Towards an Improved Integrated Understanding of The Threats on Groundwater in Karst Water Catchment: Importance of Monitoring Water Systems in Decision Making.

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pH	potential Hydrogen
EC	Electrical Conductivity
PSD	Particle Size Distribution
TOC	Total Organic Carbon
DO	Dissolved Oxygen
T	Temperature

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ABSTRACT

It is crucial to monitor groundwater to ensure the sustainable supply of good quality water. The quality of water in Lebanon has been a major concern in recent years due to a range of factors including pollution, water scarcity, and aging infrastructure. Since collecting samples and laboratory analysis can be costly, and since karsts are dynamic environments that require more frequent measurements, we came up with adequate monitoring systems. These monitoring systems can help infer the degree of contamination through measuring indicator parameters in the targeted water system (such as turbidity, electrical conductivity, temperature …). The study area comprises the catchment area of El Kalb River which drains into four springs: Assal, Laban, Qachqouch and Jeita. This work provides the set-up of the needed monitoring systems, the way to read and interpret the data, come up with early warning systems, and how to mitigate contamination.

I. INTRODUCTION

Groundwater from karst aquifers represents one of the most valuable sources of drinking water across the world (Ford and Williams, 2007). However, karst systems are very dynamic environments and highly vulnerable to contamination since they contain solution features and are characterized by fast infiltration, rapid transport in karst conduits, and high permeability that provide a relatively quick and easy access of pollutants to the system (Doummar et al., 2012; Reberski et al., 2022; Figure 1). In order to mitigate contamination outbreaks, monitoring is crucial as it gives insight into the quantity and quality of water, therefore providing a warning in order to act in time and ensure a sustainable supply of potable water.

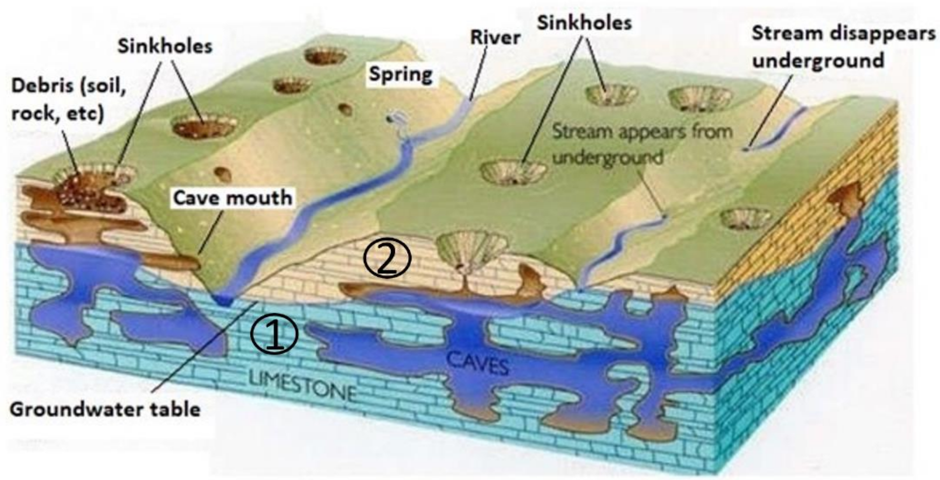

Figure 1- Schematic representation of a karst groundwater system showing its complex geometry such as sinkholes that present fast infiltration pathways. 1 represents the saturated zone while 2 represents the undersaturated zone of the system (Baker, 2015).

Many previous works have targeted monitoring systems in karst environments. For example, monitoring of the karst system of Wintimdouine cave in Morocco included using a multiparameter probe to measure pH, temperature, and EC, and titration to measure alkalinity of the water (Yassine et al., 2019). In Serbia, monitoring parameters were divided into quantitative and qualitative (Poledica and Stevanović, 2016). Quantitative parameters include discharge and groundwater level, while the qualitative parameters include DO, pH, EC, nitrates, turbidity and microbiological composition. Stevanovic and Stevanovic (2021) suggested measuring water turbidity, total organic carbon (TOC), total coliforms, E. coli and particle size distribution for water quality monitoring. As for the frequency of measurement, many factors must be taken into consideration being the accessibility of the area, the instrumentation used, the task performed, the expected results and the geology of the aquifer (Milanovic and Ljiljana, 2015). For example, In the case of Karst aquifers, quantitative parameters must be measured on a daily basis, while qualitative parameters should be measured twice a month in order to obtain sufficient results for good analysis (Milanovic and Ljiljana, 2015).

Due to the dynamic and variable nature of karst aquifers, they require more frequent sampling and higher frequency of measurements which makes monitoring in such terrains more costly than in others (Stevanovic and Stevanovic, 2021). However, one can come up with low-cost monitoring systems that measure indicator parameters that can be correlated to the presence of specific contaminants and help assess the quantity of water.

II. FIELD SITE

This section provides an overview of the study area that comprises El Kalb River catchment which is associated with four groundwater systems: Assal, Laban, Qashqoush, and Jeita groundwater basins.

2.1. Catchment Area / Location / Discharge:

The four springs to be investigated are located in the Middle East- Lebanon, north of the capital Beirut. They are part of the El Kalb River catchment. The catchment is characterized by Jurassic and Cretaceous rock sequences with an elevation that extends from sea level up to 2600 m above sea level (Figure 2; Bakalowicz, 2015). The four important springs that this catchment is drained by are:

1. Jeita Spring: it is the main source of water supply for Beirut as it provides drinking water for about 1.5 million inhabitants. It is characterized by mean flowrates of 8 m^3/s. The discharge of the Jeita spring ranges from 1 m^3/s during low flow periods to about 20 m^3/s during high flow periods (Doummar et al., 2014).

2. Qashqoush Spring: it is the second most important source of water supply for Beirut, which complements the water deficit in the capital and its surrounding areas. The

spring is located at an elevation of 64 m above sea level and emerges from fractured limestone and basalts that belong to the Jurassic age. According to Dubois et al. (2020), Qashqoush spring has a total annual discharge that reach 35-55 Mm^3 with flowrates that range between 2 m^3/s and 10 m^3/s.

