wells are licensed with an average extraction rate of 66 m^3/d per well (min 12 m^3/d and max 180 m^3/d). Unlicensed wells are estimated at 4,737, or three times the number of licensed ones.

Another survey mapped around 4,200 wells for 35,416 houses in Zahle caza (Kehdy, 2013). This amounts to roughly 1 well for every 9 houses. Kehdy even notes that this number is an under-estimation, for owners are often reluctant to disclose their presence in fear of heavy fines.

Water table monitoring data, on the other hand, reveals an average drop of 2 m per year (from 2011 to 2012) in domestic wells tapping the Quaternary (q) formation, the main formation in and around Zahle city (Kehdy, 2013). This illustrates the fragility of this unconfined aquifer in response to over abstraction (or over pumping). As a side note, this aquifer constitutes a large part of the previously mentioned 11a basin system.

Shallow wells in Zahleh city (between 60-200m) that tap into the quaternary (q) allow them to extract from said aquifer which is also categorized as unconfined and thus susceptible to contamination from surficial sources and through wells alike.

Deeper wells (exceeding roughly 200 meters) tap the deeper Eocene (e) aquifer, and very deep wells (400m or more) can even reach the deeper confined Sannine-Maameltein (C_4-C_5) aquifers (UNICEF & ELARD, 2017).

The following figure shows the mapped private wells in Zahle Caza on a geologic background (ELARD, 2018). Evidently, high concentration of private wells are present in Zahle city, as well as Rayak, Wadi Al Arayesh and Ablah, most of which tap the fragile unconfined Quaternary/Neogene aquifer basin (11a) composed of the quaternary (q) and miocene (ml) aquifers.

This very same aquifer basin (**11a**) as well as the adjoining Mount Lebanon-Bekaa Cretaceous Basin designated (**3**) to the north, are both unconfined aquifer systems and as such are extremely susceptible to point and non-point sources of pollution as well as continued drawdown of the water table due to excessive pumping.

Additionally, all wells should be treated as routes for potential groundwater contamination if misused for illicit disposal purposes.

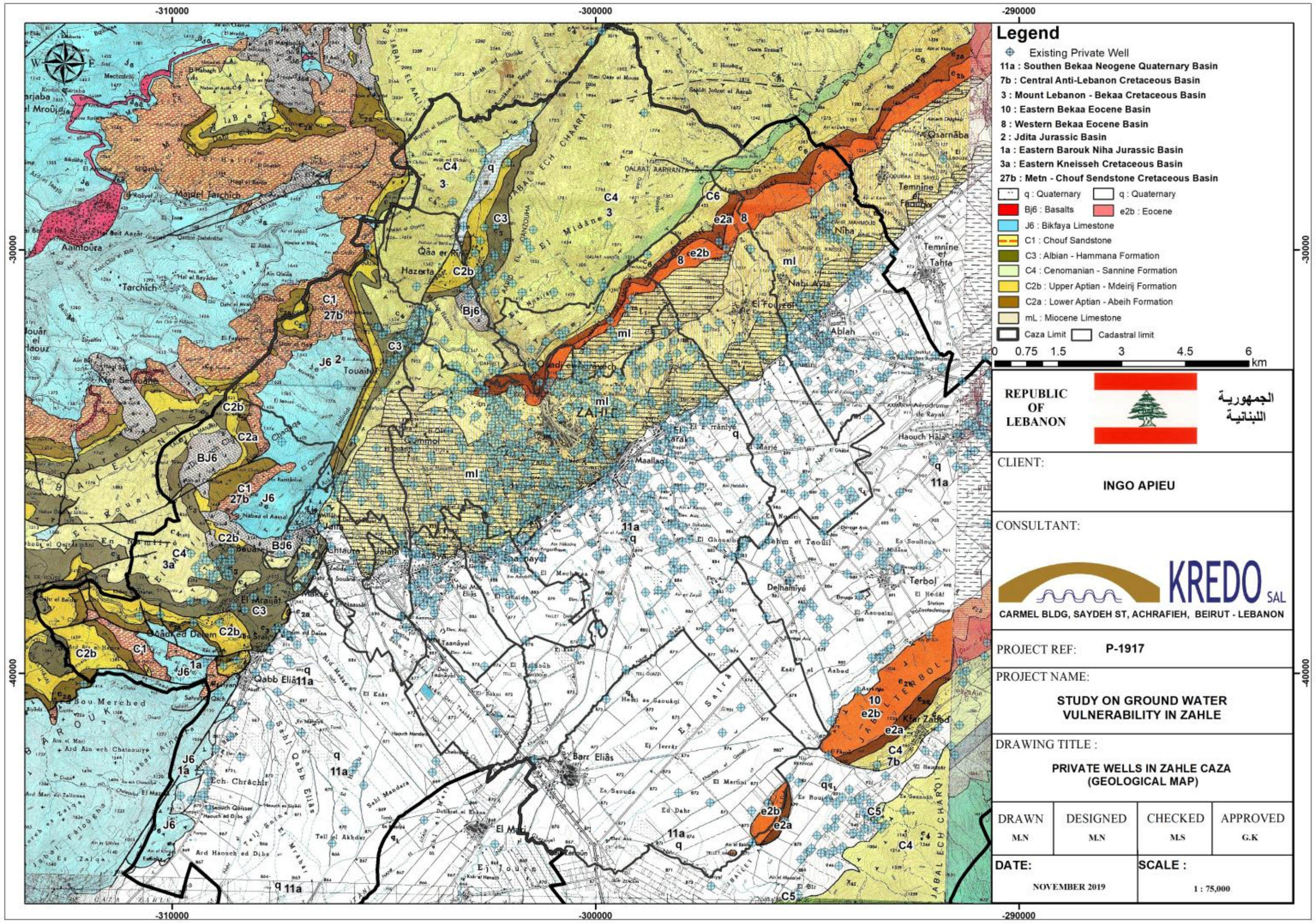

Figure 9: Private Wells in Zahle Caza (KREDO)

5.2. Quality

Surface and groundwater in the Upper Litani Basin is undoubtedly heavily polluted because of the years of incessant discharges of raw sewage, solid wastes, and copious agrochemicals (International Resources Group, IRG/USAID, 2012a).

Despite the proposal for added wastewater treatment plants in Anjar/El Marej (KREDO; DAI, 2015), they were not constructed at the time of the report. As a conequence, several areas in Zahle caza likely still discharge their wastewater into unlined septic tanks, illicit wells or straight into streams and rivers.

Moreover, most studies claim that fertilizers are applied at 1.5 to 3 times the needed application rates (International Resources Group, IRG/USAID, 2012b). This leads to agricultural runoff with high levels of nitrates and phosphates that end up in streams, with the former eventually finding its way to groundwater.

These two analyses are especially harmful in that they cause widespread eutrophication of rivers and the Qaraoun reservoir.

