CONSULTANCY SERVICES FOR RIVER BASIN MANAGEMENT

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GHADIR RIVER BASIN

BASELINE REPORT

DECEMBER 2022

HawkaMaa - EU
حوكماء - الإتحاد الأوروبي

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ACTED

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List of Abbreviations

BMLWE	Beirut and Mount Lebanon Water Establishment
GRB	Ghadir River Basin
IWRM	Integrated Water Resources Management
LULC	LandUse and LandCover
MEW	Ministry of Energy and Water
Mm^3	Million cubic meters
MoA	Ministry of Agriculture
MoE	Ministry of Environment
NWSS	National Water Sector Strategy
PoM	Programme of Measures
SDG	Sustainable Development Goal
USD	United States Dollar
WEAP	Water Evaluation And Planning
WRMM	Water Resources Management Model
WWTP	Waste Water Treatment Plant

1 Background

1.1 Project Description

The current report is a baseline assessment of the water resources management of Ghadir River Basin (GRB) located in the upstream southern region of Beirut. It consists of developing a detailed Water Resources Management Model by establishing a node based distributed water balance model using Water Evaluation and Planning WEAP software. The assessment presents the state of the water availability, water demand, water supply, and unmet demand (per sector) in the basin during the last 2 decades, as well as the current state of surface water pollution based on a recently conducted field survey and water sampling.

The work has been conducted in the framework of the project "CONSULTANCY FOR RIVER BASIN MANAGEMENT FOR AL ASSI BASIN/BEKAA, GHADIR BASIN/ BEIRUT AND MOUNT LEBANON, NAHR AL OSTUAN BASIN/AKKAR", under EU MADAD funding and as part of the HAWKAMAA-EU Consortium partners.

The purpose of the project is to support effective multi-stakeholder decision making and action through water balance modeling to improve the conservation and management of water resources in the basin and maximize the economic, environmental and social benefits. The overall scope is to improve water management in selected river basins by implementing a bundle of demand management measures which can alleviate the prevailing water stress, increase water availability and network efficiency while decreasing losses.

In parallel to these water quantity issues, the work also focuses on assessing the current pollution levels in the river, in order to mobilize the local community and stakeholders to take action to reduce pollution loads in the basin, and mitigate the current problem.

The project promotes an inclusive participatory approach, not only by disseminating the results and outputs to the various target groups, but by also involving them in the consultation process.

The following activities have been concluded so far:

- Kickoff meeting with the client and Hawkama - EU partners.
- Data collection, desk review of previous studies and analysis of hydrometeorological, geological and land use data, information on the water supply systems, GIS cartographic data and development of a GIS database for the GRB.
- Development of a semi distributed (node-based) Water Resources Management Model for GRB in WEAP21 software, at a monthly timestep and for the period 2000-2018.
- Implementation of the first participatory workshop with the stakeholders (November 28th 2022 at Antonine University Baabda)
- Field investigation (conducted in November 2022) to assess the current situation of the stream and select sampling points in terms of their relevance to the major pollution sources.
- Sampling campaign and laboratory analysis of water samples from 6 sampling sites along GRB for the winter season conducted on December 15th 2022 by NDU.
- Drafting of the Baseline Report on the assessment of water resources in GRB, based on the outputs of the WEAP model, including a water quality assessment based on the outputs of the field survey and sampling campaign.

1.2 Link to NWSS

The Ministry of Energy and Water (MoEW) prepared and adopted the Lebanese National Water Sector Strategy (NWSS) in 2010 which was endorsed by the Government of Lebanon in 2012 (Resolution No.2, Date 09/03/2012). Seven years later, in 2019, the MoEW decided to review what has been realized from the original roadmaps and to update the water and wastewater strategies of 2012 by setting a detailed action plan to implement reforms and create a hydrogeological data management system and improve service coverage. The Updated NWSS 2020 merges the National Water and Wastewater strategies of 2012 into one consolidated strategy. It maintains the main strategic principles of the water policies adopted by the Government of Lebanon in 2012, but reassesses the previously set priorities in light of today's actual context, and sets the ground for the period extending between 2020 and 2035.

It takes into account the adopted Water Code (law 192/2020) and its structuring principles, which are in turn in line with the water sector organizing Law 221/2000 and its amendments, as well as studies and projects completed between 2012 and 2021 in the fields of potable water, wastewater and irrigation, and management initiatives implemented during the same period. The newly ratified Water Code includes several Integrated Water Resources Management (IWRM) implementation principles and aims to regulate, develop, rationalize, and exploit water resources, protect them from depletion and pollution and improve the efficiency of transport, distribution, and maintenance systems for the operation of water installations to ensure the sustainable management of the Lebanese natural water resources.

As per the water code, the Ministry aims at achieving a financially sustainable sector, that is citizen-centered and service oriented, and which would ultimately allow to reach an integrated approach of the water sector.

The updated strategy can be considered as a shift into practical, implementable plans, projects and governance initiatives that set the ground to move towards the UN's Sustainable Development Goal SDG 6 and realize the principles of an IWRM. While doing so, the updated NWSS 2020 targets as well SDG 2 (Zero Hunger), SDG 7 (Affordable and Clean Energy), SDG 13 (Climate Action), SDG 14 (Life below Water), SDG 15 (Life on Land) and SDG 17 (Partnerships for Goals); these will be explored throughout the document.

Based on the United Nations' SDG 6, the MoEW aims at providing safe, equitable and affordable water and wastewater services to all, and to properly allocate the water resources to the different economic sectors (agriculture, industry, tourism, services, etc..) based on the priorities of the Government's recovery plan.

These commitments are translated by strengthening the IWRM through targeted proposed projects and improved governance at the basin level, thus the river basin management studies of Al Assi, Ghadir and Al Ostuan.

1.3 Methodology

The assessment of the water resources management situation in GRB was carried out following the below methodology:

- Data collection and compilation of a comprehensive GIS database which included the basin boundary, landuse, geological and hydrogeological maps, etc.
- Desktop review of relevant studies mainly the geological and hydrogeological description (section 2.3), the agricultural situation (section 2.6), the findings of the NWSS on the water balance of the water distribution systems located within Ghadir i.e. water demand, water supply sources, deficit and excess, etc. (section 2.5), and the wastewater situation (section 2.4.2). The concept design for the training of Ghadir river related to the flooding of the downstream urban area of Ghadir was also reviewed (See section 2.2.3).
- Water quality sampling campaign in coordination with NDU University water laboratory, carried out on December 15th, 2022, which results will be included in the WEAP model. The lab report is attached in Appendix A.
- Development of GRB water resources management model using WEAP which assesses the current situation of the water resources management within the basin, the existing surface and groundwater sources, the supply infrastructure. It will be also used to simulate several future technical, institutional, socioeconomic, and climatic scenarios with the purpose of improving the water resources management of the river basin and optimize the economic, environmental, and social benefits of the river.
- A baseline and future water balance will be developed, assessed, and translated into policy relevant targets to further support the design corresponding Programme of Measures (PoMs), then propose an action plan in coordination with key stakeholders in the region. The detailed methodology for WEAP is described in section 4.1.
- Drafting of the Baseline Report based on the overall project area description and the outputs of the WEAP model, including a water quality assessment and the outputs of the field survey and sampling campaign.

2 Project Area Description

2.1 Location

Ghadir River Basin is one of the smallest in Lebanon located in the southern region of Beirut shared between the Casa of Baabda and Aley. The basin extends from Dhour Al-Abadiyyeh to the east of Beirut Airport and consequently the sea to the west. The river passes through the areas of Choueifat, Kfarshima, Hay El Selloum and flows into the Mediterranean Sea south of Beirut, under the Beirut International Airport.

It covers the localities of Ain Aanoub, Baabda, Bdedoun, Bleibel, Betchay, Bsaba, Bsous, Choueifat, Deir Qoubel, Houmal, Jamhour, Kahaleh, Kfarchima, Wede Chahrour, Qmatiye, etc. Ghadir river stream meets the southern urban area of Beirut starting from Kfarchima, Choueifat, going next to the Lebanese University campus of Hadath, then Amroussieh Hay el Sillum. At Hay el Sillum, the stream crosses the highway above the tunnel before running adjacently with the airport boundary where it enters a wide culvert beneath the airport domain reappearing after it at CostaBrava sea outfall. GRB delineation was expanded in this study to include within the WEAP model the regions that are supplied by same water distribution systems and their stormwater is drained into Ghadir. The location of GRB is shown in Figure 1.

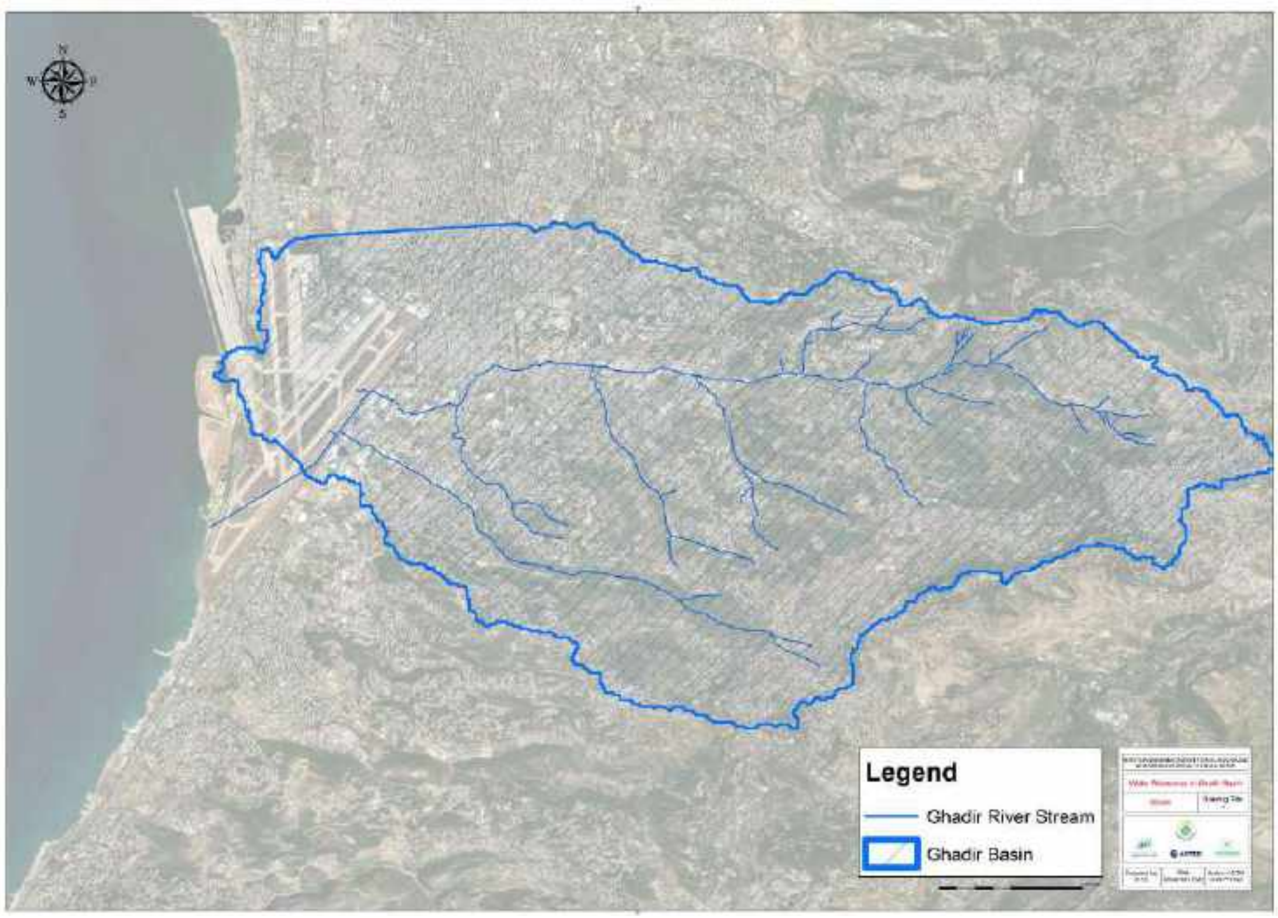

Figure 1 Ghadir River Basin study area location

2.2 Hydro Meteorological Description

2.2.1 General climate description

Lebanon is an Eastern Mediterranean country known for its moderate climate with a cold and humid winter and a hot and dry summer. Lebanon could be divided into three climatic areas and each of them to subregions from North to South. The Coastal area below 800 m altitude, the Mountainous area over 800 m altitude and the Internal Area. GRB is under the influence of coastal climate (Atlas Climatique du Liban, 1977).

According to the Lebanese Meteorological Service (LMS), the average annual precipitation at Beirut International Airport weather station is approximately 728 mm as recorded between 2000 and 2020. 80% of the precipitation fall between November and March while Jun, July and Aug are usually dry.

The average monthly temperature varies between 15°C in January being the coldest month and 28.5°C in August being the hottest month. The monthly average precipitation and temperature are presented in Table 1 below.