3. Assal Spring: It is located in the highlands of El Kalb River catchment at an elevation of 1552 m above sea level. The spring's main source of recharge is the snowmelt. They partially drain the Albian-Cenomanian rock formations composed of limestone and dolostones. Two types of infiltration occur: (1) fast infiltration of rain through dolines and (2) diffuse infiltration within the soil that depends on the type of rock facies in the Cenomanian rock sequence. According to (Doummar et al., 2018), the annual volume of the Assal spring is 22-30 Mm^3, which is used for water supply in the near villages (i.e. 24,000 m3/day).

4. Laban Spring: It is located in the highlands of El Kalb River catchment at an elevation of 1662 m above sea level. The spring emerges from highly karstified Cenomanian limestone. The water from this spring is conveyed to the Chabrouh Dam in Faraya. It has a total annual volume of 20-25 Mm^3. The overflow from Laban spring feeds the two tributaries of El Kalb River in the highlands (Doummar and Aoun, 2018a). A part of water from Laban spring is also conveyed into an irrigation canal that feeds the area of Kfar Debbiane irrigation scheme, mainly between May and September.

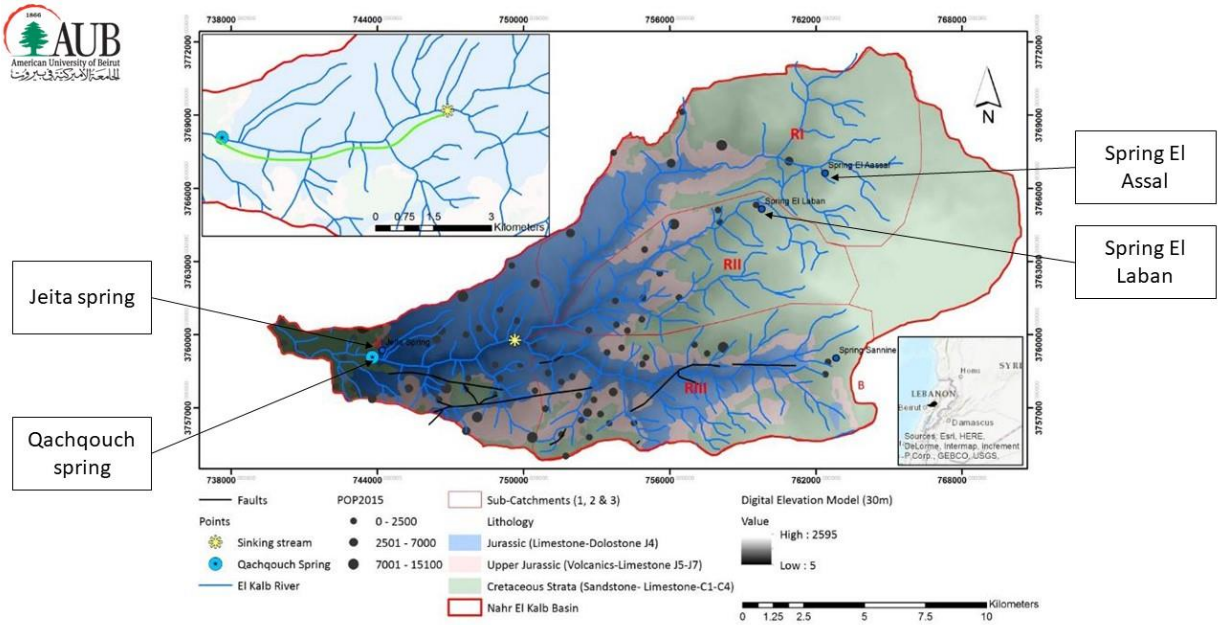

Figure 2- Catchment area of El Kalb River showing the location of the four springs: Assal, Laban, Qachqouch and Jeita.

2.2. Contamination History:

- Identified threats of contamination of the **Jeita spring**:

There are no specific threats that directly affect the Jeita spring especially since the water is naturally filtered by the limestone formations in the area. The water quality of Jeita Spring is still considered to be high. However, ongoing monitoring and management of potential source contaminants is important to ensure that the water remains safe and of high quality. These potential source contaminants generally affect all natural water resources including the Jeita spring, and were divided by Margane (2013) in two categories:

1. Non-point sources: wastewater, agriculture, and stormwater.
2. Point sources: gas stations, generators and residential heating systems, quarries, industries, feedlots and slaughterhouses, illegal dumpsites, military barracks and maneuvers, cemeteries, in addition to touristic resorts or restaurants.

- Identified threats of contamination of the **Qashqoush spring** are:

  Wastewater effluents from the urbanized area as well as surface-water input to the Qachqouch spring makes it highly polluted (Doummar et al., 2014).

- Identified threats of contamination of the **Assal spring**:

  Sewage water particularly from resorts, chalets and dwellings in Aayoun es Simane area (Schuler and Margane, 2013).

- Identified threats of contamination of the **Laban Spring**:

  Same threats as Assal spring, yet water from Laban Spring is conveyed to Chabrouh dam where it is treated (aeration, rapid sand bed filtration and chlorination) before being distributed in the Upper Keserwan district.

III. METHODOLOGY

In this section, we will discuss the dataset and methodology applied in this study to fulfill the aim of our research, being the protection of water quantity and quality as a part of integrated river basin management (Figure 3).

In order to monitor water quality and quantity in the catchment area of El-Kalb River, designing a low-cost monitoring system that is ideal for a karst topography is necessary. Two dimensions must be taken into consideration when setting this system: temporal and spatial. In brief, temporal refers to choosing the adequate parameter to measure with the optimal time interval between measurements, while special refers to choosing the right locations where to install the monitoring devices.

3.1.Temporal

The assessment of water quality is based on the presence of different types of contaminants such as pharmaceuticals, sewage, bacteria etc... On the other hand, the assessment of water quantity depends on discharge. Therefore, the continuous measurement of the degree of contamination as well as the water flow is required.