Additionally, nitrates seeping into groundwater eventually find their way into drinking water and pose an extreme hazard in the form of methemoglobinemia or the potentially fatal blue baby syndrome.

As an example, Terbol Well 1 is no longer in use due to the reported high concentration of nitrates (interview with BWE, 20.11.2019). It is also worth noting that the pollution of surface waters, normally used for domestic and irrigation purposes, has added greater pressure on groundwater resources in the form of excessive and unlicensed abstractions.

For instance, in the town of Ablah, the use of surface water from the Litani river has dropped from 75% to only 5% in just a few years due to the deterioration of the river's water quality (Kehdy, 2013).

According to recent discussions with the Bekaa Water Establishment (8 July 2020), there are currently only three operational wastewater treatment plants in the Zahleh caza and they include by far the largest in the municipality of Zahle (currently treating 22,000 cubic meters of wastewater per day), followed by Ablah (2,000 cubic meters per day) and Ferzol (1,000 cubic meters per day).

BWE also disclosed that landfills in the caza of Zahleh include the Zahleh municipality landfill which is a landfill, sorting and composting facility all in one. According to BWE, the only other sanitary landfill is currently located in the town of Bar Elias.

As for illicit dump sites of solid wastes, BWE disclosed that they have become too innumerable in recent times compounded by the high number of Syrian refugees.

Based on a different survey however done in 2017, there are about 17 dumpsites in Zahle Caza with an estimated total volume of 734,250 m^3 of municipal solid waste, 7 of which are operational and the remaining ten are ostensibly abandoned (according to UNDP; MoE, 2017).

In the aforementioned study, a risk sensitivity index of each dumpsite was evaluated based on several attributes, such as volume of waste, geology (lithology and faults), hydrology (distance to springs), distance to urban areas, quantity of waste currently dumped, open burning of waste, and the thickness of wastes among others.

Based on this risk index, Qabb Elias dumpsite in Zahle Caza (219,000 m^3) was ranked the 6^{th} highest priority dumpsite in the country in urgent need of rehabilitation (UNDP; MoE, 2017). Leachate from this dumpsite is very likely contaminating the underlying and exposed Quaternary (q)/ Neogene (ml) unconfined aquifers.

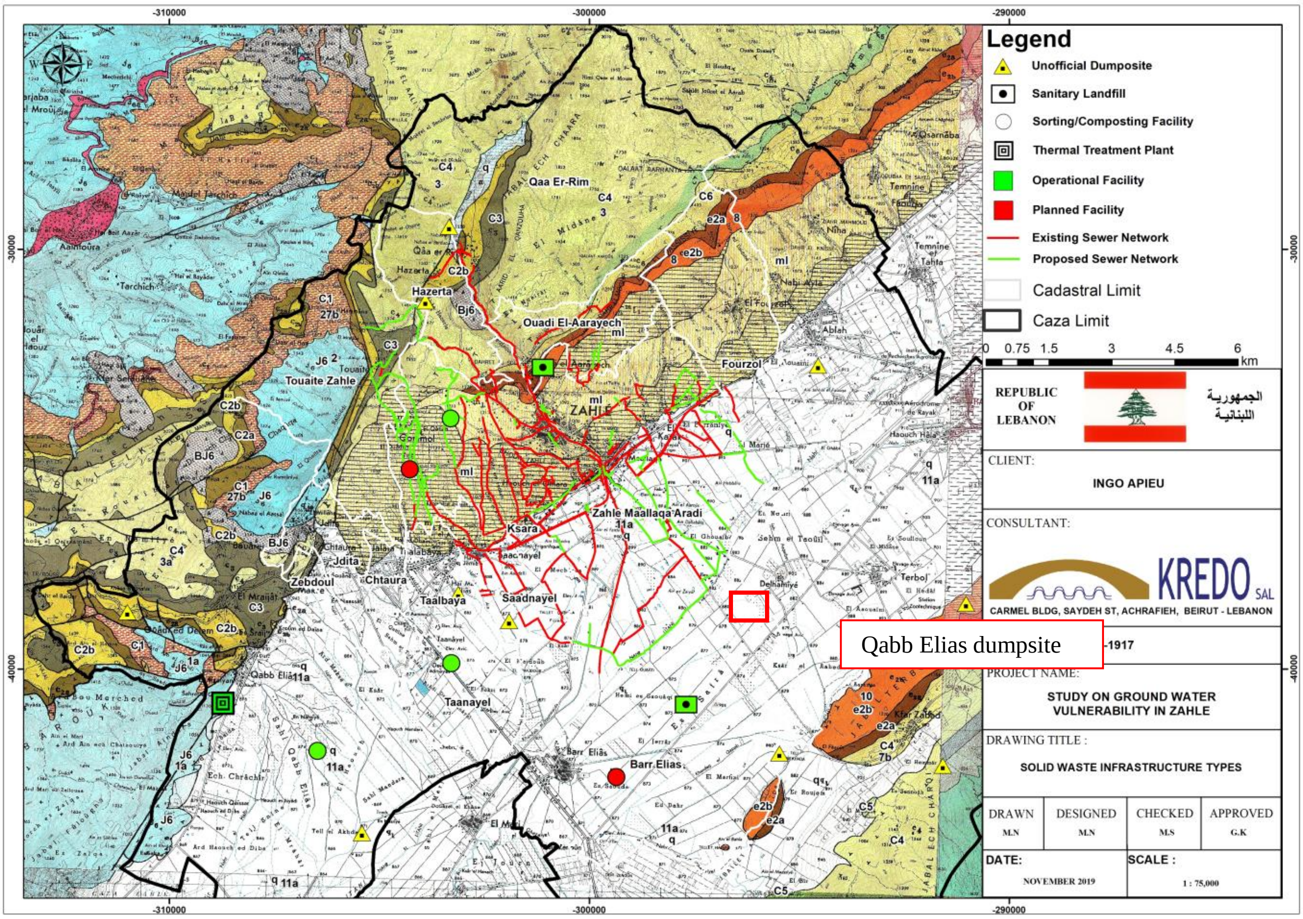

Figure 10: Municipal Solid Waste dumpsite & sewer networks (CNRS, 2020)

It is also worth noting that gas stations are also another major source for groundwater pollution due to the risk of fuel leakages from unmonitored Underground Storage Tanks or USTs.

Recent data on groundwater quality from public wells was obtained from a study carried by KREDO (KREDO, 2016) and from the office of the Bekaa Water Establishment (BWE) during 2018-19.

Test results from these sources are compared to drinking water quality standards of primary pollutants set by the US Environmental Protection Agency (USEPA) and the World Health Organization (WHO).

Primary standards for drinking water quality set maximum contaminant levels "MCL" for total coliforms (including fecal and E. coli), nitrate, nitrite, and metals just to name a few.