Table 1 Monthly average precipitation and temperature at Beirut International Airport (LMS)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Precipitation (mm)	173	128	75	33	14	1	0	0	10	54	86	154	**728**
Temperature (°C)	15.1	15.5	18.1	21.0	23.3	25.7	27.6	28.5	27.4	24.8	20.6	16.4	**22.0**

2.2.2 Ghadir river flow

Ghadir is an intermittent river draining a basin of approximately 40 km^2 at its sea mouth with an average annual runoff of 0.39 m^3/s as recorded after 2000. Ghadir basin as considered in this study is the expanded area which includes in addition to the hydrological basin, the urban area which drains the stormwater towards the stream. The river is formed by seasonal non perennial streams that mainly drains rainfall as very few intermittent springs are located within its catchment. It usually flows in wet season only in response to precipitation between November and April while being totally dry between May and October as no rainfall occurs and no major springs are located within the basin. However, some minimum flow could be recorded from wastewater. The monthly average runoff is presented in Table 2 below.

Storms accompanied with extreme rainfall events may hit Lebanon several times per year which may result in floods causing the submergence of roads by rainwater transporting tree branches, rocks and other stream clogging objects. Thus, Ghadir river witnesses several inundations annually.

Table 2 Monthly average runoff at Ghadir gauging station

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Runoff (m^3/s)	1.28	1.28	0.76	0.39	0.07	0.03	0.02	0.01	0.04	0.04	0.15	0.69	**0.39**

2.2.3 Ghadir river flood control

The Council for Development and Reconstruction (CDR) has commissioned Dar Al Handasah in 2014 to explore and seek feasible flood control and protection solutions for the recurring flood events of Ghadir River. Over the past decade, the recurrence of those flood events has led to grave consequences affecting the urbanized area west of Old Saida Road (Hay Es Sillum), in terms of property damages and, in a few cases, the unfortunate loss of human life. The following proposal offers a concept design for the training of Ghadir River, addressing viable options to mitigate the risk of flood recurrences.

Two alternatives that aim to mitigate flood recurrence risk were proposed. The first alternative was to provide a trained river channel which can contain the 100-year flood (estimated at 160 m^3/s at Hay Es Sillum) without any flood mitigation/ reduction measures in the upper Ghadir basin to the east of Old Saida Road. The implementation of this alternative will require a wide corridor which will result with very high expropriation requirements in Hay Es sillum. Very high expropriation requirements will be necessary to implement this alternative, and as such it was excluded.

The second alternative offered a new hydrological analysis of the whole river stream that was then used as a basis to design upstream flow attenuation control structures which will allow peak flood flow reduction. The reduced flow in Ghadir River would then be conveyed through a narrower concrete channel constructed within the river right of way, and meandering amongst the informal urbanization in Hay Es Sillium. Due to its narrower footprint, this alternative would help minimize future expropriation costs in that urbanized area.

The second alternative was further divided into two separate design options, labeled Option 1 and Option 2. Option 1 proposed one reservoir/dam to attenuate flow in each of the Ghadir River subcatchments. Option 2 proposed several smaller checks, constructed in sequence, in each of the subcatchments. Both options significantly reduced the peak flood values by about 40-45% without overtopping at the 100-year flood incident, thus providing viable flow attenuation and reduction methods. Both options offered a similar numerical output in terms of flow values in Ghadir River at Hay Es Sillum - 90 m^3/ s for Option 1 and 81 m^3/s for Option 2; however, the main difference was in the scale of expropriation in the upstream section of each sub-catchment, where Option 2 offered significantly less land expropriation in the catchment areas east and upstream of Old Saida Road, close to a 90% reduction. In the river channel passing through the dense urbanization west and downstream of Old Saida Road, it is proposed that the Ghadir River watercourse be channelized into a concrete channel until its outfall at the eastern boundary of Beirut International Airport.

Hydraulic studies show that the narrow corridors (4.0-6.0 m wide) can accommodate the channel, but the resulting high velocity and construction challenges make it impractical. Using GIS software, the channel can be adjusted slightly to avoid buildings in the river right-of-way (ROW), reducing the need for building expropriation. However, implementing a trained river channel will require setbacks from adjacent buildings and additional working space for excavation support techniques. A 16.0 m wide corridor will be needed for construction, which can also be used for infrastructure placement and channel access. The area marked for expropriation for the 16.0 m - wide corridor will be approximately 12,700 m^2.

The excavation and construction costs associated with Options 1 and 2 are 61.1 million US dollars and 18.9 million US dollars respectively. These costs can be divided as follows:

Table 3 Cost estimation of options 1 and 2 of Alternative 2

Item	Option 1 (Million $)	Option 2 (Million $)
Roads	6.8	9.3
Ghadir River Channel	9.8	9.2
Dams/ check structures	44.5	1.9
TOTAL	61.1	20.4

While Options 1 and 2 did deem that the construction of dams/ check walls was viable as a flood reduction method, it is important to stress that those flood control structures in both options, and especially Option 2, would lose their efficiency gradually if not maintained properly. The accumulation of soil and debris behind the dam/check walls reduces storage and attenuation time, eventually leading to overflow from those flood control structures and posing risks to the surrounding lands and properties, potentially threatening human life. The same logic applies to the concrete channel west of Old Saida Road, conveying the Ghadir River flow, as it requires maintenance to meet design standards and not pose any future flood risk.

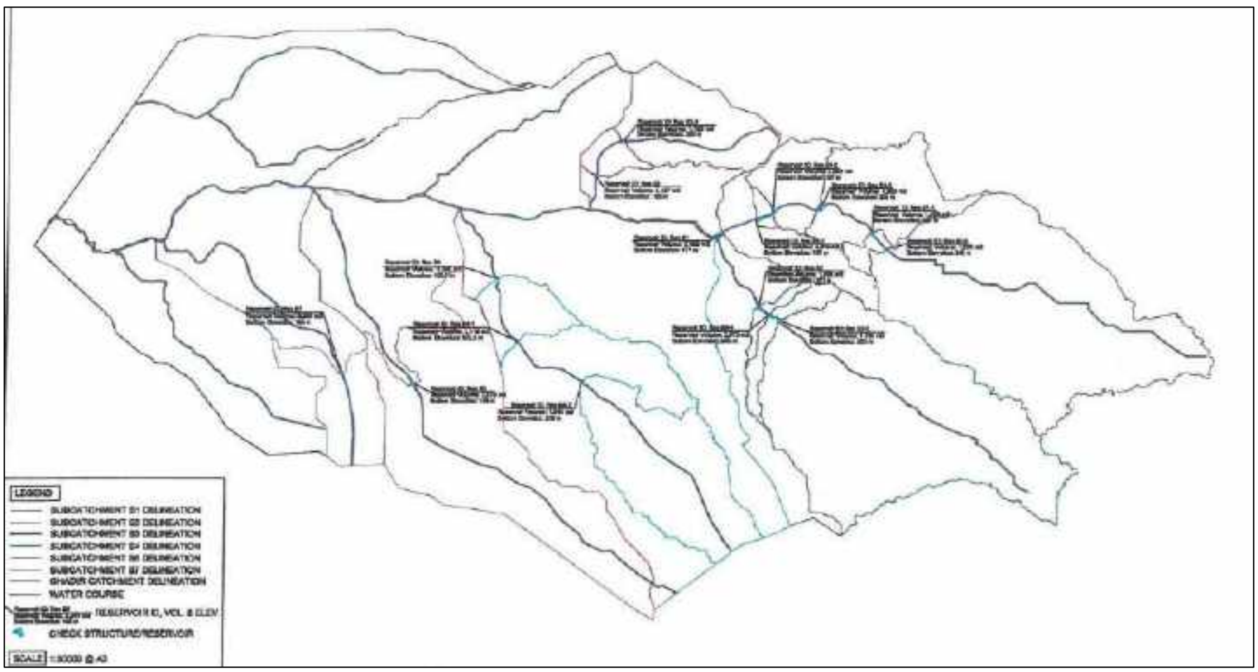

Figure 2 Schematic of the location of the proposed dams/reservoirs within Ghadir River Basin

2.3 Hydrogeology/Geology

2.3.1 Geological conditions

The geological features of Lebanon were mainly described by the French geologist, Louis Dubertret who compiled a general "Geological Map of Lebanon" on 1:200,000 scale (Dubertret, 1955) and more detailed geological maps for parts of Lebanon on 1:50,000 scale. The geological map of GRB, shown in Figure 3, was produced based on Dubertret's work. For this project, three geological sections (MN, OP, QR) were constructed to further understand and visualize the geological structure of the study area as shown in Appendix A.C. Moreover, this Appendix includes six geological sections (AB, CD, EF, GH, IJ and KL) found in the literature (Doummar et al., 2015). The locations of those cross sections are indicated on Figure 3. Appendix C also shows another geological section produced by UNDP (1970) and crossing the study area. The latter section is not indicated on the geological map due to unavailability of the section's exact spatial coordinates.

The sequence of outcropping geological formations within GRB range between Lower Cretaceous and Quaternary. The Jurassic sequence (mainly exposed to the northeast of the study area) is not outcropping in GRB. However, some public wells are expected to be tapping this formation within the study area's subsurface.

The Quaternary deposits cover around 31% of the study area and lie unconformably over the Sannine Formation in the coastal zone (to be proved since the geological cross sections found in the literature show some inconsistencies in this regard; in particular, there is a big uncertainty regarding the presence of the Chekka Senonian Formation (C6), its thickness and its hydraulic properties). This unit mainly consists of alluvial, beach and aeolian deposits with a thickness ranging between 5 and 80m according to some drillings (Ukayli, 1971). Lithologically, the Quaternary deposits mostly comprise brown soils, (decalcified) red soils, terrigenous alluvium, sandy alluvium, argillaceous colluvium, pebbles and sands. The partial and weak cementation of those lithologies gives this unit a relatively high porosity (Ukayli, 1971). It is important to note that beach deposits, found around Beirut Airport, are made of coarse-grained, rounded to sub-rounded sands mixed with shells and limestone conglomerates (Doummar et al., 2015).

According to the works of Ukayli (1971) and Elezian (1985), the Miocene Formation also lies unconformably over the Sannine Formation (to be proved, similarly to the aforementioned relation between the Quaternary and Sannine formations). Hajj (1987) highlighted that the Miocene Formation's thickness is about 100m in Choueifat area, and consists of marl and marly limestone interbedded with conglomerates. This formation, covering less than 4% of the GRB, was subject to weathering and erosion and is encountered in patches.

The Cretaceous sequence covers about 65% of the study area and includes the Sannine Formation (C4), Hammana Formation (C3), Abeih-Mdairej Formation (C2), and Chouf Formation (C1):

- Sannine Formation (C4) is of Cenomanian age (Walley, 1997), and can be as thick as 700m if not eroded (Elezian, 1985). It is composed of a succession of limestone and dolomite, noting that marly limestone and chert bands can be also encountered at different horizons (Jaouni, 1971). Nader (2000) reported that this formation becomes thinly bedded, with high chalk and chert content towards the coast. The C4 Formation is usually divided into three subunits: C4a, C4b and C4c (from oldest to youngest). It is stratigraphically overlain by the Maameltain Formation (C5) and by the Chekka Formation (C6) (both not outcropping in the study area). The Maameltain and Sannine formations have similar lithologies and are commonly known as C4-C5 Formation (i.e. Sannine-Maameltain Formation);

- Hammana Formation (C3) has an approximate thickness of 125m according to Ghattas (1975), and features Albian dolomitic and marly limestones as well as thin beds of Aptian marls at its base (Peltekian, 1980; Walley, 1997);
- Abeih Formation (C2a) of the Lower Aptian age has an approximate thickness of 175m (Doummar et al., 2015). It consists of clays and marly units (at its base) and grades into sandy limestone (Peltekian, 1980). It is interesting to note that the geological contact between this formation and the underlying Chouf Sandstone Formation is a gradational transitional contact (Walley, 1997);
- Mdairej Formation (C2b) of Aptian age (Walley, 1997) has a thickness of about 50m according to El-Kareh (1970) and mostly consists of massive, compact and reefal carbonate rocks (Ukayli, 1971). This formation is characterized by a higher porosity than C2a and is affected by mass wasting and weathering processes (noting that rock blocks are seen on the underlying Abeih Formation) (Doummar et al., 2015);
- The Chouf Formation (C1) of Neocomian age has an approximate thickness of 175m. It is mainly composed of sandstone, argillaceous sandstone, ferruginous sandstone, clay and volcanic rocks (Dubertret, 1945, Kanaan, 1966; Walley, 1997). Doummar et al. (2015) reported that this formation's sandstone consists of poorly sorted quartz grains, locally intercalating with clay beds/lenses.

Finally, the oldest formation in this sequence is the Jurassic Formation. It mainly consists of limestone, dolomitic limestones and basalts.