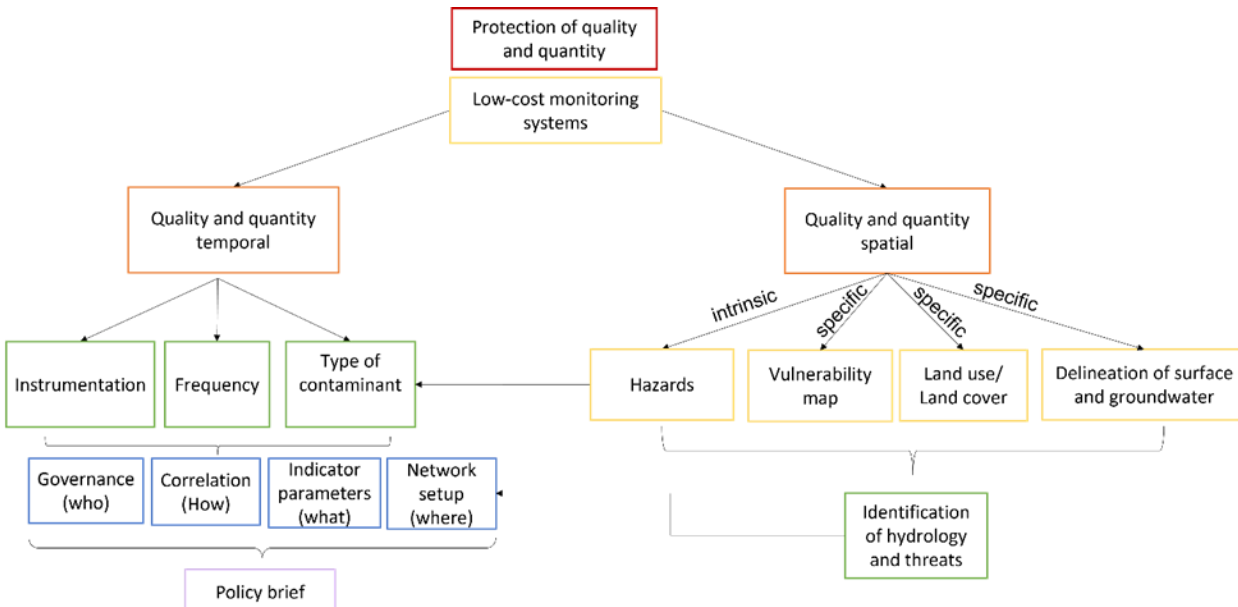

Figure 3- Schematic representation of the workflow of the project.

Measuring specific contaminants requires going to the field, grabbing samples and analyzing them in the lab which can be time consuming and expensive. A more efficient low-cost alternative is to measure indicator parameters. These parameters include electrical conductivity (EC), turbidity, particle size distribution (PSD), total organic carbon (TOC), dissolved oxygen (DO), temperature (T), pH and discharge. They can be correlated with certain water contaminants or water quantity, as such giving a full assessment of the water availability and quality. This is explained in section 4.1.

The first step in this process is to choose the suitable low-cost instruments that are efficient in karst systems. To do so, a review of previous work done in areas with similar hydrogeological characteristics to our study area is performed. The second step is to select the adequate time interval between measurements as to be both sufficient and informative. As such, we used a common approach in terms of instruments' selection and frequency of measurements. The third step is to determine the proper locations to set up the monitoring systems which will be thoroughly discussed in section 3.2.

3.2. Spatial

Areas with high infiltration rate, and high risk of contamination should be monitored extensively. Thus, when choosing gauging outlets, we should take this into account as well as the accessibility of the area. As such vulnerability maps are generated to determine the area's most prone to contamination, then land use maps are used to identify the type of potential contaminants.

the term "vulnerability of groundwater to contamination" is commonly used to define how sensitive a given groundwater source is to contamination (Doummar et al., 2012). According to the European COST Action 620, vulnerability to contamination can be either intrinsic or specific. Intrinsic vulnerability refers to the potential risk of pollution without considering the nature of the pollutant. However, specific vulnerability is the type of vulnerability that does not only depend on the hydrogeological and geological characteristics of the study area, but also on the scenario of contamination and the specific properties of each contaminant such as degradation, decay, and transit time etc. In this study, the focus will be on Intrinsic vulnerability, and land use maps will be used to predict the specific source of contamination.

In order to account for the peculiarities of the karst aquifers, a vulnerability map shown in Figure 4 was generated by Doummar et al. (2012) using the COP method designed by Vias et al. (2006). This method is the acronym of three critical factors (C, O, and P) which are used to assess the vulnerability of karst aquifers. The C factor refers to the flow concentration which underlines the role of infiltration processes in karst aquifers where both diffuse and concentrated infiltration take place. The O factor represents the capacity of the overlying layers to attenuate the pollutant.

This factor constitutes the soil and the lithology of the unsaturated zone. The third factor (P) refers to the influence of precipitation in the definition of vulnerability (Vias et al., 2006). This final map shows a huge impact of the C Factor on vulnerability, especially because the area located within 500 meters from a sinkhole are found to be highly vulnerable. The reason behind this is the fact that pollutant can pass directly from the origin (surface) towards the saturated zone through a sinkhole without being attenuated by the unsaturated zone. Therefore, sinkholes represent a relatively good monitoring outlet.

Land use maps show contamination sources such as quarries, hospitals, industrial sites, and dumping of sewage water etc… Monitoring outlets should be close to these sources to record any outbreaks. This is very important in policy making, as monitoring the anthropogenic activities can help to make decisions that prevent outbreaks and mitigate them.

The last step of this research is to design a white paper including:

1. indicator parameters.
2. instruments needed to monitor said parameters.
3. frequency of measurement.
4. land use restrictions that must be applied to prevent water pollution.
5. measures to be taken in case of outbreaks occur.

This white paper can be used by policy makers and governed by the ministry of energy and water as well as water establishments in Lebanon.