The results, shown in the following tables, can be clearly summarized as follows:

- Bacteriological contamination, mainly from untreated raw sewage discharge, is found in 3 wells; Ali Al Nahry, Zahle Saadaka, and Zahle Yoyo. These wells which tap into unconfined Quaternary/Neogene aquifers are quite heavily polluted with total and fecal coliforms.
- Nitrate concentration in wells tapping into the unconfined Quaternary/Neogene aquifers in Zahle were close to or even higher than maximum contaminant levels allowed by USEPA and WHO drinking water guidelines.
- Several wells are also contaminated with nickel originating from the industrial sector. Ingesting nickel in contaminated water can pose a threat to human health leading to liver and kidney damage. Aquifers contaminated with nickel are the Quaternary/Neogene aquifer in Zahle, Eocene aquifer in Niha, and the Jurassic J_6 aquifer in Qabb Elias. Data being sparse, the only certainty is that unconfined aquifers are more vulnerable to point and non-point (diffuse) sources of pollution than deeper confined aquifers.

KREDO also compared actual water quality results to irrigation quality guidelines set by the Food and Agricultural Organization (FAO). The following guidelines are cited:

- pH should be between 6.5 and 8.4
- Nitrate nitrogen (NO_3-N) should be between 0 to 10 mg/L
- Total Dissolved Solids should be between 0 to 2000 mg/L
- Chloride should be between 0 to 1000 mg/L
- Sulfate should be between 0 to 300 mg/L
- Magnesium should be between 0 to 60 mg/L
- Sodium should be between 0 to 900 mg/L

Based on the above guidelines, water extracted from some wells in Zahle city exceeded the above mentioned FAO guidelines especially for nitrates and nickel. As such, slight to moderate restrictions on the continued use of this groundwater for irrigational purposes is recommended.

Table 6: Bacteriological groundwater quality tests at public wells – 2016 (KREDO) & 2018-2019 (BWE)

	Total Coliform		Fecal Coliform		E coli		Aquifer (Basin)
EPA/WHO MCL	**< 1 cfu in 100 ml**		**< 1 cfu in 250 ml**		**< 1 cfu in 250 ml**		
Water quality test results at wells	**2016**	**2018-2019**	**2016**	**2018-2019**	**2016**	**2018-2019**	
Zahle Maalaqa well 2 (Sadaka well)	> 100 cfu in 100 ml	Absent	**57 cfu in 250 ml**		Absent in 250 ml	Absent in 250 ml	Quaternary/Neoge (11a)
Ali Al Nahry well	**20 cfu in 100 ml**		**9 cfu in 250 ml**		Absent in 250 ml		Quaternary/Neoge (11a)
Zahle Lycee Well 1	<1 cfu in 100 ml	Absent	< 1 cfu in 250 ml		Absent in 250 ml	Absent in 250 ml	Quaternary/Neoge (11a)
Zahle Lycee Well 2	3 cfu in 100 ml	Absent	< 1 cfu in 250 ml		Absent in 250 ml	Absent in 250 ml	Quaternary/Neoge (11a)
Zahle Yoyo Well	2 cfu in 100 ml	Absent	**1 cfu in 250 ml**		Absent in 250 ml	Absent in 250 ml	Quaternary/Neoge (11a)
Qabb Elias Well	<1 cfu in 100 ml		<1 cfu in 250 ml		Absent in 250 ml		J6 (1a)
Niha Well	26 cfu in 100 ml	Absent	<1 cfu in 250 ml		Absent in 250 ml	Absent in 250 ml	Eocene e2b – e2a (8)

Zahle Maalaqa well 3 (Red Cross well)	96 cfu in 100 ml	Absent	<1 cfu in 250 ml		Absent in 250 ml	Absent in 250 ml	Quaternary/Neogen (11a)
Zahle Maalaqa well 1 (Kuwaiti Well)	<1 cfu in 100 ml		<1 cfu in 250 ml		Absent in 250 ml		Quaternary/Neogen (11a)
Jdita well 3	<1 cfu in 100 ml	Absent	<1 cfu in 250 ml		Absent in 250 ml	Absent in 250 ml	J6 (2)
Jdita well 2	<1 cfu in 100 ml	Absent	<1 cfu in 250 ml		Absent in 250 ml	Absent in 250 ml	J6 (2)
Jdita well 1	<1 cfu in 100 ml	Absent	<1 cfu in 250 ml		Absent in 250 ml	Absent in 250 ml	J6 (2)
Zahle Moustadira Well		Absent	<1 cfu in 250 ml			Absent in 250 ml	Quaternary/Neogen (11a)
Hoshmosh Well		Absent				Absent in 250 ml	Quaternary/Neogen (11a)
Dhour Zahle (Hzarta Well 1)		Absent				Absent in 250 ml	C5-C4

Table 7: Groundwater quality tests 2016 (KREDO) & 2018-2019 (BWE) evaluated for primary pollutants for drinking water quality

	TDS	**Nitrates as NO3-N**	**Nitrites as NO2-N**	**Turbidity**	**Metals exceeding allowable limits**	**Aquifer (Basin)**
EPA/WHO MCL	**1000 mg/l**	**10 mg/l as nitrate nitrogen**	**1 mg/l**	**3 NTU**		

Water quality test results at wells	2016	2018-2019	2016	2018-2019	2016	2018-2019	2016	2018-2019	2016	2018-2019	
Zahle Maalaqa well 2 (Sadaka well)	346	379	**9.55**	2.93	<0.05	0.009	<1		**Ni**		Quaternary/Neogene (11a)
Ali Al Nahry well	222		4.79		<0.05		<1		**Ni**		Quaternary/Neogene (11a)
Zahle Lycee Well 1	307		**9.24**		<0.05		<1		**Ni**		Quaternary/Neogene (11a)
Zahle Lycee Well 2	324		**9.69**		<0.05		<1		**Ni**		Quaternary/Neogene (11a)
Zahle Yoyo Well	336		**18.3**		<0.05		<1		**Ni**		Quaternary/Neogene (11a)
Qabb Elias Well	203		4.41		<0.05		<1		**Ni**		J6 (1a)
Niha Well	272	148	<1	2.1	<0.05	0.00325	2.72		**Ni**		Eocene e2b – e2a (8)
Zahle Maalaqa well 3 (Red Cross well)	203	320	9	4.67	<0.05	0.012	<1		**Ni**		Quaternary/Neogene (11a)
Zahle Maalaqa well 1 (Kuwaiti Well)	316		**10.2**		<0.05		<1		**Ni**		Quaternary/Neogene (11a)
Jdita well 3	154	150	<1	1.2	<0.05	0.005	<1		-		J6 (2)
Jdita well 2	158	155	<1	0.7	<0.05	0.003	<1		-		J6 (2)
Jdita well 1	154	153.5	<1	2.3	<0.05	0.003	<1		-		J6 (2)
Zahle Moustadira	292		3.4	2.6	<0.05						Quaternary/Neogene (11a)

Well											
Hoshmosh Well		250		2.4		0.004					Quaternary/Neogene (11a)
Dhour Zahle (Hzarta Well 1)		201.5		0.8		0.0045					C5-C4

Water quality tests at Qaa El Rim spring carried out by the Bekaa Water Establishment (BWE) in 2018 indicate that at the start of the rainy season, the spring water is turbid and has a high level of E. coli and total coliform contamination. This is likely due to contaminated surface runoff that has apparently found its way to the Sannine (C_4) aquifer and manifests itself in wells or springs. Again hard data was not provided by the BWE despite repeated requests.