From a structural geology perspective, the study area lies to the west of the Yammouneh Fault and north of Roum Fault. Walley (1997) highlighted that Mount Lebanon Anticline caused the dipping of the coastal strata towards the Mediterranean Sea. The formations in the study area (especially in its southeastern part) were displaced by multiple E-W faults. In addition, numerous secondary faults resulted in the disturbance of the geological sequence (as reflected in the geological cross sections). Doummar et. al (2015) also highlighted that deformation is partly accommodated by two fault systems in the GRB: a first system consisting of E-W to ENE-WSW striking structures, and a second system consisting of NW-SE striking structures. In the majority of the rock formations encountered within the study area, the faults' activity and the larger-scale tectonic pressures are associated with closely-spaced joints, fissures and cracks (Doummar et al., 2015). It is noteworthy to mention that well-developed fractures generally form excellent groundwater flow pathways (unless filled with fine material).

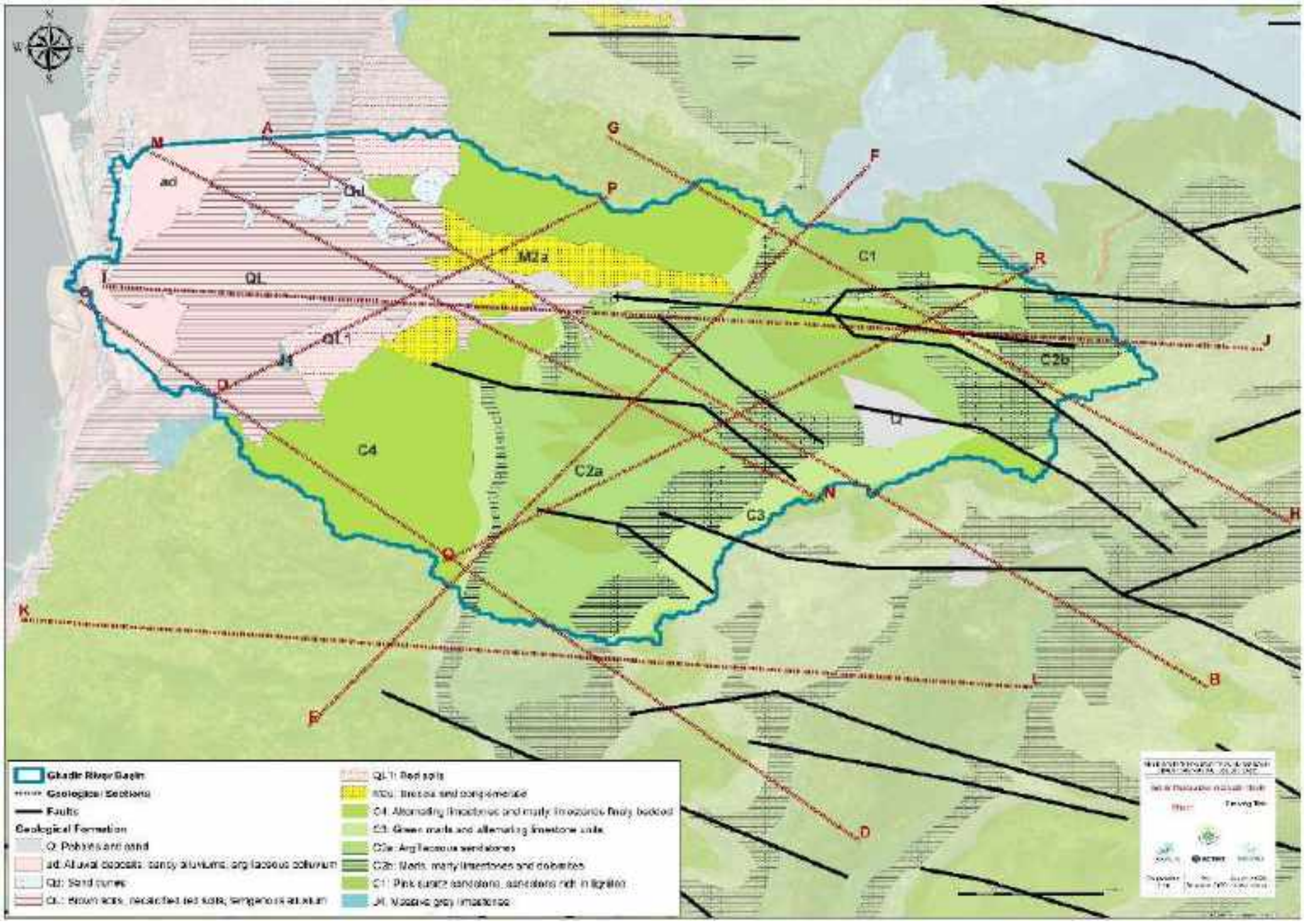

Figure 3 Geological map of GRB (modified from Dubertret (1955)) showing the location of the geological cross sections

2.3.2 Hydrogeological conditions

2.3.2.1 Hydrogeological formations and properties

UNDP (1970) published a 1:200,000 hydrogeological map covering Lebanon. The work carried out by UNDP (1970) led to the most comprehensive groundwater study for the country since the presented conclusions were based on drillings, geophysical studies, pumping tests, chemical analyses, groundwater level monitoring, and on information provided by various organizations responsible for meteorology and hydrology. It is important to note that the 1:200,000 geological map of Dubertret (1955) was adopted for all stratigraphic and structural data. Figure 4 shows the outcropping hydrogeological formations (as per the hydrogeological map produced by UNDP (1970)) as well as the springs emerging within the study area. However, the delineated springs are small-scale springs mainly discharging during high flow periods (no discharge data were available for those springs). Most of them originate from the Chouf Formation and at the boundary between the Mdairej marls and the Hammana dolomitic limestone.

It is worth noting that most of the hydrogeological formations encountered within the GRB extend beyond the basin's surface limits. The main tapped aquifers in the GRB subsurface are (from older to younger): the Jurassic Complex (J4-J7) (noting that J5 can particularly act as aquiclude, and J6-J7 can be considered as semi-aquifers according to Walley (1995)), Sannine Formation (C4) except its middle member (C4b), Miocene Formation, and the Quaternary deposits. The

Chouf Formation (C1) is considered a semi-aquifer while Abeih-Mdairej Formation (C2) as well as Hammana Formation (C3) are generally characterized by poor hydraulic properties (with some exceptions that will be further highlighted in the next paragraphs).

Quaternary alluvial deposits are reported to be permeable with transmissivity values ranging between 1E-04 and 1E-03 m^2/s and a storage coefficient of around 0.1 (UNDP 1970). On the other hand, sand dunes have a relatively small extent and thickness. However, the different lithologies of the Quaternary are partially and weakly cemented (Ukayli, 1971) which should typically lead to favorable hydraulic properties within this formation. In some parts of the study area (as shown by the geological section IJ produced by Doummar et al. (2015) and that of UNDP (1970), both included in Appendix A), the marl layers of the Chekka Formation (C6) act as a flow barrier between the Quaternary and Sannine formations. On the other hand, Peltekian (1980) mentioned that the Quaternary Formation overlies the Sannine Formation in some locations, which allows hydraulic connection between those two formations.

The most important aquifer in the study area is the Sannine Formation of Cenomanian Age (C4): it is a highly karstified aquifer (characterized by a high secondary porosity), hence groundwater mainly flows through conduits and fractures. The upper and lower hydrogeological units C4c and C4a are considered karst aquifers due to their significant secondary porosity, while the middle unit (C4b) acts as an aquiclude (due to its low permeability) separating the two permeable units (Khadra 2003). As such, C4a is considered as a confined aquifer (except in its recharge areas) since it is overlain by an aquiclude (C4b) and underlain by the impervious Hammana Formation (C3). The analysis of pumping tests carried out on 12 wells tapping the Sannine Formation in the vicinity of GRB showed a transmissivity value of 6E-04 m^2/s and a storage coefficient of 3E-02 (UNDP, 1970). The same report stated that around 21% of rainwater infiltrates into this aquifer. Finally, it should be noted that the extensive abstractions from this aquifer as well as its proximity to the Sea, and its fractured nature increase the aquifer's vulnerability to seawater intrusion.

In the GRB, the Albian Hammana Formation (C3) isolates the Quaternary and Sannine aquifers from the rest of the underlying formations. Ghattas (1975) highlighted that the C3 marls protect the underlying formations from salinization caused by seawater intrusion.

Mdairej formation, characterized by extensive jointing (hence good fracture permeability) is considered as semi-aquifer due to its limited geometry and recharge area. On the other hand, Abeih Formation acts as an aquiclude limiting the hydraulic connection between the Chouf and Mdairej formations unless potential for preferential flow through faults and fractures exists. In fact, the presence of fractures may facilitate the flow between the different formations.

The Chouf Sandstone Formation was considered a porous medium semi-aquifer by MoEW and UNDP (2014) due to its relatively good permeability and minor storage of groundwater. The Chouf Formation features a steady flow since groundwater percolates and moves slowly between its sand grains. In addition, it is expected that this formation has a lower productivity as compared to the Sannine and Jurassic formations (as hinted by Section 2.3.2.5). In fact, UNDP (1970) stated that the flow observed in wells and springs emerging from the Chouf Formation is less than 10 L/s (equivalent to 36 m^3/h). However, other authors consider the Chouf Formation as an aquifer (and locally as a semi-aquifer) since it is characterized by matrix porosity where cementation is weathered and eroded (Doummar et al., 2015). Pumping tests carried out in some wells tapping this formation (but far away upstream of the study area) revealed a transmissivity value of 3E-04 m^2/s (UNDP, 1970). This value is just indicative and should not be considered as site-specific for this case study. On another note, Doummar et al. (2015) highlighted that the Chouf Formation is locally characterized by high iron content caused by oxidation reactions.

Finally, the uplift in the late Jurassic to early Cretaceous Eras led to the exposure, erosion and karstification of the Jurassic Limestone. In particular, the Middle Jurassic Formation (J4), lithologically composed of karstic limestone, is one of the major aquifers in Lebanon. Although the Jurassic Complex is not outcropping within the study area, few wells are tapping it.

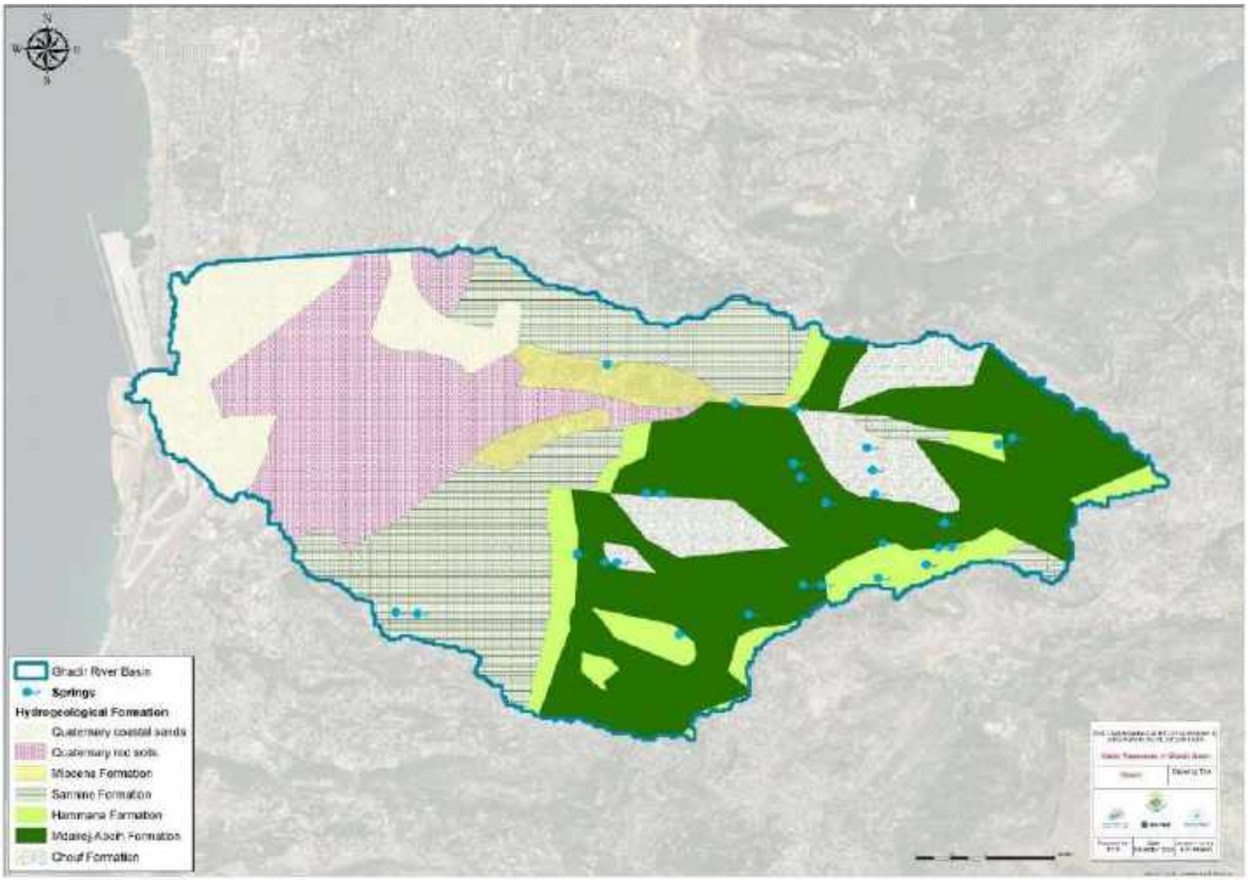

Figure 4 Hydrogeological map of GRB (modified from UNDP (1970))

2.3.2.2 Groundwater levels and directions

Within the study area, groundwater mainly flows in a western direction following the major dip directions. Groundwater flow in the carbonate rock aquifers present within the study area seems to be mostly governed by fracture flow (particularly along the west/northwest – east/southeast faults). Figure 5 shows the groundwater level contours reported by UNDP (1970) for the Quaternary aquifer within the limits of the GRB. The reported contours (for the year 1970) show groundwater levels of 1 to 8m above sea level for the Quaternary aquifer (with an estimated hydraulic gradient of 0.0018 in the southern part of the river Basin and 0.0029 in the northern part for the year 1970). Those contours also show that the natural groundwater direction in the concerned aquifer is towards the west (i.e. towards the Mediterranean Sea). MoEW and UNDP (2014) reported that the groundwater levels in coastal formations are still comparable to the levels reported by UNDP (1970) since the abstracted freshwater is mostly compensated by the intruding seawater.