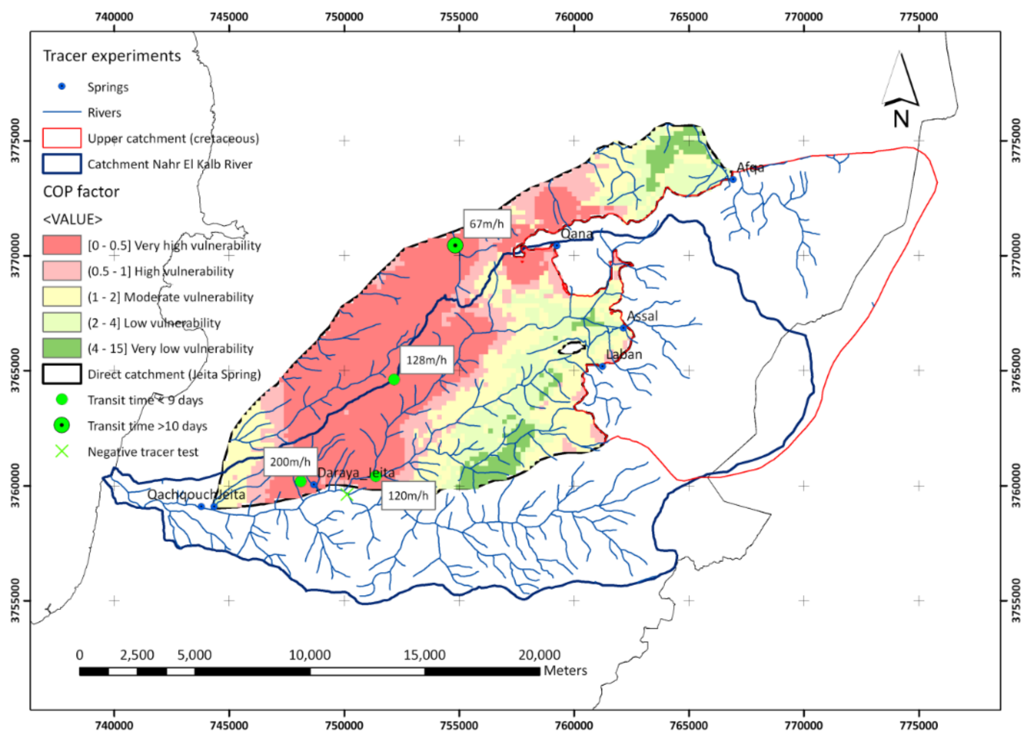

Figure 4- vulnerability map of the El Kalb River catchment area using the COP method (Doummar et al., 2012).

IV. RESULTS AND DISCUSSIONS:

Water is not consistently monitored and examined due to the absence of funds and regulations. The results of this research provided an effective alternative to high analysis cost at laboratories, which is measuring certain parameters that indicate contamination. After reviewing all potential correlations of certain parameters with water contamination, the presented results show the specific parameters that need to be continuously measured, and the locations where the measurements should take place.

In brief, the tactic used is to find indicator parameters to correlate with water quality and quantity in order to design a low-cost monitoring system. First, we identify suitable locations to set the monitoring systems based on hydrogeologic maps. Then, we provide the needed instrumentation and sampling techniques, parameters to be measured, frequency of measurement, processing and data and interpretation. The budget is used in field work, where a tracer test is conducted.

4.1. Indicator parameters

This section introduces all the crucial parameter that must be taken into consideration and measured to assess water quality and quantity. These parameters indicate the presence of contaminants as well as the period of contamination. We are going to focus on low-cost indicator parameters such as turbidity, temperature, dissolved oxygen (DO), pH, total organic carbon (TOC) and others.

4.1.1. Turbidity, PSD, TOC

Turbidity is the measure of the water clarity which is related to the presence of suspended particles (silt, organisms, contaminants…) in the water. The sunlight can be absorbed and scattered by these particles giving a muddy or cloudy appearance to the water. Turbidity sensors (nephelometer) measure the light scattered by the suspended particles as light is shined into the water sample (YSI, 2022). Normally, a multiparameter probe can be used to get a measure of turbidity every 20 minutes (Doummar et al., 2014).

For example, turbidity can indicate contamination such as combined sewer overflow. Sewer is mixed with water in intense raining events that later pollute water bodies causing a peak in turbidity (Carstea et al., 2010).

There are 2 types of turbidity, primary and secondary.

1. Primary turbidity (autochthonous)

This type of turbidity represents the movement of suspended particles that arise from the aquifer itself (hence it is called autochthonous), triggered during a rain event, and associated with an increase in discharge (Pronk et al., 2007a).

2. Secondary turbidity (allochthonous)

This type of turbidity is associated with suspended particles transported from outside the karst system (hence it is called allochthonous), many days after a rain event (Pronk et al., 2007a).

While moving sediments during a rain event can cause a peak in turbidity, this peak is primary, and typically lasts for a relatively short period of time. In contrast, a peak in turbidity caused by sewer contamination persists for an extended period, depending on the severity of the contamination. In addition, a peak in turbidity caused by moving sediments during a rain event is likely to occur in rivers and streams where the flow of water is high, and less likely (but still occurs) in groundwater where the flow of water is relatively lower.

High turbidity always coincides with high bacterial contents whereby observations revealed narrow turbidity peaks overlapping with much wider bacteria signals. Secondary turbidity is usually correlated with water contamination since it indicates the arrival of contaminants from outside the system. For example, Pronk et al. (2007) secondary turbidity was correlated with the transportation of allochthonous particles from a swallow hole (i.e., source of contamination) to the aquifer. The measurement of this indicator parameter is important and useful as the detection of microbial activity can be hard since the time interval of sampling and laboratory analysis is rather large.

However, during certain flood events primary and secondary turbidity can overlap making it hard to identify the one bringing the fecal bacteria. For this reason, Pronk et al. (2007) suggested the use of the total organic carbon (TOC) and particle size distribution (PSD) in parallel with turbidity as an indicator to wastewater contamination and as a way to discriminate between the different turbidity signals.

TOC is the measure of organic carbon present in the water as solid or dissolved particles. If there are no sources of contamination from surface water, TOC originates from incomplete degradation of soil material (Batiot et al., 2003). However, it can originate from allochthonous sources where TOC can be correlated with faecal bacteria (Pronk et al., 2007a).

PSD is the measurement of distribution of the sizes of particles suspended in a water system.