6. Vulnerability of Groundwater Resources

Groundwater vulnerability is a term used to represent the natural ground/aquifer characteristics that determine the ease with which groundwater may be contaminated by anthropogenic activities.

More scientifically, groundwater vulnerability embodies the characteristics of the intrinsic geological and hydrogeological features at a site that determine the ease of contamination of groundwater.

The vulnerability category assigned to a site or an area is thus based on the relative ease with which infiltrating water and potential contaminants may reach groundwater often in sub-vertical directions. As all groundwater is hydrologically connected to the land surface, it is the effectiveness of this connection that determines the relative vulnerability of an aquifer to contamination.

Conceptually therefore, understanding and mapping vulnerability of aquifers is by no means a simple and straight forward task. Models from around the world assign different weights to different parameters in order to suit their local needs, hence there is no one size fits all approach.

As such, the following suggestions and approaches are adopted by different countries around the world and may find some applicability in the current study of Zahle caza.

6.1. Groundwater Vulnerability Mapping – DRASTIC Method

A groundwater vulnerability assessment model was evaluated using the DRASTIC method (EPA, 1985) to determine the sensitivity of groundwater quality to potential contamination (DAI, 2005).

Nevertheless, the DRASTIC method has a major setback and that is its limitation in applicability to karstic aquifers which dominate Lebanon's geological formations.

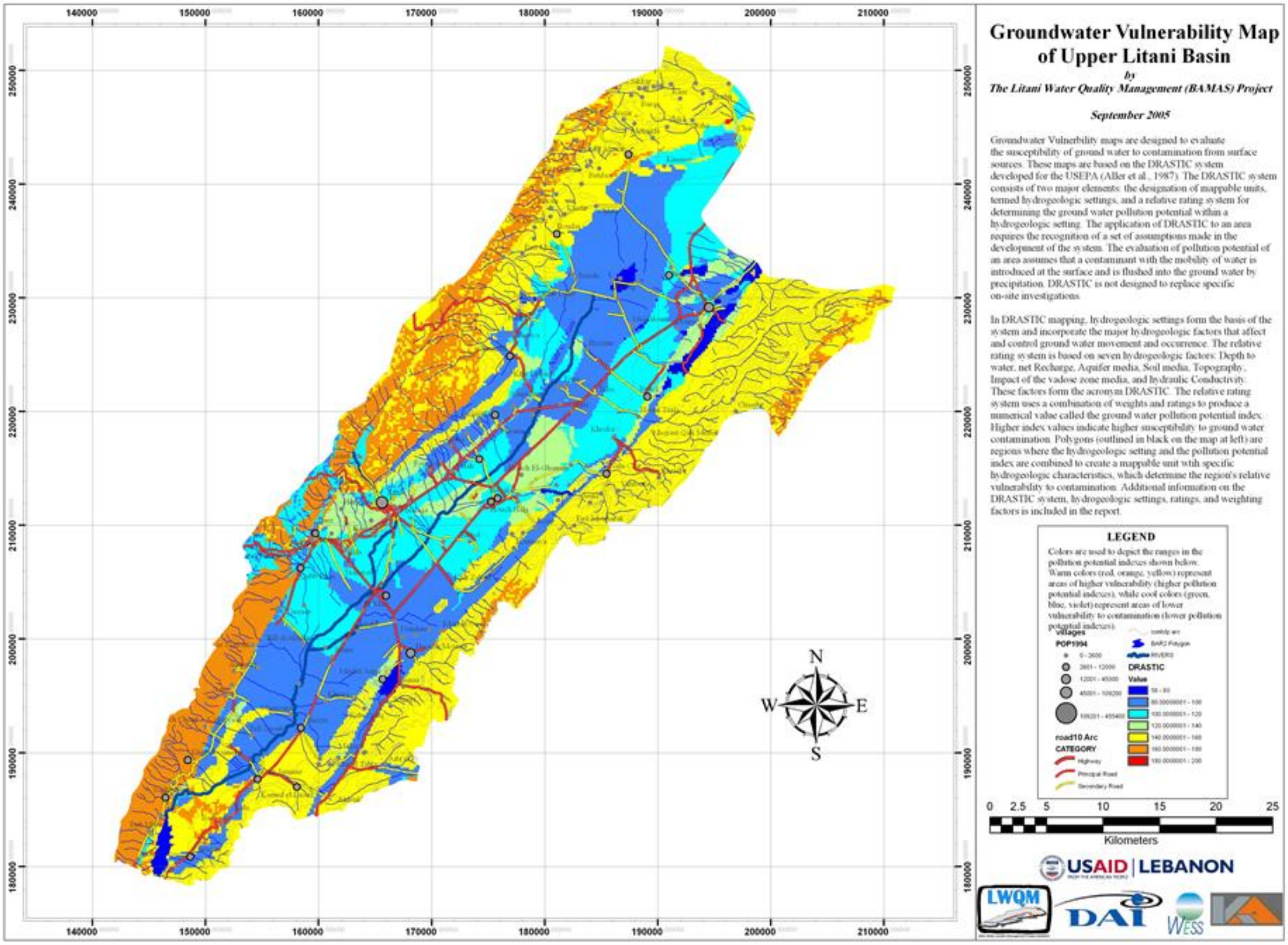

Figure 11: Groundwater Vulnerability Map of Litani Upper Basin (BAMAS, 2005)

The DRASTIC method is weighed by specific characteristics of the aquifer, namely depth to water, net recharge, aquifer media, soil media, topography, impact of the unsaturated (vadose) zone media, and hydraulic conductivity of the aquifer.

Results indicated that Cenomanian (C_4), source of the Qaa el Rim, and the Jurassic (J_6) formations over the Mount Lebanon and Anti-Lebanon mountain ranges have high pollution vulnerability indexes. This means that contamination is more likely to spread in such formations, compared to others of low DRASTIC score, such as the Quaternary (q) and Neogene (ml) formations in the middle of the Bekaa plain.

As such, the aforementioned formations should be avoided at any and all cost from further exploitation by enforcing a moratorium on any permits for new wells and various potential sources of contamination.

Additionally, the unconfined Quaternary and Neogene basin (11a) as well as the adjoining Bekaa Cretaceous basin (3), are heavily polluted according to various reports, especially in Zahle municipality, with the presence of elevated levels of total coliforms (indicative of raw sewage) and nitrates (indicative of agrochemical overuse).

While this contamination poses risks to public health through the use of this water for drinking purposes, said contamination will not likely percolate into underlying confined aquifers due to the presence of stratigraphic units of low hydraulic conductivity (aquitards).