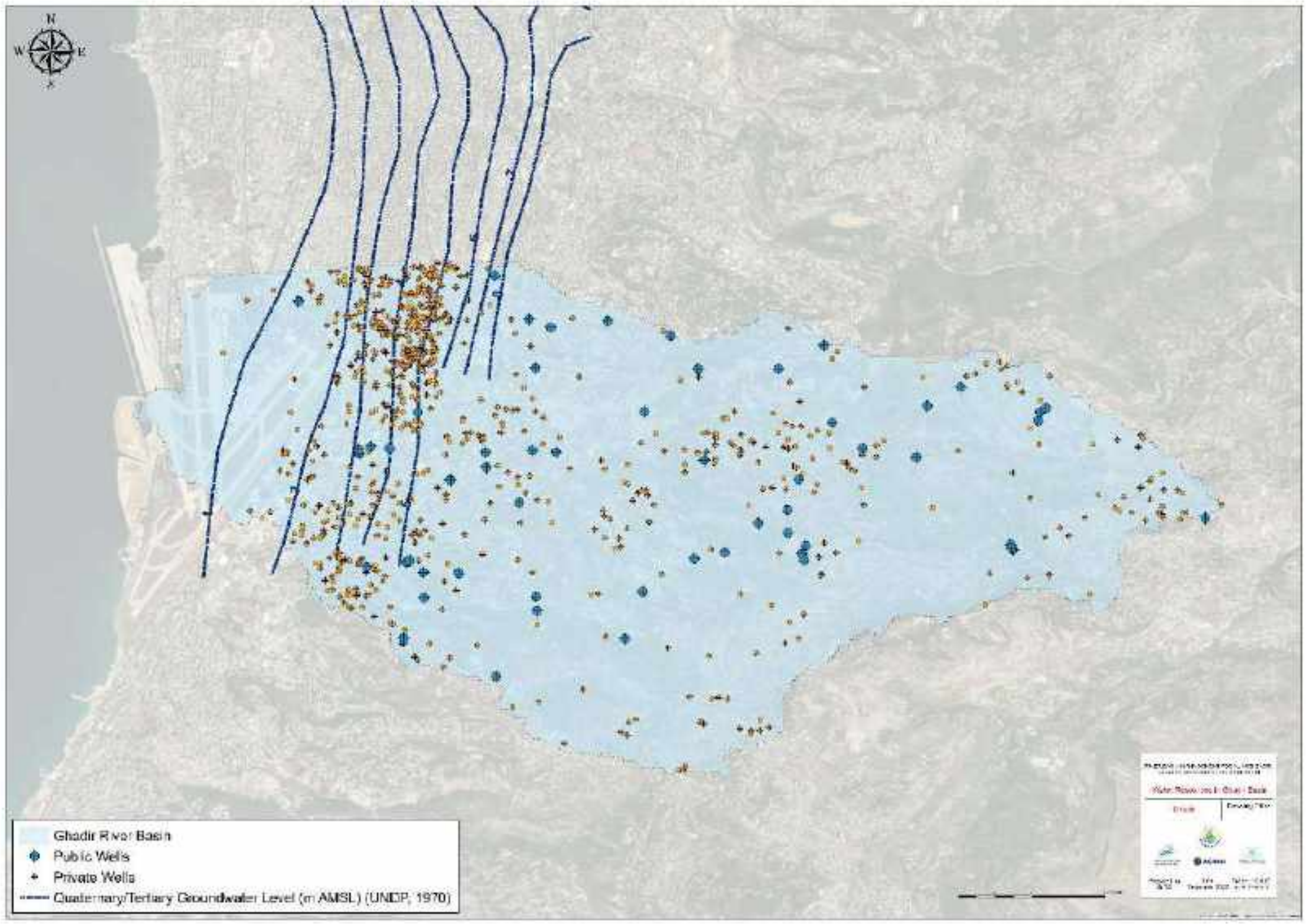

Figure 5 Public and private wells of GRB

2.3.2.3 Groundwater quality considerations

The reported extent of seawater intrusion in the year 1970 is shown in Figure 6. Within the study area, this extent reached 2000 to 2700m away from the shoreline. However, UNDP (1970) mentioned that the transition from freshwater to seawater is very gradual. Recent measurements can help indicating the current seawater intrusion extent. Groundwater salinity levels (as TDS) within Greater Beirut were reported to be over 5000 mg/l in some public and private wells (Saadeh, 2008). This concentration reflects a high salinity level, hence strong evidence of mixing with seawater in this case. Moreover, spot measurements carried out in 2015 (Figure 6) were still consistent with the 1970's seawater intrusion limit. However, it is anticipated that the current limit might be further inland than the one identified in the year 1970 due to water resources mismanagement (mainly reflected by groundwater over-abstractions) and land-use mismanagement (reflected by random and extensive urban growth). MoEW and UNDP (2014) stated that the freshwater-saltwater interface shifted further inland and is at a shallower depth than 1970. This statement is supported by the measurements carried out by BTD in 2020 for 22 wells tapping the Sannine Formation and located within and in the vicinity of the study area (UNICEF, 2022). As shown by Figure 6, the intrusion limit is most likely moving further inland as two wells located beyond the 1970's limit showed brackish groundwater (with average EC levels of 9601 and 18648 µS/cm). However, it is interesting to note that the 2020 field campaign also showed medium-brackish groundwater in three wells located near the shoreline (with average EC values varying between 3372 and 7606 µS/cm).

It is important to note that the complexities of the geological and structural settings have an important role not only in the recharge processes but also in regulating the seawater intrusion dynamics. In fact, faulting and folding structures can form conduits or barriers for groundwater recharge and/or seawater intrusion. Where present, the poorly permeable Senonian formation (C6) forms a screen which can locally limit the exchange between freshwater and seawater and which also confines the underlying limestone aquifers. However, the network of faults may still allow seawater intrusion in those areas.

Groundwater quality is also negatively affected by vertical pollution (i.e. infiltrating contaminants from the surface due to anthropogenic activities). The main sources of pollution in GRB include municipal and agricultural wastes, industrial effluents of pulp, paper, dyes, tans, batteries, ceramics, distilleries, car oils, stones and marbles and serum products and wastes from the farms of sheep and poultry (Mcheik et al., 2015a). Those effluents are mostly released to the river. Hence, sediments and soils became contaminated; the downward leaching of the pollutants may result in groundwater contamination (Mcheik et al., 2015b) especially in the lower course of the river (Mcheik et al., 2013).

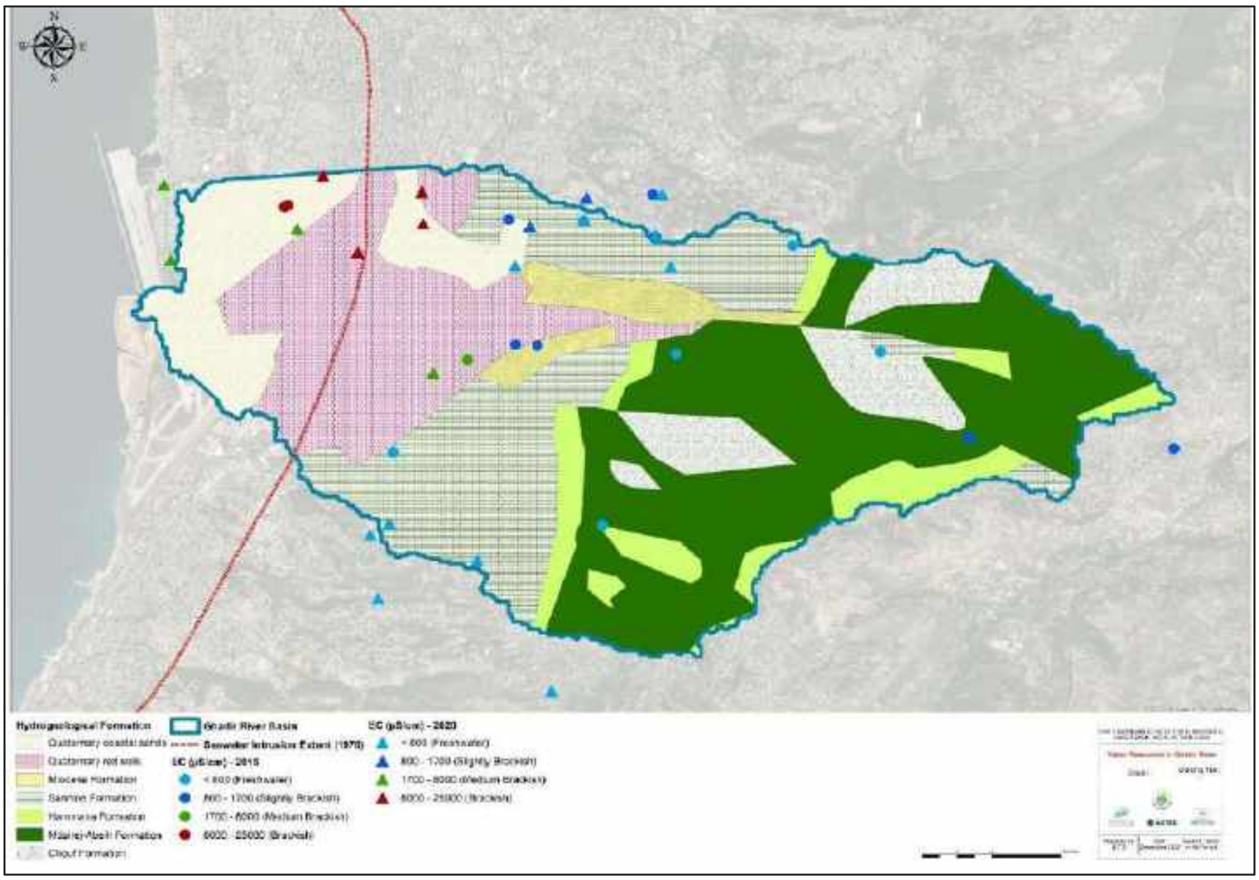

Figure 6 Seawater intrusion line (1970) and measured EC values (2015 and 2020)

2.3.2.4 Groundwater recharge and storage

According to UNDP (1970), around 21% of the rainfall contributes to the groundwater recharge of the Sannine Formation. However, this value might be greater due to the karstic nature of this aquifer. A recent study (Frem and Saad, 2021) produced a spatially distributed groundwater recharge map for Lebanon based on the GROWA model (Kunkel and Wendland, 2002). Based on the results of that study, 37% of the rainfall can contribute to the groundwater recharge of the Sannine Formation within the study area. Estimations for other formations show a natural recharge rate of 19% for the Miocene and Chouf formations, and 17% for the Abeih-Mdairej Formation. Due to the high urbanization coinciding with the outcropping areas of the Quaternary deposits, natural groundwater recharge into that formation can be assumed to be negligible (noting that leakage from wet utilities can be expected). Hence, a tentative maximum recharge rate of 5% can be assumed for the Quaternary Formation. From a structural geology perspective, Doummar et al. (2015) suggested that faults are possibly conveying most of the recharged water from the higher areas into conduits that were developed along them.

Storage was also estimated for the different permeable to semi-permeable formations. Hence, the subsurface extent of those formations as well as the average thickness were estimated based on the produced and available geological cross sections. In addition to the formation's geometry, information on storage coefficient were needed. With the absence of extensive pumping test data within the study area, the storage coefficient ranges were mainly assumed based on pumping test results reported by UNDP (1970) and tabled values (Domenico and Mifflin, 1965; Morris and Johnson, 1967; Heath, 1983). It is important to note that the range of storage values for the rock formations is wide since their storage coefficients may vary by orders of magnitude. Hence, the adopted average values are prone to uncertainties and should be cautiously used in context groundwater modeling or water resources management.

2.3.2.5 Groundwater abstractions

Error! Reference source not found. shows the spatial distribution of the public and private wells w ithin the study area.