TOC can be measured from water samples collected at an interval of 2 to 4 hours using a TOC analyzer, and PSD can be measured using a portable particle counter (coulter counter; Frank et al., 2018). Pronk et al. (2007) related a peak in TOC to allochthonous waters since it derives from soil and surface water, and therefore allows the identification of secondary turbidity signals. However, it should be taken into consideration that the detected signals of TOC lag those of turbidity and are narrower due to the difference in both the velocity and transport processes of the suspended particles and TOC. PSD analysis allows a more accurate identification of the contamination period when turbidity signals coincide. A wide variety of particle sizes is correlated with primary turbidity where in situ sediments are brought back to suspension because of rain events, and the predominant presence of fine particles is correlated with secondary turbidity indicative of the contamination period. Similarly, Frank et al. (2018) observed a secondary turbidity peak with an increase of small particle size and TOC, and correlated them to contamination with faecal bacteria.

4.1.2. Electrical conductivity (EC)

Electrical conductivity represents another parameter that helps us indicate the presence of contaminants in the targeted water system. Electrical conductivity, water levels, and turbidity can be monitored every 20 minutes by using a multi-parameter probe that is installed at the spring (Doummar et al., 2014).

EC values are considered crucial indicators of contamination especially when accompanied by other parameters, such as turbidity. The background EC values in a karst system are usually high due to elevated calcium carbonate (dissolved into residing water). When new water enters the system, it has low calcium carbonate and magnesium content which leads to a decrease in EC for a short time. Thus, low EC values that are accompanied by high turbidity scores should indicate the arrival of new contaminated water into the system. After, EC values will increase again beyond the background level due to the presence of high chloride and phosphate levels from household products in sewage when compared to tap water levels. Another scenario would be the direct increase in EC values that is accompanied by the increase in turbidity scores. If this happens, it will represent an easy indicator of emerging micropollutants (such as pharmaceutical from sewage, i.e., CBZ).

In addition to the scenarios mentioned above, if the winter runoff, containing salt, reaches the spring, the EC values would elevate temporarily in the spring (Kate, 2019).

4.1.3. Temperature, Dissolved Oxygen, and pH

The increase in turbidity always lead to the increase in temperature since the suspended particles can absorb heat more effectively than water. The heat is then transferred from the particles to the water molecules, elevating the temperature of the water system. This relation between turbidity and water temperature makes the latter another contamination indicator. In addition, an increase in temperature can be indicative of thermal pollution as industrial and municipal effluents will alter water temperature.

An increase in temperature can be accompanied by a decrease in the pH and the DO. In addition, organic waste from animal farms, domestic and hospital sewage as well as industrial waste directly cause a decrease in DO levels. This is because the present bacteria uses the oxygen in water to decompose this waste (Haddad et al., 2021). Hence, high contamination is mainly associated with high turbidity, high water temperature, and low pH and DO respectively.

4.1.4. Discharge

Discharge rates can be measured by means of pressure probes and rectangular weirs. Also, the recorded water level from pressure transducers can be combined with the rating curve obtained under different flow conditions (snowmelt, high flow, medium flow, and low flow) to estimate discharge measurements. These measurements allow the identification of quantities of water available for supply and the calculation of contaminant masses.

Tracer experiments can be used to reflect the transport mechanism of a conservative pollutant from different origins (i.e., dolines, river, stream...) to the target (i.e., aquifer). As for a non-reactive pollutant, its duration of breakthrough is provided by the duration of the tracer recovery. The observed tracer concentration is indicative of the intensity of contamination above admissible limits for a certain contaminant load (Doummar et al., 2018a).

Higher discharge leads to higher bacterial transport (during flood events), but it can dilute contaminants. So, on its own, discharge is not an accurate correlation. However, analyzing discharge data parallel to turbidity data can be very informative. Increasing discharge accompanied by a primary turbidity peak (during a rainfall event) indicates autochthonous particles coming into suspension, whereas decreasing discharge (days after rainfall event) can be correlated with a secondary turbidity peak, TOC increase indicating feacal contamination.

All the indicator parameters are summarized in Figure 5.

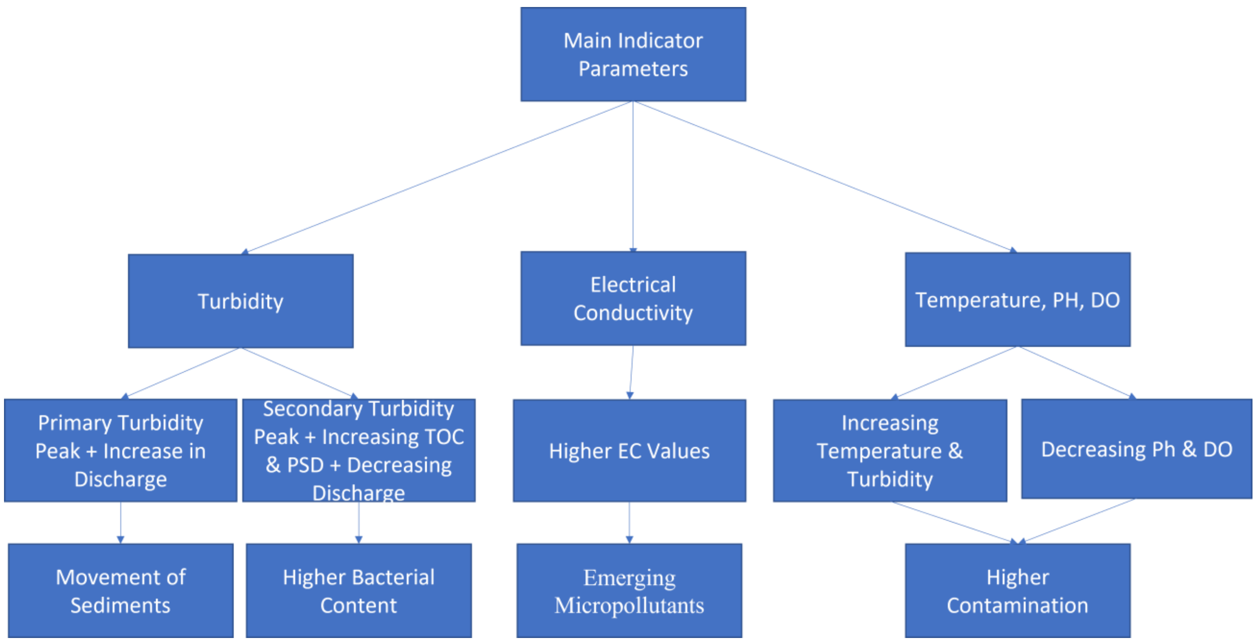

Figure 5- Summary of indicator parameters, their correlation and significance.