For this Quaternary and Neogene basin (11a), a practical recommendation would be to recharge it as often as possible with surface runoff diverted from torrential rain regardless of quality to induce a degree of dilution of groundwater.

6.2. Buffer Zones for Springs or Wells

(Zhu & Balke, 2008) recommend delineating a protection or buffer zone around springs or wells to protect them from potential contamination. Zones are set based on the amount of water to be discharged from the well, annual groundwater recharge of the aquifer, and the hydrogeological characteristics of the aquifer (hydraulic conductivity, transmissivity, flow direction and velocity).

Limestone and sandstone aquifers have a higher hydraulic conductivity and broader fissures than unconsolidated aquifers, such as Quaternary and Neogene (11a). Therefore, their recharge area extends over a wide radius from wells or springs, and it is more difficult to delineate, and protect (Zhu & Balke, 2008).

For unconsolidated aquifers, protection zone I, remedial action zone, is approximately a 10 m radius protected by fencing, and sloped away from the well or spring, with grazing activities for instance prohibited (Zhu & Balke, 2008).

Protection zone II, attenuation zone, has a 50 – day line radius which is basically the distance it takes for groundwater to travel 50 days in the aquifer. The radius (in meters) is calculated by multiplying the hydraulic conductivity (in m/d) of the aquifer by 50.

Given the high density of wells in Zahle Caza and the fact that some areas are densely populated, it might not be feasible to apply the 50-day line radius recommendation. Taking into consideration the extent of existing wells littering underlying aquifers, a smaller and more practical radius of 300 m is recommended for major springs and wells in Zahle Caza not unlike the distances adopted by the BWE and Ministry of Energy and Water (MoEW).

Within this protection zone, it is recommended to prohibit the presence of any petrol stations or fuel storage areas, roads, cemeteries, quarries, intensive grazing activities, and fertilized agricultural areas (Zhu & Balke, 2008).

The figure below delineates a 300 m protection zone around springs and public wells. As evident in the figure, the safe distance between two adjacent wells and between wells and springs is not always fully enforced in myriad cases, such as in Touaite, Wadi el Arayesh, Anjar, Terbol, Bouarej, Jdita, Ablah, and Zahle.

With the addition of private wells (permitted and illicit), the 300m protection zones become practically non-applicable and as such new wells should be prohibited until all wells have been accounted for accurately.

Considering land uses, there are currently no protected areas within any of the delineated protection zones. And as such, any recommendations should enforce the minimum safe distance of at least 300 meters between all wells and their respective distances from springs and each other.

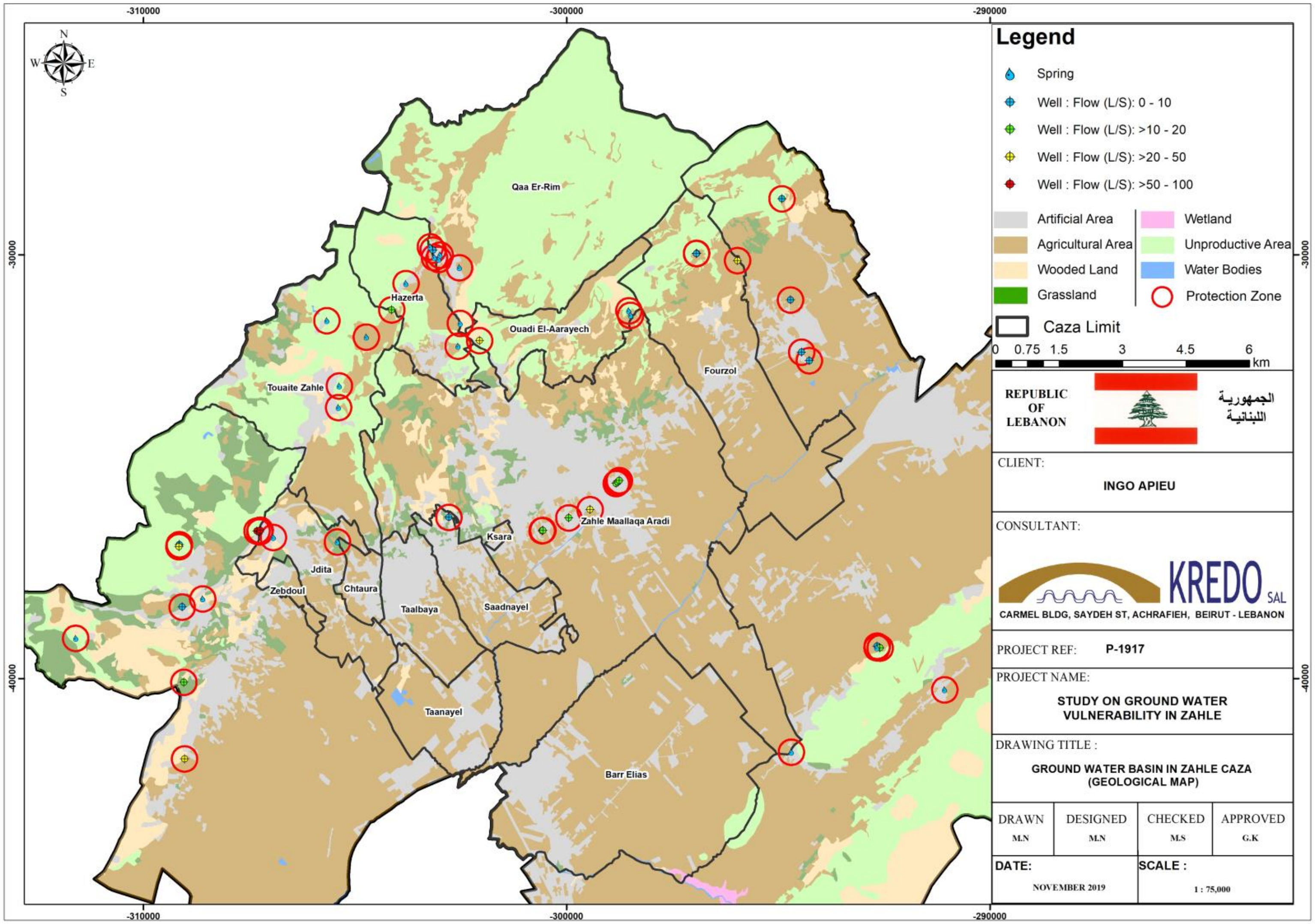

Figure 9: 300 m Protection Zone around Public Wells and Springs

6.3. Surface Water and Groundwater

Because most rivers in the Bekaa valley are heavily polluted (LRA meeting October 2019 etc.), and are inter-connected to unconfined aquifers through hyporheic zones, improving the quality of rivers is an imperative for improving groundwater quality in turn, and subsequently the quality of water pumped for irrigation and other purposes.