According to the available data, it is expected that 30 public wells are operational within the extents of the GRB (BMLWE and BTD data). In the absence of well construction details (mainly screened/open interval), well depth can usually support the analysis aiming to predict which aquifer is tapped (with a reasonable level of certainty). 70% of the public wells are tapping the C4 aquifer (Sannine Formation) while the remaining wells are tapping the C1, C2 and Jurassic formations. The estimated total public abstractions for current domestic use (assuming 24 hours operation) are about 39000 m^3/d (noting that abstractions from the C4 aquifer alone accounts for about 31900 m^3/d). On average, public wells tapping the C4 Formation have an average yield of 63 m^3/h while those tapping the Jurassic Formation have a comparable yield of 62 m^3/h. On the other hand, public wells tapping the C1 and C2 formations have respective yields of 23 and 11 m^3/h. This observation is in-line with the fact that the C4 and Jurassic formations are the most important aquifers within the study area's subsurface and are hence expected to be the most productive aquifers, while C1 is considered as a semi-aquifer and C2 is divided into a semi-aquifer in its upper part (C2b) and aquiclude in its lower part (C2a). Doummar et al. (2015) highlighted that many operational wells are drilled along west/northwest – east/southeast trending faults. On another note, Mechref wells located outside of the study area are tapping the C4 aquifer. This information was included due to the importance of those public wells for GRB's water supply.

Basic data on 742 private wells were available from MoEW and UNDP (2014) as well as BMLWE. Well depths were reported for only 21% of those wells. Hence, almost one third of the private wells with depth information are expected to be tapping the Quaternary deposits (especially in the northwestern part of the study area), and another third is expected to be tapping the Sannine Formation. Figure 7 shows the depth distribution histogram of the private wells. Based on basic calculations performed by the authors, it can be seen that the majority of the wells (around 38%) are relatively shallow and have a depth of less than 50m. However, a considerable number of private wells (around 34% of them) is also tapping a depth of 100 to 150m. Out of the 742 private wells, only 51 wells had information on pumping rates. Basic statistics were performed on the available pumping rate data. Hence, it was found that the minimum abstraction is 5 m^3/d while the maximum abstraction is 86 m^3/d. On average, the abstraction per private well is 59 m^3/d (with a standard deviation of about 20 m^3/d). Estimating total abstractions from private wells is challenging due to uncertainty on the total number of wells (licensed and unlicensed), their operation mode, well diameter, pump capacity, well depth, etc.

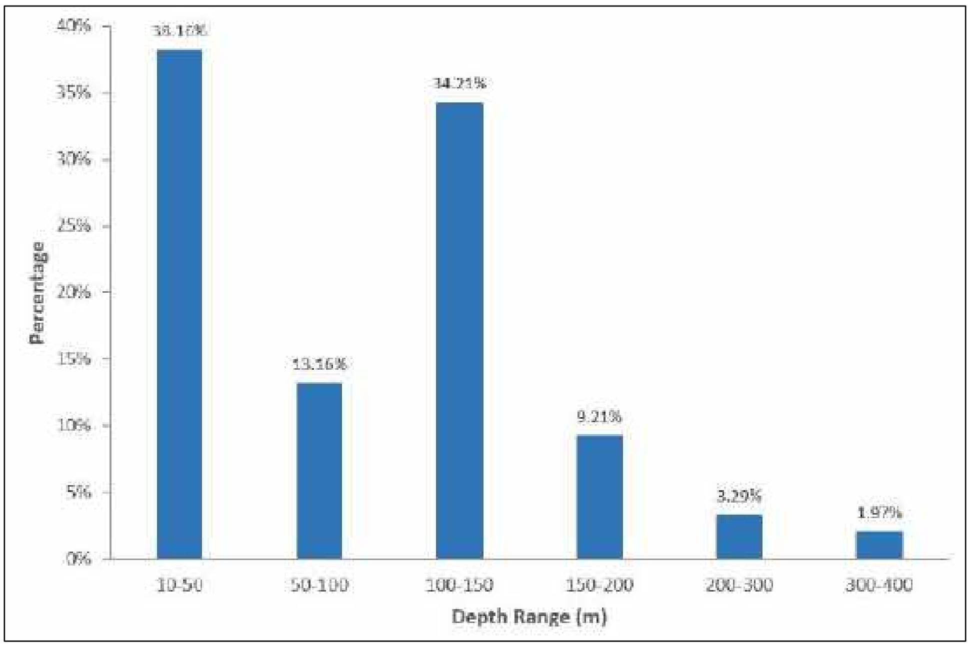

Figure 7 Depth distribution of private wells with depth information

2.4 Environment

2.4.1 LandUse and LandCover

Landscape refers to the natural scenery constituted of the visible features of a certain area. It comprises the physical elements such as landforms, living elements of fauna and flora, physical conditions like weather and water forms, and human elements such as human activity and the built environment.

A geospatial assessment was conducted in order to determine the LandUse and LandCover (LULC) composition of GRB area. The LandUse Classification was obtained from CORINE Land Cover CLC map of 2017 as a shapefile covering the area with different levels of aggregation.

GRB is dominated by approximately 43% of urban fabric. Other than the urban side, the basin also hosts the Airport (7%) and a number of industrial areas (6%) which include the Beirut Southern Suburbs, Choueifat/Kfarchima and Haadath/Baabda areas.

However, the basin also includes dense mixed wooded lands (at 18%) which constitute of (Pinus brutia the wild pine trees and Quercus calliprinos the common Oak trees). These patches of trees are native to the Mediterranean region. They are home to many wildlife species, namely migrant birds, insects, and mammals, which play an essential role in the hydrologic system as they mitigate the effect of other land-use on the riparian ecosystem and influence water quality variables at a catchment scale.

The remaining 28% of the basin is divided among pines (5%), grasslands (3%), Olives (3%), fruit trees (2%), field crops (2%), scrubland (6%), and others.

It is concluded from the LULC distribution that the GRB exhibits typical urban characteristics with high presence of industrial and commercial areas and low presence of wooded lands.

Table 4 GRB Land Use class by area ratio

LULC Type	Percent Distribution in GRB
Medium density Urban fabric	19%
Dense Urban Fabric	19%
Dense Mixed Wooded Lands	18%
Airport	7%
Industrial or Commercial Areas	6%
Scrubland with some dispersed bigger trees	5%
Dense Pines	3%
Clear Grassland	3%
Olives	3%
Fruit Trees	2%
Clear Pines	2%
Diverse Equipment	2%
Field Crops in Small Fields/Terrace	2%
Clear Mixed Wooded Lands	2%
Low Density Urban Fabric	2%
Scrubland	1%
Others	3%

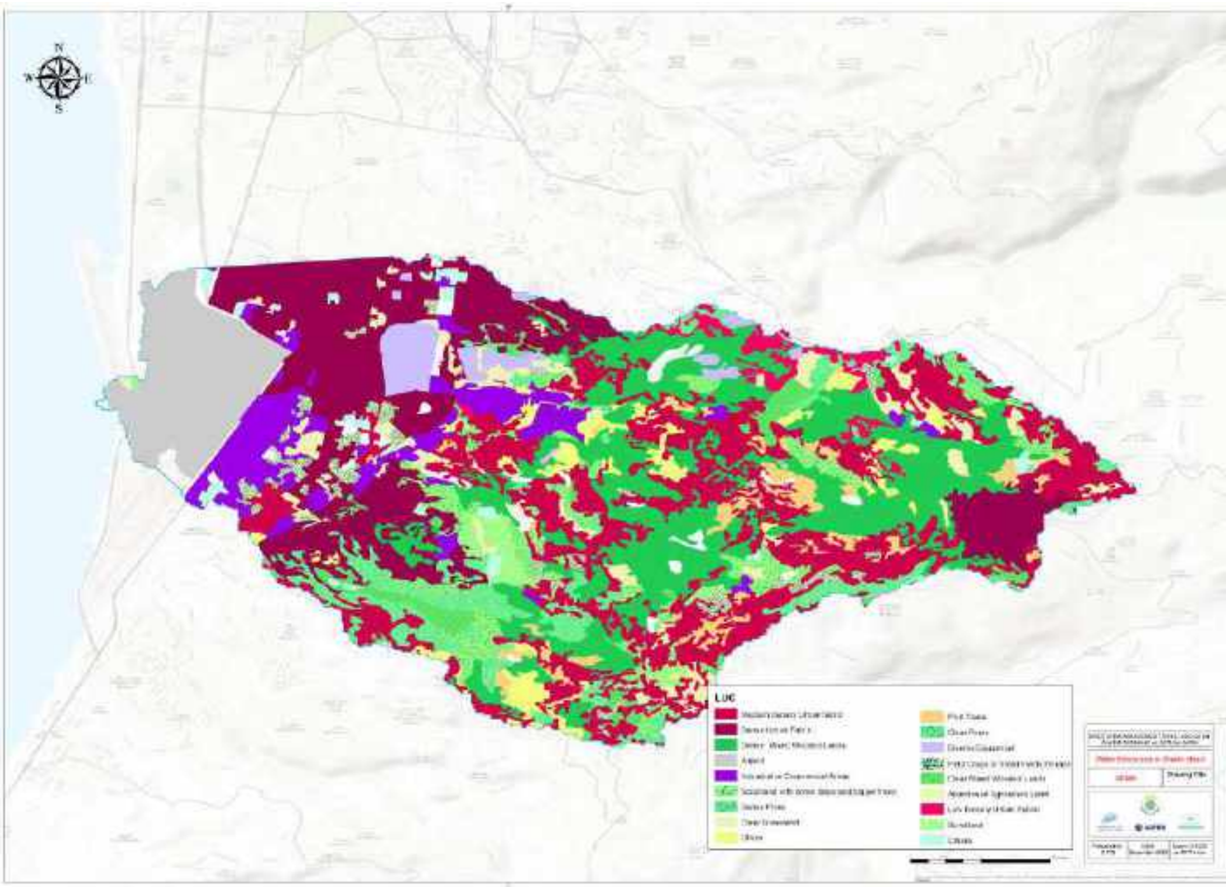

Figure 8 LandUse classification in GRB

2.4.2 Wastewater Collection and Treatment

Ghadir Wastewater Treatment Plant is located in the cadastral area of Baabda, belonging to Mount Lebanon Governorate. It is designed to achieve preliminary treatment level with a design capacity of 224 640 m^3/d and current capacity is 55 000 m^3/d with provision for an extension with an additional treatment line. Ghadir plant is a two lines conventional pretreatment plant that consists of a coarse screening followed by grit/grease removal.

Ghadir WWTP receives water from Damour pumping station which receives the water from Meshref pilot city, Naameh pumping station which receives water form heights of Khaldeh, Dawhet AL Hoss, West Shahar and Al Mabarat region. In addition, Ghadir treatment plant receives water form Khaldeh pumping stations which in turn receives water from Khaldeh region.

Data collected from the CANA-CNRS by ELARD in the ESIA in 2012 for the extension of Ghadir WWTP, seawater quality in the area of the basin and the plant was assessed. The results showed that the pre-treated water discharged from Al-Ghadir WWTP is always loaded with all sorts of contaminants and that an upwelling of contaminants from bottom till surface is taking place throughout the water column.