4.2.Case example

At the Moulinet 6A karst spring, in Switzerland, discharge, electrical conductivity, TOC and turbidity were continuously monitored (Pronk et al., 2007b). Discharge was measured using pressure probes and weirs, and OC and turbidity were measured with a fluorimeter (Schnegg, 2013). The measurements using these instruments were validated by comparing them to laboratory analyses and physical samples. A tracer test (released in a swallow hole) was used to understand the dynamics of the system. It was found that secondary turbidity indicated allochthonous contaminations as follows:

1. The time taken by the tracer to reach the aquifer was equivalent to the lag time between rainfall event and secondary turbidity peak.

2. This Turbidity peak was accompanied by a decreasing discharge, an increasing TOC, and a high bacterial content.

4.3. Gauging outlet location

The monitoring systems must be setup in specific locations as to assess the contamination of groundwater accurately and effectively. As such, we selected 4 gauging outlets downstream of each of the springs. In addition, two quarries, a chicken farm and a hospital are located in the catchment of El Kaleb River and present point contamination sources. In order to determine the risk of each on groundwater, a monitoring outlet must be setup downstream of each. In addition, wastewater is being discharged directly in the river. This contaminated river water acts as an input to groundwater through a sinking stream. This sinking stream transports allochthonous contaminants into groundwater at a relatively high velocity (which is the reason of the high contamination rate in Qachqouch spring; Doummar and Aoun, 2018b). Due to the close interaction of surface water with groundwater, a monitoring outlet should be implemented near the sinking stream, similarly to (Pronk et al., 2007a) where turbidity, TOC, discharge, and water temperature were continuously measured at a swallow hole. In addition, the number of outlets is higher near the Qachqouch and Jeita springs since this area is highly vulnerable to contamination (Figure 4). As such, Figure 6 shows the selected locations for the needed monitoring outlets.

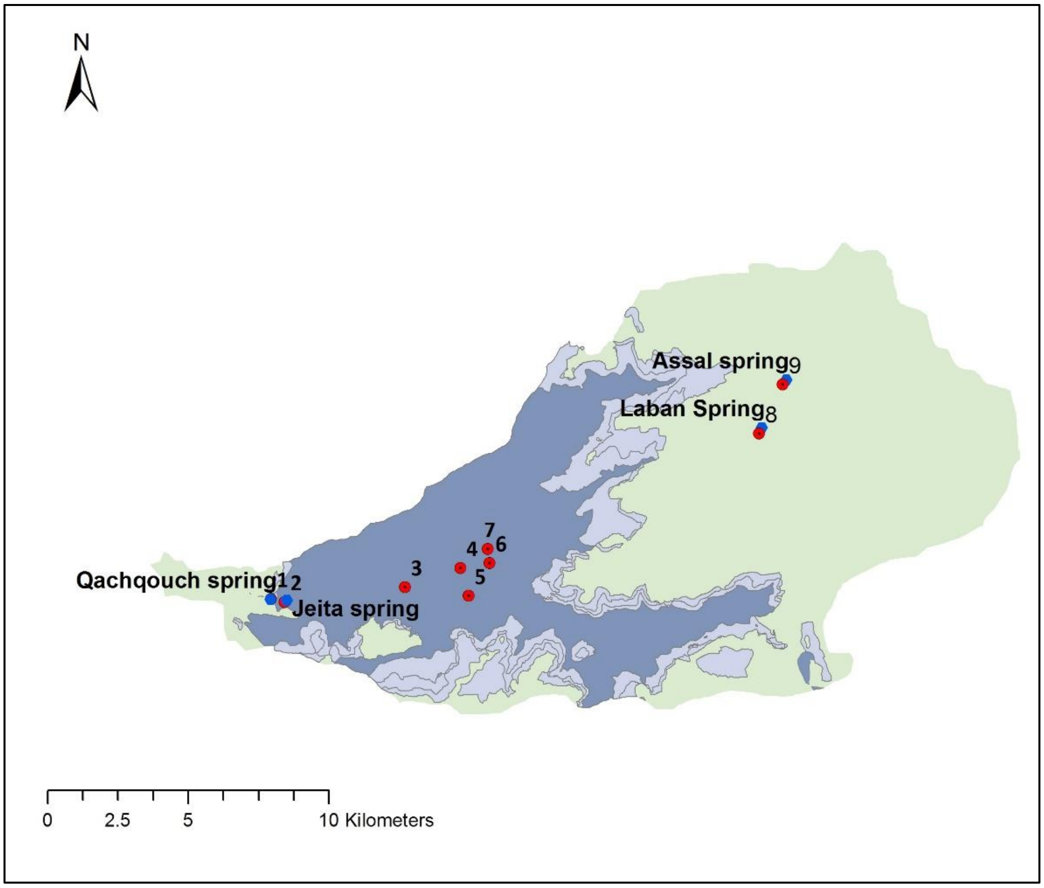

Figure 6- Geologic map of the field site: Nahr El Kalb River showing the four springs (blue dots) and the monitoring outlet locations (red circles).

4.4.Tracer test results

We introduced uranine (a dye) into Nahr El Kalb river upstream from the Qachqouch and Keita springs. The tracer was detected in both springs, indicating that there is a hydraulic connection between the river and the springs, and the springs are likely fed by the river. This highlights the need for integrated water management, so that any study conducted about water availability and quality must include both groundwater and surface water.