Most standards from around the world dictate strict guidelines for aquifer water storage and recovery projects. In other words, any surface water intended for groundwater recharge should have a quality which is not deleterious to aquifers. As a general rule of thumb, water intended for groundwater recharge should often match the quality of potable water (Pyne, David, 1995).

Again, in light of the excessive pollution evident in all surface and groundwater aquifers in the Bekaa Valley and especially Zahle, recharging aquifers using Aquifer Storage and Recovery (**ASR**) projects using surface runoff for instance is a viable option that may lead to some degree of attenuation of groundwater contaminants through dilution if implemented correctly (Pyne, David, 1995).

6.4. Groundwater Balance

A groundwater balance has been evaluated by (UNDP, 2014) and referenced in (UNICEF & ELARD, 2017) for two years; 2010-2011 considered a typical dry year, and 2011-2012 considered a typical wet year.

The groundwater balance, in a nutshell, is the difference between recharge and discharge of an aquifer or aquifer system.

Table 8: Components of water balance

Recharge -	**Discharge =**	**Groundwater Balance**
Infiltration from rainfall and snowmelt	Extraction of groundwater from wells for domestic or irrigation purposes	Positive water balance (basin is not over exploited) **OR** Negative water balance (basin is over exploited)
Return flow from irrigation and wastewater network leakages	Spring discharges from basins	
Groundwater gains from other basins/aquifers	Groundwater losses to other basins/aquifers	

Data on rainfall is limited to one station covering the entire Caza with an area of 436.3 km^2. Furthermore, data on the amount of water generated from snow is similarly not measured at meteorological stations, but rather estimated using models that rely on satellite images of snow cover. Therefore, precipitation over the basins in Zahle Caza is at best a crude estimation.

Since precipitation is the starting point in the hydrologic cycle, calculations of evapotranspiration, infiltration, and runoff as percentages of precipitation will also be mere estimations with degrees of uncertainty.

Additionally, since irrigation networks are not metered and are often made of dug channels, as is the case in Zahle municipality, and since households are often unconnected to wastewater networks, discharging sewage straight into surface waters, wells or overflowing septic tanks is common practice, and as such, the return flow from irrigation and wastewater network leakages is difficult to assess accurately. It can however be estimated as a percentage of water supplied – which is also un-metered – and considered a percentage of losses in the network.

Moreover, since there are more than 5,000 private unmetered wells in Zahle Caza by most accounts, as well as dozens of public wells operated by BWE that are scantly monitored, any abstraction (or volumes pumped) from groundwater basins are also crude estimates at best.

The same conservative approach can be applied to spring discharges. There is no continuous monitoring system at the present for springs in and around Zahle municipality. Additionally, the absence of long-term monitoring of groundwater basins, the gains and losses between aquifers cannot be evaluated accurately at this time.

Therefore, in light of the above, the positive or negative results of the water balance of the nine aquifer systems detailed by the UNICEF report will be used to assess the quantitative vulnerability of the basins taking into consideration all the above uncertainties.

Negative water balances for aquifers indicate over-pumping and are therefore in serious threat of being depleted as well as susceptible to pollution. Positive water balances for aquifers on the other hand have recharge rates exceeding discharge rates and are currently not prone to depleting water reserves.

Table 9: Water balance per basin

Groundwater Basin	Water Balance	Comments
Southern Bekaa Neogene / Quaternary Basin (11a)	Negative – extensively exploited	Hundreds of private wells
Central Anti-Lebanon Cretaceous	Negative – in Zahle Caza	Chamsine spring along foot of Eastern mountain chain has dried up due to over pumping through nearby

Basin (7b)		wells
Mount Lebanon – Bekaa Cretaceous Basin (3)	Positive	Unconfined C_4 aquifer, source of many springs with a positive water balance for potential wells is highly susceptible to point and non-point sources of pollution. Encompasses most of Wadi El Arayesh.
Eastern Bekaa Eocene Basin (10)	Positive/negative (wet/dry year)	Minor surplus of water balance in wet year. Susceptible to water pollution.
Western Bekaa Eocene Basin (8)	Negative – over exploited	Avoid drilling of potential new wells.
Jdita Jurassic Basin (2)	Positive/Negative (wet/dry year)	Minor surplus in wet year Overexploitation from excess private wells
Eastern Barouk Niha Jurassic Basin (1a)	Negative – in Zahle Caza	Avoid at all costs drilling of new wells.
Eastern Kneisseh Cretaceous Basin (3a)	Negative	Avoid at all costs drilling of new wells.
Metn- Chouf Sandstone Cretaceous Basin (27b)	Positive	Limited exposure in Zahle Caza. Limited potential for drilling new wells but at risk of contamination.

Of the above UNICEF mentioned nine (9) aquifer basins, five score negatively for water balance and are under threat of depletion and pollution.

Of these five negatively affected basins, the Southern Bekaa Neogene (ml)/Quaternary (q) basin (**11a**) is of most interest since it encompasses all of Zahle city and Wadi el Arayesh, as well as the Mount Lebanon-Bekaa Cretaceous Basin (**3**) which encompasses Qaa er Rim spring for example.

The so called Bekaa Neogene/Quaternary basin includes two aquiferous formations, the Quaternary (q) and the miocene (ml) with approximate thicknesses of 100m and 400m respectively, while the Mount Lebanon-Bekaa Cretaceous (**3**) basin comprises overwhelmingly the Cenomanian or locally referred to Sannine (C_4) aquifer.

Touaite on the other hand, resting on the 27b designated aquifer basin composed of the J_6 and C_1 aquifers has a positive water balance according to the previous table, which indicates limited room for additional new wells being drilled, and a susceptibility for groundwater contamination.

It is obvious from the following figure that said basin has the largest share of private wells in the caza. Additionally, since both aquifers are unconfined, they are highly susceptible to pollution from surface sources namely wastewater and agriculture chemicals, further corroborated by the concurrent work of Dr Talal Darwish incorporated into said figure as a layer of four colored exposure levels.