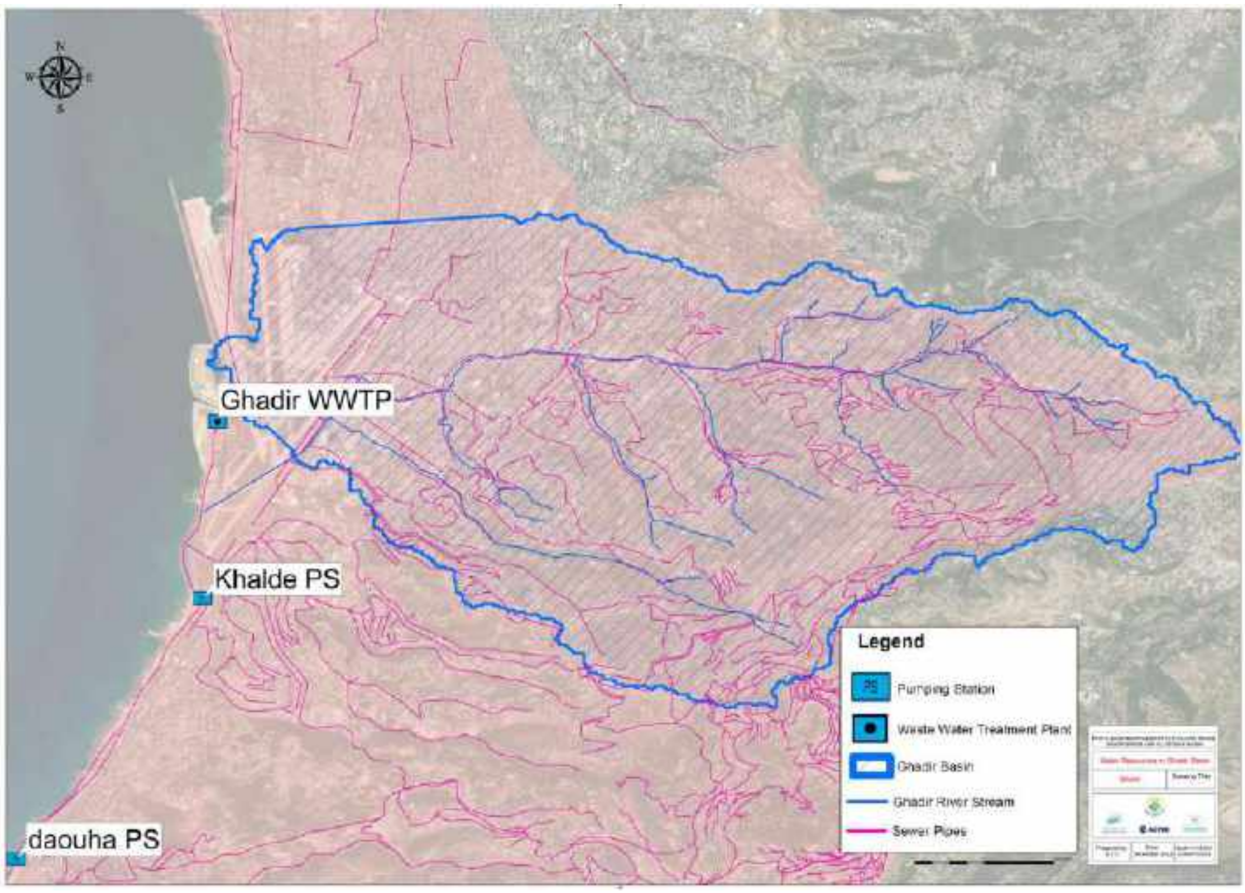

Figure 9 Ghadir wastewater system and WWTP at CostaBrava and main pumping stations

Since 2022 and until the redaction of this report, the plant is not operational because the pumping stations that feeds the plant don't have energy source. As a result, the flow reaching the plant is not enough to operate it even though the station has a direct service electrical line from EDL. Also, because of the worsening of the economic crisis in Lebanon, the operator doesn't have the needed budget to afford fuel for the generator. The operator is performing the minimal maintenance needed to preserve the equipment. During these non-functional hours the flow is directed to the overflow without any treatment. The flow rate to the existing wastewater treatment facility increases during periods of intense rainfall. Extreme rainfall or wet weather events can generate large quantities of stormwater, which are entering the wastewater collection system mainly via sewer manholes.

Figure 10 *Ghadir WWTP coarse screens*

2.4.3 Quarries and Dumpsite

A total of 4 dumpsites and 3 quarries exists inside GRB, divided among the villages as shown in Table 5. All of the 4 dumpsites are operational and accept only Municipal Solid Waste, and out of the 4, 3 are located in private lands and the remaining one is situated in communal land (e.g., Mashaa land belonging to the monasteries) (see Table 6).

Out of the 3 quarries, 2 do not have a legal license to operate and both are currently operational (see Table 7). The other one legal quarry is operational.

Table 5 Distribution of number of dumpsites and quarries within GRB villages

Villages	Dumpsite	Quarry
Aaytat	2	2
Bsous	1	-
Kahhale	1	-
Bmekkin	-	1

Table 6 Condition of dumpsites within GRB

Status	Number of Dumpsites
Operational	**4**
Municipal Solid Waste (MSW)	**4**
Machaa/Communal Land	1
Other	1
Private Land	3
Industrial	1
No information	1
Residential	1
Grand Total	**4**

Table 7 Condition of quarries within GRB

Licensing	Number of Quarries
No	**2**
Operational	2
Yes	**1**
Operational	1
Grand Total	**3**

2.4.4 Water Quality

Lebanon depends on water for agriculture (60%) and municipal (29%) and industrial uses (11%). In addition, it has been estimated that 45% of the irrigated land in Lebanon depends on surface water as a primary source. As a result, water pollution in Lebanon poses a significant risk to public health and the economy.

In general, use of contaminated water has been linked to outbreaks of severe disease. Widespread pollution from untreated sewage has raised concerns about water quality in Lebanon, a country with well-documented infrastructure problems.

In addition, Lebanon's water is increasingly at risk from pollution, mainly due to (1) population growth, including an influx of ~1.5 million refugees (~1 refugee per 4 nationals) since 2011, (2) poor wastewater and solid waste management, and (3) the absence of monitoring and surveillance programs (Dagher et al., 2021).

In the context of Ghadir river and basin, a study done by the Lebanese University (Mcheik et al., 2013) showed that a high degree of pollution and general degradation is found in the river. The quantities of heavy metals found in the river water were in the range: Cd (5.28-20.078 µg/l); Cr (10.4-32.43 µg/l); Cu (2.8-14.22 µg/l); Fe (2043.4-18705.1 µg/l); Mn (7.5-21.58 µg/l); Pb (20.5-45.45µg/l); Zn (5.805-15.4 µg/l), respectively. The water pollution is mainly related to parameters indicators of organic pollution from urban sewage. In sediments, higher concentrations of trace metals were found in different points. A new sampling campaign in the context of this study has been carried out on December 15th and results are detailed in section 2.6.

In another study, Mcheik et al., 2017 assessed the domestic water profile of the region surrounding Ghadir River at Kfarshima and Al-Sahra. Samples were taken from 3 types of domestic water sources (municipal water, private wells and water sold gallons) and evaluated in terms of their physicochemical and bacteriological profile. The results showed a pattern of deterioration in the water quality profile in three sources. The measured physico-chemical and bacteriological parameters point to degree of contamination to private sources of wells near the sea and sewage infiltration.

High densities of fecal coliforms and fecal streptococcus colonies were measured at the surface of seawater (>200 cfu/100mL with the guide value being set at 100 cfu/100mL, accompanied by high levels of chlorophyll. These concentrations were greater than those usually measured in oligotrophic regions. Seasonal thermocline, natural barrier, did not prevent the ascending of contaminants up till surface when it existed.

The pollution in the Ghadir river has several consequences:

- Families face the risk of respiratory disease and cancer,
- The smell of toxic waste spread across the area, especially in the summer,
- The river floods the houses and shops in the winter, and the area is a hotspot for future pandemics.

2.4.5 Air Quality

The ambient air pollution can be a significant source of pollutant input to surface water.

In the context of nitrogen dioxide (NO2) air pollutant presented in this project, studies show that precipitation is a significant source of nitrogen in surface waters, and the significance of the associated pollution appears to be a function of increased industrial or agricultural activity. Atmospheric input of nitrogen from the air can come from windblown dust from fertilized soil, from direct fallout of pollutant emissions from fossil fuel combustion, and from precipitation (rainfall).

Atmospheric air quality data was collected from the Sentinel 5P Tropomi Satellite which provides daily freely publicly available near real time data for various gases in the atmosphere. The satellite was launched in 2018, the mean tropospheric NO2 column density was calculated using the Google earth engine code java script editor resulting in Figure 11 which shows the mean NO2 values in mol/m^2 across the border of Lebanon between year 2018 up to December 2022. In the big picture, it is clear from the legend that the NO2 pollution is concentrated above the Beirut area and decreases when moving east to reach its lowest value in the eastern Bekaa plain and in Baalbek and Hermel districts.

The border of GRB, highlighted in white in Figure 11, is located within Baabda and Aley districts, which are both highly urbanized cities and host a multitude of industrial areas as a result of the coastal location and proximity to Beirut. It is obvious from the land characteristics of GRB (refer to LULC map in Figure 8) that the area is highly polluted and this is confirmed by the high concentration or column density of NO2 in the atmosphere above the basin.

Finally, an NO2 timeseries was plotted (Figure 12) comparing pollution in GRB (located within Beirut surrounding) and relatively cleaner areas in Bekaa and Hermel. It is clear from the results that the Ghadir basin (located in Baabda and Aley districts) witnesses a very high NO2 concentration with large daily fluctuations, the pattern is better expressed when compared to the clean areas as shown below. This analysis enables us to conclude, aside from the industrial and domestic raw sewage discharge into the surface water bodies, that the probability of Ghadir river to be polluted from ambient air pollution in the area is very highly probable.

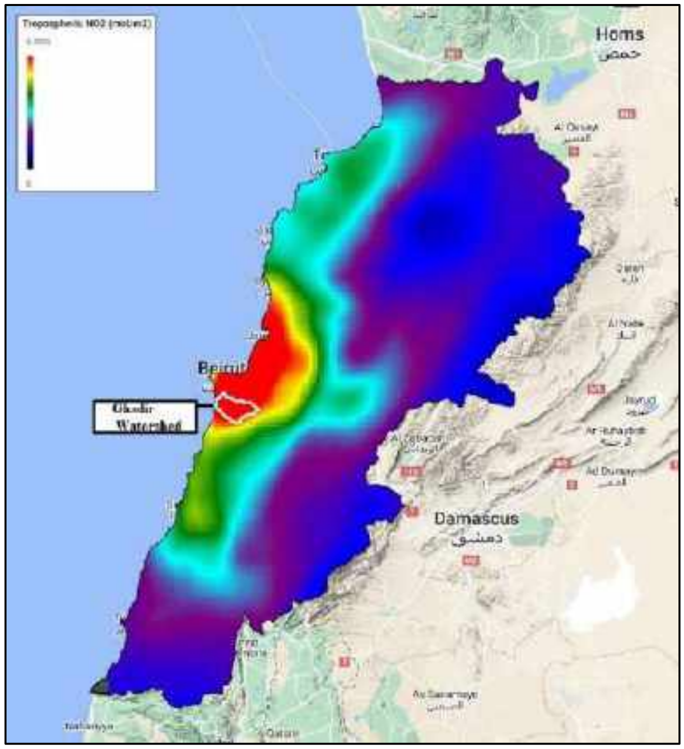

Figure 11 Distribution of air pollutant Nitrogen Dioxide (NO2) in the troposphere above the Lebanese border average from year 2018 up to October 2022 (data retained from Sentinel-5 precursor/TROPOMI Level 2 Product)

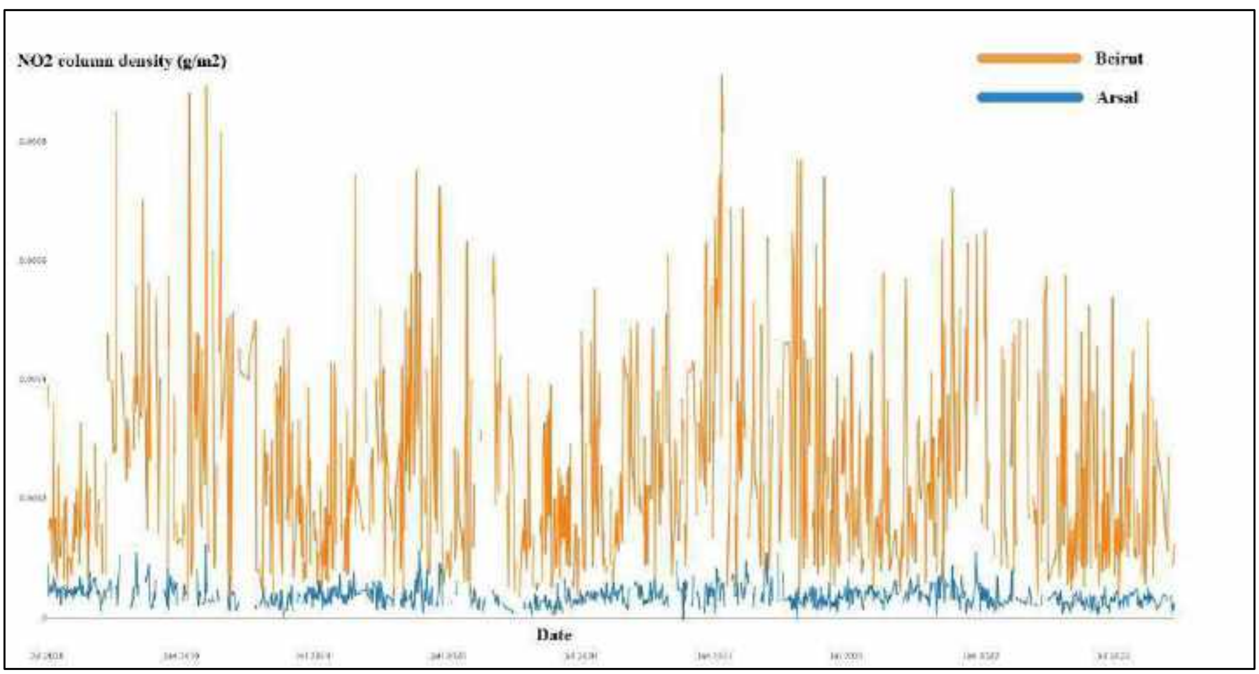

Figure 12 Time series comparing level of NO2 in the troposphere between Beirut (GRB area) and a relatively pollution free area in North Eastern Lebanon (data retained from Sentinel-5 precursor/TROPOMI Level 2 Product)

2.4.6 Socioeconomic Environment

2.4.6.1 Demographical Profile

The survey results (CAS 2020) show that in 2018 – 2019, the caza of Beirut hosted 7.1 % of residents of Lebanon despite its relatively small geographical size, with around 341,700 residents. 54 % of the residents were females and 46% males. Almost 50% of the residents in Beirut were found in the age group 25–64 years. The younger residents of less than 24 years old represented 34.3 % of the total, whereas the older residents (65+ years old) represented 16.5%.