4.5. Actions to be taken in case of a contamination outbreak.

When a contamination outbreak occurs in water, there are several immediate corrective actions that should be taken to address the situation:

- Stop using the contaminated water: The first thing that should be done is to stop using the contaminated water. This means stopping all consumption of the water, as well as any other activities that involve using the water, such as bathing or washing clothes.
- Notify authorities: It is important to notify the appropriate authorities as soon as possible. This can include local health departments, water utility companies, or emergency services.
- Identify the source of contamination: Once authorities have been notified, efforts should be made to identify the source of the contamination. This may involve additional water testing to determine what specific contaminants are present and where they are coming from in order to stop any further contamination.
- Provide alternative sources of water: In cases where the contamination is severe or long-lasting, it may be necessary to provide alternative sources of water to affected populations. This can include distributing bottled water or setting up temporary water treatment facilities.
- Communicate with the public: It is important to keep the public informed about the situation and what steps are being taken to address it. This can help to prevent panic and ensure that people take the necessary precautions to protect their health.

In addition, the contaminated water must be treated. there are water treatment plants in Lebanon that are designed to treat water and remove contaminants. Here are some of the major ones:

1. Beirut and Mount Lebanon Water Establishment: This is the largest water treatment plant in Lebanon, serving the greater Beirut area and the surrounding regions. It is located in the Karantina neighborhood of Beirut.
2. South Lebanon Water Establishment: This water treatment plant serves the southern regions of Lebanon, including Tyre, Sidon, and Nabatieh. It is located in the city of Jezzine.

3. North Lebanon Water Establishment: This water treatment plant serves the northern regions of Lebanon, including Tripoli, Akkar, and Batroun. It is located in the city of Zgharta.
4. Bekaa Water Establishment: This water treatment plant serves the Bekaa Valley region of Lebanon, including the cities of Zahle and Baalbek. It is located in the city of Chtaura.
5. Litani River Authority: This organization manages the water resources of the Litani River basin, which covers a large portion of southern and central Lebanon. It operates several water treatment plants along the river, including the Qaraoun Dam and the Bisri Dam.

There are also many smaller water treatment plants and facilities located throughout Lebanon, including private and community-run operations.

However, the country has been facing significant challenges related to water quality and availability in recent years due to a variety of factors, including political instability, economic turmoil, and environmental degradation. Water treatment facilities in Lebanon have faced a range of issues, including inadequate funding, outdated equipment, and insufficient staffing. As a result, the quality of treated water in some areas may not meet international standards, and there have been cases of waterborne illnesses linked to contaminated water sources. In the event of a contamination outbreak in Lebanon, water treatment plants would be a key resource for addressing the situation. However, it is important to note that effective response would also require prompt action from government agencies, healthcare providers, and the public to identify the source of the contamination, implement appropriate disinfection procedures, and provide alternative sources of water if necessary.

4.6. Community inclusion and participation

Community inclusion and participation can play a crucial role in protecting and sustaining aquifers in Lebanon. The following are some actions that must be taken towards sustainable practices:

1. Raise awareness: Communities need to be informed about the importance of aquifers and the need to protect them. This can be done through educational programs and awareness campaigns that target all stakeholders, including school children, farmers, and industry representatives.
2. Reduce water use: Overuse of water is a significant factor in the depletion of aquifers. Communities can reduce water consumption by implementing water conservation practices, such as fixing leaky pipes, using water-efficient appliances, and adopting irrigation techniques that use less water.
3. Promote recycling and reuse: Recycling and reusing water can help reduce the pressure on aquifers. Communities can promote the use of recycled water for non-potable purposes such as irrigation and industrial use.
4. Control pollution: Pollution of aquifers can be reduced by managing waste and enforcing regulations to limit the discharge of pollutants. Communities can work together to ensure that industries, agriculture, and households use environmentally friendly practices to reduce pollution.
5. Engage in participatory planning: Community participation is essential in developing plans and policies to protect aquifers. Communities can work with local government and water authorities to develop sustainable water management plans that reflect the needs and priorities of the community.

CONCLUSION

Water is not consistently monitored and examined due to the absence of funds and regulations. An effective alternative to high analysis cost at laboratories would be measuring certain parameters that indicate contamination. Since surface water can leach into groundwater or directly mix with it through swallow holes. Therefore, these two systems are interconnected and the contamination of one would affect the other. As such, the monitoring systems presented in his project and their location would allow the integrated surface water - groundwater monitoring which is a crucial part of river basin management.

It is recommended that the monitoring systems presented in this report be implemented in the specified locations. In addition, measured data must be well interpreted in order to detect any contamination. In case of an outbreak, the source of contamination can be correlated with industrial, domestic or organic wastes at the vicinity. This acts as an early-warning systems (EWS) that help mitigate contamination and take the proper measures to manage anthropogenic activity or point source pollution.

The successful implementation of this project in the study area will allow us to generalize over all groundwater systems and rivers in Lebanon. The outcome would be a white paper (Appendix I) that could be potentially used by policy makers and eventually a potential law.

PERSPECTIVE

1. Problem and context:

Due to the absence of wastewater treatment plants in Lebanon, anthropogenic waste is directly disposed in rivers and water bodies. This leads to water contamination threatening by that its quality and quantity.

2. Objective:

we want to influence policy change to ensure sustainable supply in water quality and quantity. By that we mean adding a policy that all fresh water in Lebanon must be continuously monitored. In addition, add a policy that specifies measures to be taken towards nearby facilities in case monitoring data shows they are contributing to water contamination. Finally, add a policy for mitigation measurements in case outbreaks occur.

3. Stakeholders' analysis:

The Stakeholders of this project are:

Decision makers that are the power holders. They are responsible for the implementation and modification of the policies.

Investors that provide funds to buy the instrumentation needed for setting up the monitoring systems. The water establishments in Lebanon can fund such a project since they are responsible for maintaining and installing new water infrastructure meant to develop and restore the nation's domestic water supplies. These establishments get their funding from the European Union for this purpose which make them important stakeholders for this project.

4. Take home messages:

It is crucial to monitor groundwater and river basins as they are prone to contamination and the quantity of water is threatened. Karst aquifers are the primary source of potable water for nearby villages and cities, and if monitored correctly they can provide a sustainable supply all year round.