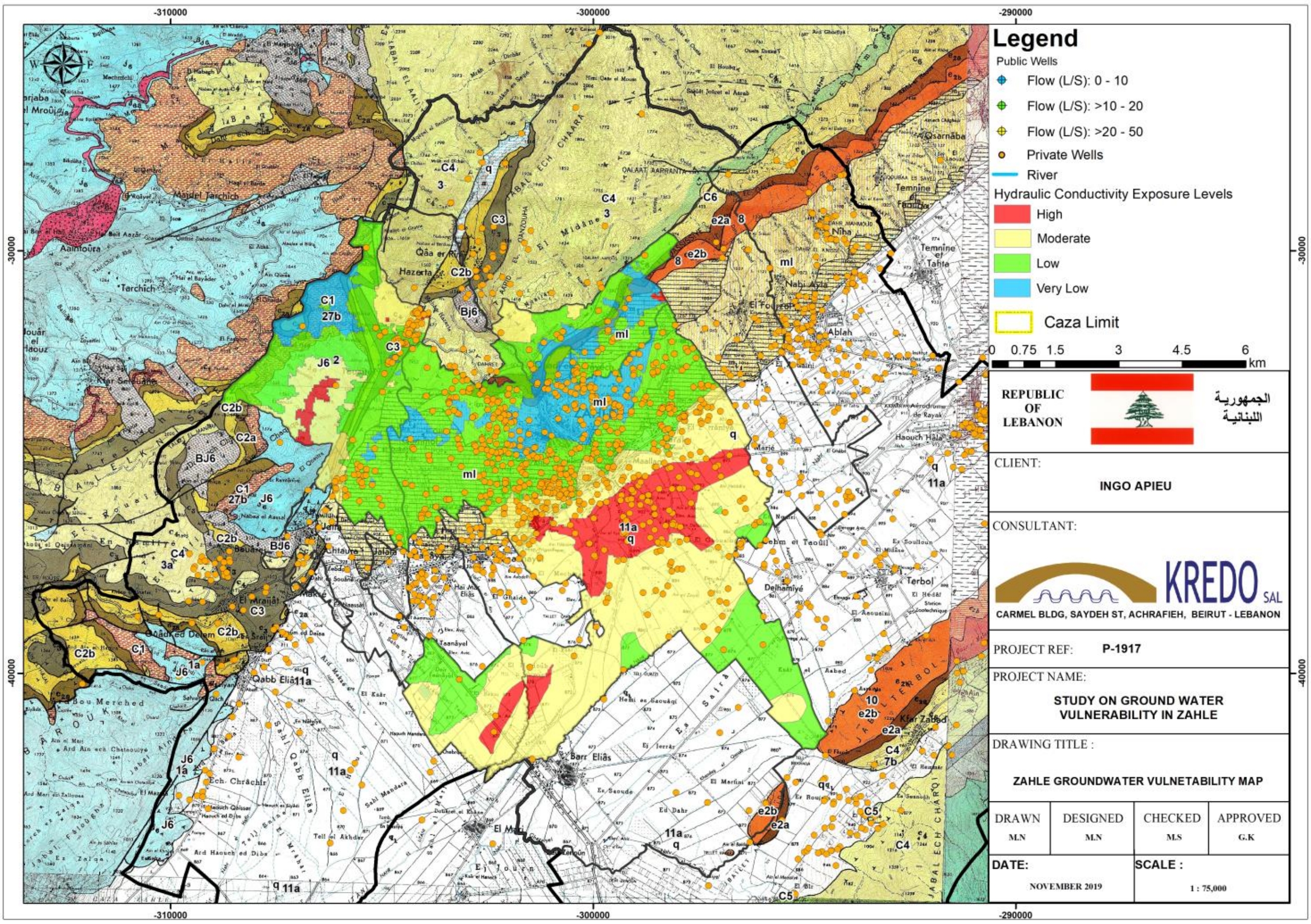

Figure 13: Groundwater Vulnerability Map of Zahle Caza (INGO APIUE)

6.5. Vulnerability Assessment

The following table briefly summarizes the aforementioned aquifer basins in term of their respective vulnerabilities considering such parameters as aquifer geometry, pollution levels, density of wells and the water balance of each whenever available.

The end result is an assessment of said aquifer basins as being slightly, moderately or very vulnerable.

Table 10: Vulnerability assessment per basin

Groundwater Basin	Vulnerability
Southern Bekaa Neogene / Quaternary Basin (11a)	• Unconfined aquifer • Polluted notably with nickel (Ni) • Bacteriological contamination in some wells • High nitrate levels in many wells • High density of private and public wells • Presence of open municipal waste dumpsites • Negative water balance – heavily exploited • **Tantamount to a very vulnerable basin**
Central Anti-Lebanon Cretaceous Basin (7b)	• Negative water balance • Absence of any data pertaining to wells and contamination • Dumpsites present in the basin • **Tantamount to a moderately vulnerable basin**
Mount Lebanon – Bekaa Cretaceous Basin (3)	• Presence of several private wells • Positive water balance • Absence of contamination data • Dumpsites present in basin • **Tantamount to a moderately vulnerable basin**
Eastern Bekaa Eocene Basin (10)	• Positive water balance in wet year • Negative water balance in dry year • No data on wells or contamination • Dumpsites present in basin • **Tantamount to a moderately vulnerable basin**
Western Bekaa Eocene Basin (8)	• Slight nickel contamination in one well • Negative water balance – heavily exploited • No dumpsites present in basin • **Tantamount to a very vulnerable basin**
Jdita Jurassic Basin (2)	• Positive water balance in wet year • Negative water balance in dry year • No data on wells or contamination • No dumpsites present in basin • **Tantamount to a slightly vulnerable basin**
Eastern Barouk Niha Jurassic Basin (1a)	• Slight nickel contamination in one well • Negative water balance – heavily exploited • No dumpsites present in basin • **Tantamount to a very vulnerable basin**
Eastern Kneisseh Cretaceous Basin (3a)	• Negative water balance • Absence of any data pertaining to wells and contamination • No dumpsites present in the basin

	• **Tantamount to a slightly vulnerable basin**
Metn- Chouf Sandstone Cretaceous Basin (27b)	• Presence of several private wells • Positive water balance • Absence of contamination data • No dumpsites present in basin • **Tantamount to a slightly vulnerable basin**

From the aforementioned table, the following towns and villages within the Zahleh caza are characterized in terms of said water balance as well as pollution potential:

Table 11: Vulnerability assessment per basin

Cazas	Aquifer Water Balance	Pollution Potential
Zahleh	Negative	High
Toueiti	Positive/ Negative	Moderate
Wadi El Arayesh	Negative	High
Deir Tanaayel	Negative	High
Saadnayel	Negative	High
Bar Elias	Negative	High
Zebdol	Negative	High
Chtaura	Negative	High
Taalabaya	Negative	High
El Forzol	Negative	High
Hazerta	Positive	Low
Qaa El Rim	Positive	Low
Ksara	Negative	High
Jdita	Negative	High

Of the above mentioned fourteen (14) towns and villages etc., an overwhelming eleven (11) are negatively labelled for water balance with high propensities for contamination or pollution, including the city of Zahle.

The only towns/villages with a positive aquifer water balances as well as a low potential for pollution include Hazerta, Qaa El Rim, and to some extent Toueiti. As such, they are the only areas with potential for controlled groundwater abstraction in contrast to the remaining eleven areas.

7. Recommendations

The following recommendations summarize practical approaches to the current situation of groundwater quality and quantity in the caza of Zahle.

By no means are these recommendations a one size fits all for the problem at hand, however from a pragmatic point of view, it reflects an acceptable platform to be adopted by all stakeholders in mind and specifically the Bekaa Water Establishment (BWE):

- Implement measures to mitigate sources of contamination, drilling of wells etc as per the vulnerability of each of the following basins, towns, and villages etc mentioned in Table 11.