2.4.6.2 Connectivity to infrastructure and utilities

Non-piped water supply was the main source of drinking water in Beirut (91.9 %) and more prevalent at the district level than the national level (76.9%). On the other side, piped water supply was among the lowest at the caza level: for only 8.1% of households, drinking water was in the form of a supply piped directly to the residence.

Table 8 Yearly expenditures on services for main dwellings (in thousand LBP)

Services	Beirut		Lebanon	
	Mean	Median	Mean	Median
Public water	330	316	293	300
Electricity	985	720	671	480
Generator	1070	900	1100	900
Satellite/Dish	249	240	231	240
Fixed phones (without internet)	453	360	433	360
Total yearly Expenses on services	3568	3170	3308	2940

2.4.6.3 Work and Employment

In Figure 13 on unemployment rate by governorate, the light orange columns present the data for 2018-2019, and the dark orange columns the data for 2022. It can be observed that the unemployment rate increased in all governorates without exception. The largest increase was in Baalbek-Hermel from 11% to 40%. In Beirut area, the unemployment rate increased by approximately 10%, and is now at 24.8%, which is below the national figure of 29.6% (LFS 2022).

In Figure 14, the services sector was the largest employment sector for women and men, with respectively 95.7% and 81.8 % in Beirut, compared to 91.7% and 68.8 % in Lebanon. In this sector, women surpassed men by 13.9 % points at the caza level. It was particularly noticeable that 17.8 % of working men and 4.1% of working women were employed in industry in Beirut, compared to 26.6 % of working men and 6.7% of working women in the whole of Lebanon. Agriculture in Beirut was almost absent for both men and women. (CAS 2020).

In Figure 15, it is shown that about one third of households in Beirut (30.3%) had a total income from all sources ranging between 1,200 and 2,400 thousand LBP (equivalent to $800 and $1,600 when 1$ = 1,500L.L. , a proportion almost equal to that observed at the national level (29.7%). That was followed by almost an equal distribution of households at the caza level who had total earnings between [2400 5000[and [650-1200] thousand LBP income ranges (22.8% and 22.6% respectively).

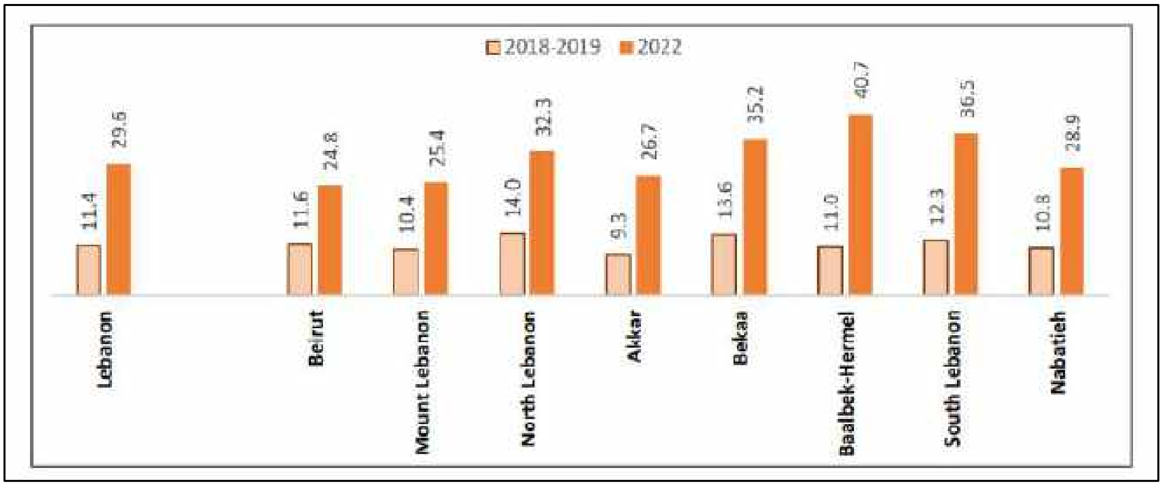

Figure 13 Unemployment rate by governorate, LFHLCS 2018-2019 and LFS 2022 (%)

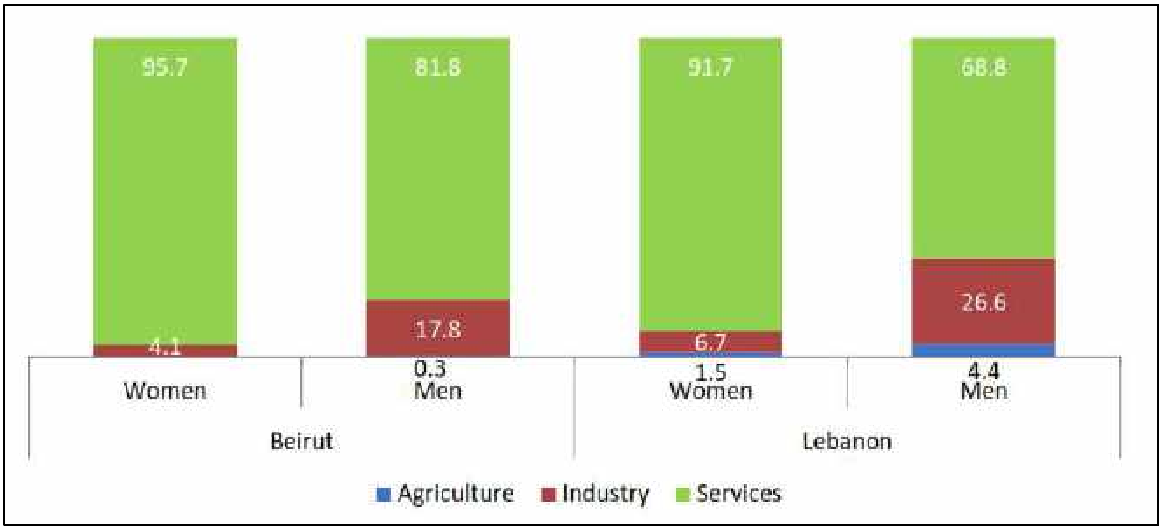

Figure 14 Economic activity sector by sex (%)

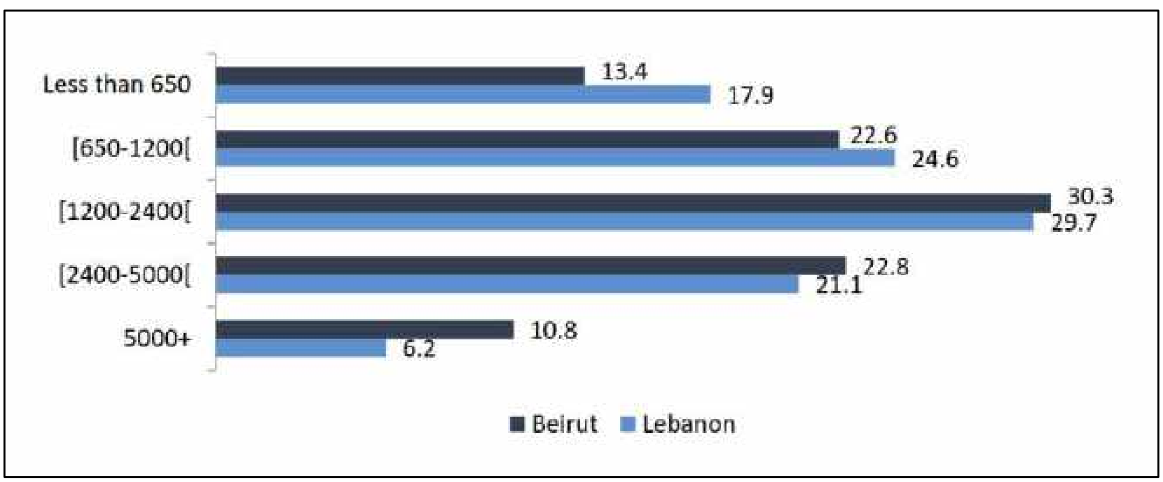

Figure 15 Household income range from all sources Percent in the month preceding the Survey in thousand LBP (%) (1$ = 1,500LBP)

2.5 Water supply

2.5.1 Water systems, villages, population and water demand

In order to estimate the future population living in the basin, the following formula was adopted from the updated NWSS 2020 and applied to each village population:

$$P_t = P_0 e^{\alpha t}$$

Where:
- P_t = Population at time t
- P_0 = Population at time 0 (year 2020)
- α = growth rate (1.5% for rural areas and 0.75% for urban areas)
- t = time period in years

According to the updated NWSS – 2020, the drinking water demand per capita in 2035 was set as follows:

- Domestic consumption: 125 l/cap/day
- Non-Domestic = 20 % of the domestic 25 l/cap/day

150 l/cap/day

- Physical losses = 25 % of the total needs 50 l/cap/day

Total needs 200 l/cap/day

There are 11 different water distribution systems that are partially or totally included within GRB. Each water system consists of one or more villages from Baabda and Aley casas. The villages and population of the 11 water distribution systems are shown in Table 9 below.

GRB accommodates in 2020 a total of 309,455 persons with an estimated water need of 61,891 m^3/d. In 2035, the future population living within the basin is supposed to reach a total of 350,735 with an estimated water need of 70,147 m^3/d.

Table 9 GRB water distribution systems

ID	Water System Name	Total population of the water system	Ratio of the water distribution system population that falls within GRB	Served population within GRB		Demand of the served population (m^3/d)	
				2020	2035	2020	2035
1	Raayan	229968	15%	34495	41433	6899	8287
2	Bsous	3215	100%	3215	4026	643	805
3	Choueifat	94810	90%	85329	95489	17066	19098
4	Ain El Delbe	150415	40%	60166	67946	12033	13589
5	Bsaba	1700	100%	1700	2129	340	426
6	Daychouniyeh	393461	23%	88529	99070	17706	19814
7	Boutchay	681	100%	681	853	136	171
8	Kfarchima	21258	100%	21258	23789	4252	4758
9	Bleibel	948	100%	948	1187	190	237
10	Deir Qoubel	1735	50%	868	1086	174	217
11	Mechref wells	204446	6%	12267	13727	2453	2745
Total				**309455**	**350735**	**61891**	**70147**

2.5.2 Water Sources

The water systems mentioned above are supplied by their own wells and springs located within or beyond GRB. There are several sources of water located within GRB; 30 in total. The locations of these water sources are shown on the map in Figure 16 below.

Table 10 List of wells located within GRB (NWSS 2020)

Well Name	Status	Total Yield for domestic use (m^3/d)	Water Distribution System	Extracted yield for resident population (m^3/d) 2020	2035
Baabda	In service	1037	Ain el Delbe	207	207
Jamhour	In service	1123		1123	1123
Wede Chahrour 2	In service	518		518	518
Wadi Chahrour 1 Well	In service	3024		3024	3024
Bleibel	In service	1901	Bleibil	1901	1901
Betchay well 1	In service	691	Boutchay	691	691
Bsaba Well	In service	1296	Bsaba	1296	1296
Bsous Well	In service	86	Bsous	86	86
Al rayess well	In service	3888	Choueifat	3888	3888
Kartoun Well	In service	1469		1469	1469
Choueifat well richani	In service	2765		2765	2765
Haret El Qobbe	In service	346		346	346
Haret El Qobbe - Qobbeh (Choueifat)	In service	1210		1210	1210
Richane (Chouaifet)	In service	2419		2419	2765
Saab 1	In service	2592		2592	2592
Saab 2	In service	3888		3888	3888
Zakka	In service	778		778	778
Deir Qoubel 2 - School well	Out of Service	0	Deir Qoubel	0	6
Deir Qoubel 3	In service	259		130	130
Deir Qoubel Well	In service	518		259	259
Antounieh	In service	1123	El Daychounieh	258	258
Kanaan Well	In service	1123	Kfarchima	1123	1123
Oussaily Well	In service	3370		3370	3370
Houmal	In service	173	Raayan	173	173
Ain Aanoub (Maaroufiye)	In service	1728		1728	1728
Bdedoun	In service	173		173	173
Qmatiye	In service	173		173	173
Qmatiyeh 1	In service	173		173	173
Qmatiyeh 2	In service	346		346	346
Kahaleh	In service	864		864	864
TOTAL		**39054**		**36971**	**37323**