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APPENDIX I
WHITE PAPER

1. Executive summary:

It is crucial to monitor groundwater to ensure the sustainable supply of good quality water. Since collecting samples and laboratory analysis can be costly, and since karsts are dynamic environments that require more frequent measurements, we came up with adequate monitoring systems. These monitoring systems can help infer the degree of contamination through measuring indicator parameters in the targeted water system (such as turbidity, electrical conductivity, temperature …). The study area comprises the catchment area of El Kalb River which drains into four springs: Assal, Laban, Qachqouch and Jeita. This work provides the set-up of the needed monitoring systems, the way to read and interpret the data, come up with early warning systems, and how to mitigate contamination.

2. Introduction:

Groundwater from karst aquifers represents one of the most valuable sources of drinking water across the world. In Lebanon, the Jeita spring is the main source of water supply for Beirut as it provides drinking water for about 1.5 million inhabitants. The Qachqouch spring is the second most important source of water supply for Beirut, which complements the water deficit in the capital and its surrounding areas. The overflow from Laban spring feeds the two tributaries of El Kalb River in the highlands, and a part of it is also conveyed into an irrigation canal that feeds the area of Kfar Debbiane irrigation scheme, mainly between May and September. As for the Assal spring, it is used for water supply in the near villages. Therefore, these four springs provide an important source of water supply to Lebanon. However, these springs face severe contamination risk that threatens their water quality. For example, wastewater effluents from the urbanized area near the Qachqouch spring as well as surface-water input to this spring makes it highly polluted. In addition, sewage water particularly from resorts, chalets and dwellings in Aayoun es Simane area contaminate the Assal spring. Thus, it is crucial to monitor, prevent and mitigate any contamination in El Kalb River Basin.

3. Research overview:

The assessment of water quality is based on the presence of different types of contaminants such as pharmaceuticals, sewage, bacteria etc... On the other hand, the assessment of water quantity depends on discharge. Therefore, the continuous measurement of the degree of contamination as well as the water flow is required.

Measuring specific contaminants requires going to the field, grabbing samples and analyzing them in the lab which can be time consuming and expensive. A more efficient low-cost alternative is to measure indicator parameters. These parameters include electrical conductivity (EC), turbidity, particle size distribution (PSD), total organic carbon (TOC), dissolved oxygen (DO), temperature (T), pH and discharge. They can be correlated with certain water contaminants or water quantity, as such giving a full assessment of the water availability and quality.

The first step in this process is to choose the suitable low-cost instruments that are efficient in karst systems. To do so, a review of previous work done in areas with similar hydrogeological characteristics to our study area is performed. The second step is to select the adequate time interval between measurements as to be both sufficient and informative. As such, we used a common approach in terms of instruments' selection and frequency of measurements. The third step is to determine the proper locations to set up the monitoring systems.

Monitoring outlets should be close to contamination sources such as quarries, hospitals, industrial sites, and dumping of sewage water etc… to record any outbreaks. This is very important in policy making, as monitoring the anthropogenic activities can help to make decisions that prevent outbreaks and mitigate them.

4. Discussion/analysis of research findings:

Each parameter can be interpreted in order to assess the degree of contamination. Our findings can be summarized as follows:

When turbidity measurements show two peaks, the first is referred to as primary and the second as secondary. Secondary turbidity always coincides with high bacterial contents, so it is usually correlated with water contamination since it indicates the arrival of contaminants from outside the system. Turbidity is measured by a multiparameter probe at an interval of 20 minutes.

The total organic carbon (TOC) and particle size distribution (PSD) can be measured in parallel with turbidity as a way to validate wastewater contamination. TOC can be measured from water samples collected at an interval of 2 to 4 hours using a TOC analyzer, and PSD can be measured using a portable particle counter (coulter counter).

When EC values increase beyond the background level, it is due to the presence of high chloride and phosphate levels that may come from household products in sewage when compared to tap water levels. If high EC values are accompanied by an increase in turbidity, it can be an easy indicator for emerging micropollutants such as pharmaceutical from sewage. Similar to turbidity, EC can be measured every 20 minutes using a multi-parameter probe.

High contamination is mainly associated with high turbidity, high water temperature, and low pH and dissolved oxygen (DO) respectively. pH and temperature can also be measured using a multiparameter probe at a 20-minute interval. DO can be measured using a dissolved oxygen meter.

Increasing discharge accompanied by a primary turbidity peak (during a rainfall event) indicating autochthonous particles coming into suspension, whereas decreasing discharge (days after rainfall event) can be correlated with a secondary turbidity peak, TOC increase indicating feacal contamination. Discharge rates can be measured by means of pressure probes and rectangular weirs.

Initially we selected 4 gauging outlets downstream of each of the four springs to monitor them. However, two quarries, a chicken farm and a hospital are located in the catchment of El Kaleb River presenting point contamination sources. Therefore, in order to determine the risk of each on groundwater, a monitoring outlet must be setup downstream of each. In addition, wastewater is being discharged directly in the river through a doline. Due to the close interaction of surface water with groundwater, a monitoring outlet should be implemented near the sinking stream.

5. Conclusions and recommendations:

Water is not consistently monitored and examined due to the absence of funds and regulations. An effective alternative to high analysis cost at laboratories would be measuring certain parameters that indicate contamination. Since surface water can leach into groundwater or directly mix with it through swallow holes. Therefore, these two systems are interconnected and the contamination of one would affect the other. As such, the monitoring systems presented in his project and their location would allow the integrated surface water - groundwater monitoring which is a crucial part of river basin management.

In brief, protecting aquifers in Lebanon requires a concerted effort from all stakeholders. It is recommended that the monitoring systems presented in this report be implemented in the specified locations. In addition, measured data must be well interpreted in order to detect any contamination. In case of an outbreak, the source of contamination can be correlated with industrial, domestic or organic wastes at the vicinity. This acts as an early warning system that help mitigate or control contamination and take the proper measures to manage anthropogenic activity or point source pollution. If contamination got out of hand, there are corrective actions to be followed to protect the people. Moreover, Community inclusion and participation are critical to developing sustainable practices that can ensure the long-term viability of aquifers. By raising awareness, reducing water use, promoting recycling and reuse, controlling pollution, and engaging in participatory planning, communities can take action towards sustainable practices to protect aquifers.