  The following towns, villages should be avoided from further water abstraction until the water table eventually re-stabilizes. Furthermore said towns are tapping into heavily polluted aquifers which means that they require some form of purification prior to home use or even irrigation. These urban centres include the following:

  - **Zahleh city**
  - **Ouadi Arayesh**
  - Taanayel
  - Saadnayel
  - Bar Elias
  - Zebdol
  - Chtaura
  - Taalabaya
  - Fourzol
  - Jdita
  - Ksara

- As for the following towns/villages, although few, display positive aquifer balances with moderate to low pollution potentials as per Table 11. With that in mind, they may be further exploited for groundwater extraction within strict confines of the recommendations.

  They include the following urban centres:

  - Toueiti
  - Hazerta
  - Quaa El Rim

- The aforementioned urban centres are all underlain by unconfined aquifers, and as such, are highly susceptible to potential surficial sources of pollution. For instance, most wells of Toueiti tap into the Miocene (ml) and Sannine (C_4) unconfined aquifers, while Quaa El Rim and Hazerta are predominantly underlain by the Sannine (C_4) unconfined aquifer.

- Install additional meteorological stations for improved coverage in the Zahle Caza that also take into account snow measurements.

- Well and spring protection zones are recommended as per (Zhu & Balke, 2008) including the 10 meter zone and the 50 day zone.

- Develop an ArcGIS database for all springs, wells, point and non-point (diffuse) sources of pollution to name a few with regular updating of said database.

- Prepare a monitoring program for springs that includes quantity and quality parameters that may be eventually compared to drinking water guidelines as well as irrigation guidelines. Recommended to be administered by the Bekaa Water Establishment (BWE).

- Equip all future public wells including the current 39 with sensors and flow meters to meet the above mentioned guidelines.

- Regulate the drilling of new private wells in the vein of the aforementioned, such as a mandated minimum safe distance of 300 meters between wells and springs, as well as limiting abstraction rates as per Decree 14438/1970 of the MoEW

- Zahleh city in particular, should avoid **uncontrolled** abstraction of ground water until the water table re-stabilizes, as opposed to continued lowering and running the possibility of entirely depleting the underlying aquifers (q and ml).

- All wells in Zahleh city, whether public or private should be equipped with flow meters in order to track their abstraction rates.

- Any and all abstracted groundwater in Zahleh, especially public wells, should be treated to some degree if intended for domestic uses. Treatment methods include but are not limited to chlorination, filtration, sedimentation etc.

- The domestic water supply network of Zahleh should be re-examined and upgraded (metering) to minimize water losses or "Non-revenue water" in the form of real losses and apparent losses.

- Implementation of a general plan to gradually turn Zahleh into a porous city by replacing impermeable asphalt and concrete surfaces with permeable ones.

8. APPENDIX

Public Wells of Zahleh Caza

Locality	Well_Name	Drilling Depth	Flow (L/s)	Flow (m^3/d)	Average volume pumped daily (m3)	Basin	Aquifer
Ablah	Ablah High well	120	2	173	108	Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary / Neogene
Ablah	Ablah Garden well	80	1	121	76	Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary / Neogene
Ablah	Ablah Dalloul well	200	1	121	76	Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary / Neogene
Ali Al Nahry	Ali Al Nahry Well 1	160	25	2160	1350	Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary / Neogene
Ali Al Nahry	Ali Al Nahry Well 2	290	25	2160	1350	Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary / Neogene
Anjar	Anjar Well 1	131	1	121	76	Central Anti-Lebanon Cretaceous Basin (7b)	C5-C4
Anjar	Anjar Well 2	125	1	121	76	Central Anti-Lebanon Cretaceous Basin (7b)	C5-C4
Bouwarej	Bouwarej Old well	110	1	43	27	Jdita Jurassic Basin (2)	BJ_6
Bouwarej	Bouwarej New well	120	1	86	54	Jdita Jurassic Basin (2)	BJ_6
Bouwarej	Bouwarej Exploded well	120	50	4320	2700	Jdita Jurassic Basin (2)	BJ_6
Chamssine	Chamssine Well 1	20	100	8640	5400	Central Anti-Lebanon Cretaceous Basin (7b)	C5-C4
Chamssine	Chamssine Well 2	20	100	8640	5400	Central Anti-Lebanon Cretaceous Basin (7b)	C5-C4
Chamssine	Chamssine Well 3	20	100	8640	5400	Central Anti-Lebanon Cretaceous Basin (7b)	C5-C4
Ferzol	Ferzol 2nd well	70	6	475	297	Western Bekaa Eocene Basin (8)	Eocene e_{2b} – e_{2a}
Ferzol	Ferzol 1st well	105	6	475	297	Western Bekaa Eocene Basin (8)	Eocene e_{2b} – e_{2a}
Hazerta	Dhour Zahle (Hzarta Well 1)	260	15	1296	810	Mount Lebanon – Bekaa Cretaceous Basin (3)	C5-C4
Hoshmosh	Hoshmosh Well	292	20	1728	1080	Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary / Neogene
Jdita	Jdita Well 1	101	90	7776	4860	Jdita Jurassic Basin (2)	J6
Jdita	Jdita Well 2	120	90	7776	4860	Jdita Jurassic Basin (2)	J6
Jdita	Jdita Well 3	100	90	7776	4860	Jdita Jurassic Basin (2)	J6
Majdel Anjar	Majdel Anjar	300	19	1642	1026	Central Anti-Lebanon Cretaceous Basin (7b)	C5-C4
Mrayjat	Mrayjat	271	7	588	367	Metn- Chouf Sandstone Cretaceous Basin (27b)	C1
Naby Ayla	Naby Ayla	140	27	2341	1463	Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary / Neogene
Nasriye	Nassreh	325	7	605	378	Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary / Neogene
Niha	Niha	210	10	864	540	Western Bekaa Eocene Basin (8)	Eocene e_{2b} – e_{2a}
Qaa El Rim	Qaa El Rim	100	1	86	54	Central Anti-Lebanon Cretaceous Basin (7b)	C5-C4
Qaab Elias	Qabb Elias	130	22	1901	1188	Eastern Barouk Niha Jurassic Basin (1a)	J6
Qabb Elias	Qabb Elias Solar Well	150	12	1037	648	Metn- Chouf Sandstone Cretaceous Basin (27b)	C1
Saadnayel	Saadnayel	150	1	69	43	Southern Bekaa Neogene / Quaternary Basin (11a)	Quaternary / Neogene
Terbol	Terbol Well 1	96	10	864	540	Eastern Bekaa Eocene Basin (10)	Eocene e_{2b} – e_{2a}
Terbol	Terbol Well 2	208	15	1296	810	Eastern Bekaa Eocene Basin (10)	Eocene e_{2b} – e_{2a}
Wadi Arayech	Wadi Arayech2	390	22	1901	1188	Mount Lebanon – Bekaa Cretaceous Basin (3)	C5-C4

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