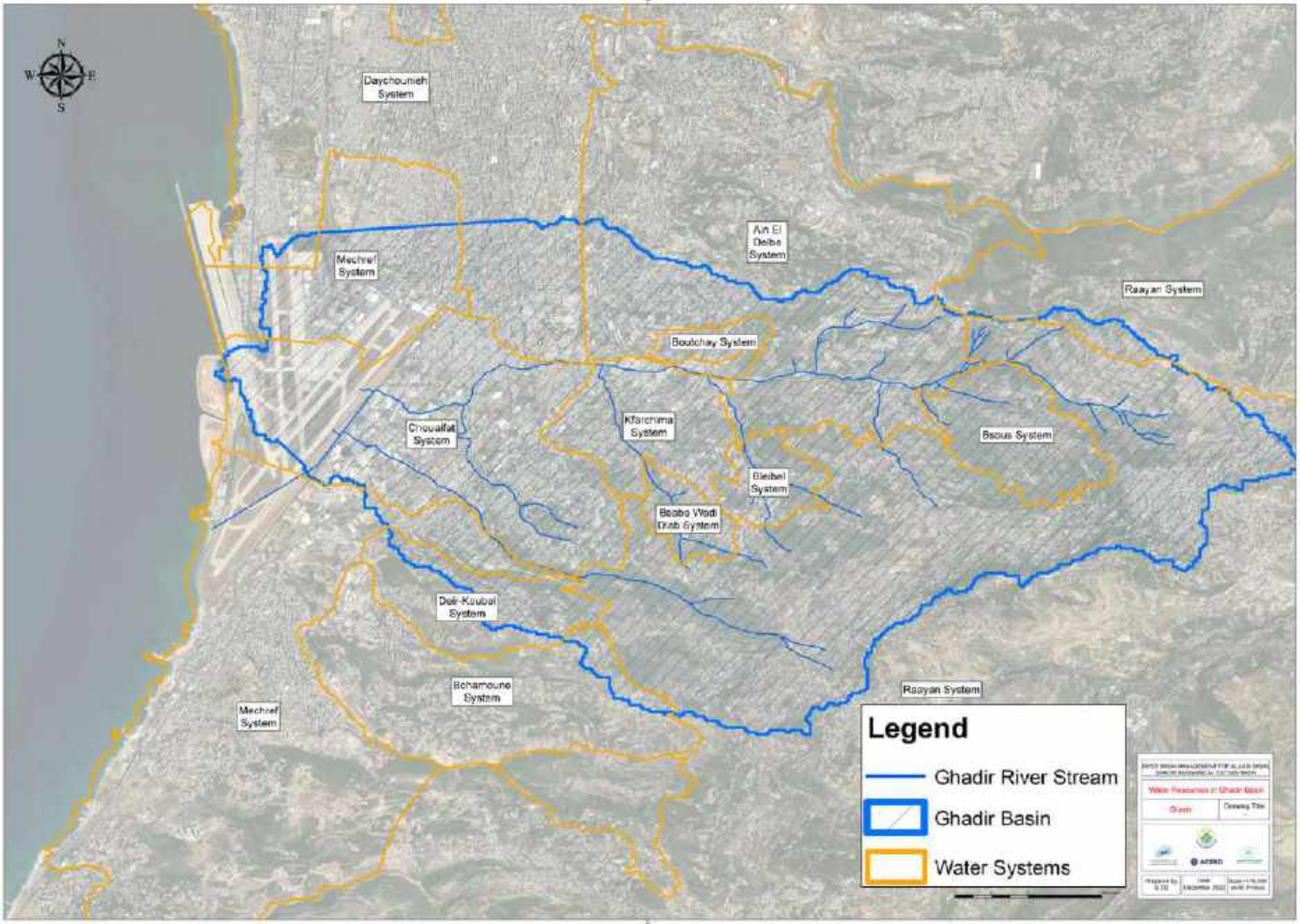

Figure 16 *GRB water distribution systems*

As we can see from the table above, the wells are supplying a total flow of 36,971 m^3/d to feed the population living within the basin while a flow of 2,083 m^3/d is diverted to feed the population living outside the basin. In 2035, additional flow will be extracted from Richane wells. to reach a total flow of 37,323 m^3/d. It is worth noting that these flows were estimated under optimal operation conditions of 24 hours continuously to cover the deficit with the current infrastructure and management.

There are 4 tapped springs falling outside GRB that are supplying the basin with domestic water. Der Qoubel spring is currently out of service and not feeding the system. In addition, Mechref wells are also contributing with a small part in Ghadir, specifically Bourj el Barajnet. Hence, a total flow of 8,237 m^3/d is currently diverted from external springs which is expected to increase to 9,625 m^3/d in 2035, see Table 11.

Table 11 List of external sources supplying GRB

Source Name	Status	Average Discharge (m^3/d)	Total Exploited flow for domestic use (m^3/d)	Water Distribution System	Exploited flow for resident population (m^3/d)	
					2020	2035
Raayan spring	In service	120000	17000	Raayan	3269	4657
Ain el Delbe spring	Only in winter	20400	6000	Ain el Delbe	2400	2400
Daychounieh spring	In service	39000	6000	Daychouniyeh	1380	1380
Deir Qoubel spring	Out of service	-	0	Deir Qoubel	0	0
Mechref Wells	In service	19800	19800	Mechref wells	1188	1188
Total					**8237**	**9625**

The deficit in GRB water supply is remarkable as the total supply in 2020 is 45,208 m^3/d while the total demand is 61,891 (m^3/d). However, at the water distribution system level, some are in excess like Raayan system while others are in deficit like Bsous, Ain el Delbe, Daychounieh and Mechref wells. These deficits shall be covered by Awali project in 2035. Table 12 below shows the deficit within GRB of each water distribution system.

Table 12 Total deficit by water distribution system

ID	Water System Name	Demand of the served population (m^3/d)	
		2020	2035
1	Raayan	0	0
2	Bsous	-557	-719
3	Choueifat	0	0
4	Ain El Delbe	-4761	-6317
5	Bsaba	0	0
6	Daychouniyeh	-16068	-18176
7	Boutchay	0	0
8	Kfarchima	0	-265
9	Bleibel	0	0
10	Deir Qoubel	0	0
11	Mechref wells	-1265	-1557
Total		-22651	-27034

2.6 Agriculture

2.6.1 Historical background

Before the 1950s, GRB landscape was mostly agricultural. The Sahra Choueifat area, where the river goes through, was known for its olive groves, which according to its long-time residents, produced the highest quality of olive oil.

Overtime, the area slowly transformed from an agricultural landscape into a residential and industrial one. Between 1950 and 1975, two major events caused a shift in the landscape of the area surrounding Ghadir river. First, the area became more residential due to a wave of rural-urban migration from Beqaa to Sahra Choueifat area. Second, Choueifat and Kfarshima areas witnessed the construction of large factories and intensification of industrial activities especially along the riverbanks after both areas have been classified as industrial zones in the zoning plan for the Greater Beirut Area. Reference??

2.6.2 Modern irrigation development

Despite being one of the region's most significant practices in the past, agriculture has experienced a decline in recent years due to urbanization and the shift towards industrialization. As a result, there has been a reduction in the amount of agricultural land available. Nonetheless, the basin still has two distinct types of agriculture: arable fields located in the coastal area and terraced olive and fruit orchards in the foothills.

2.6.3 Main crops and available cultivated areas

The cultivated area can be assessed through remote sensing from Corine Land Cover. The 'Coordination of information on the environment' (Corine) is an inventory of European land cover split into 44 different land cover classes. Corine also shows the changes between classes over four periods since 1990. Both land cover and land cover change are shown at high resolution on a cartographic map.
CORINE Land Cover CLC map of 2017, revealed the existence of some 430 ha of cultivated land as per the following breakdown in Table 13.

Table 13 Type of crops in GRB as per CLC 2017

Type of Crops	Ratio of cultivated land (%)
Olive trees	34.9%
Fruit trees	29.6%
Field crops	29.5%
Protected agricultures	5.5%
Citrus fruits	0.5%
Total	100%

Within the scope of the present study BTD has identified by examining the August 2022 Google Earth LandSat satellite images, some 347 ha of cultivated land, refer to Figure 17 below.

The repartition of the cultivated area according to altitude is as follows:

- Cultivated area located below contour line 250mm: 129 ha
- Cultivated area located between contour line 250mm and contour line 500: 141 ha
- Cultivated area located above contour line 500mm: 77 ha

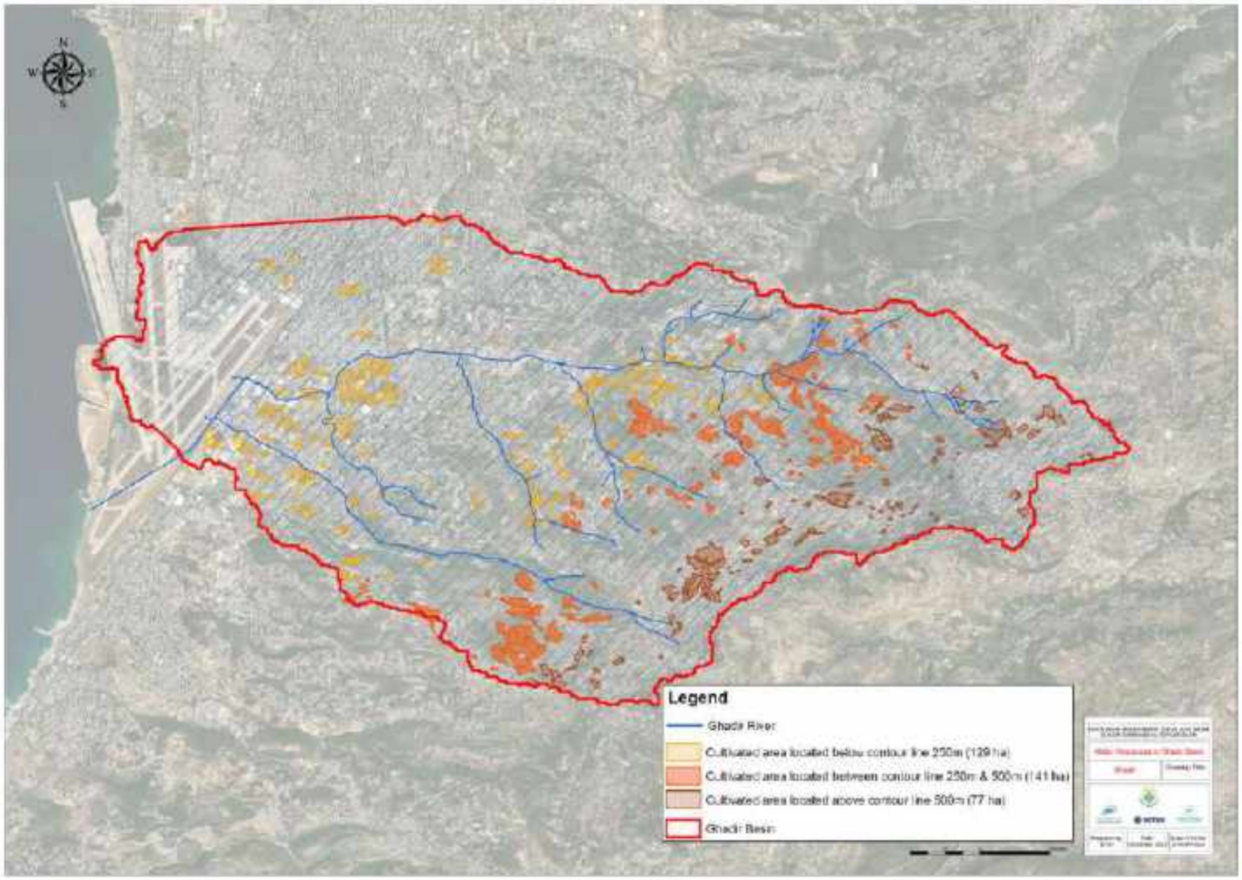

Figure 17 GRB cultivated areas

Based on the knowledge of the study area and on available information, crop distribution over the cultivated area would be as follows:

Table 14 Type of crops in GRB as per Satellite images of 2022

Type of Crops	Gross area Ha	Irrigated area Ha
Olive trees	122	0
Fruit trees	102	41
Field crops	102	51
Protected agricultures	19	16
Citrus fruits	2	1.5
Total	347Ha	110 Ha

Monthly Crop coefficients (Kc) were assigned from previous experience with a deeper analysis for the agricultural areas. Kc usually ranges between 0.1 & 1.2 according to the land cover as defined by FAO and plant life cycle (FAO, 1998). With this in mind, a weighted average was computed considering the area covered by these, as seen in

Table 15.

Table 15 Monthly crop coefficients Kc for agricultural areas

Type of Crops	Gross Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Olive trees	122	0.2	0.2	0.3	0.3	0.4	0.7	0.8	0.95	0.9	0.5	0.3	0.2
Fruit trees	102	0.2	0.2	0.3	0.3	0.4	0.7	0.8	0.95	0.9	0.5	0.3	0.2
Field crops	102	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.4
Protected agricultures	19	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Citrus fruits	2	0.2	0.2	0.3	0.3	0.4	0.7	0.8	0.95	0.9	0.5	0.3	0.2
Average Kc	347	0.27	0.26	0.33	0.33	0.40	0.54	0.61	0.71	0.68	0.42	0.30	0.25

2.6.4 Irrigation considerations

2.6.4.1 Origin of water – irrigation method

Actually, in the last decades, the project area witnessed the drilling of more than 700 private wells (UNDP 2014) distributed as follows:

- Below contour line 250 m 605
- Between contour line 250 – 500 m 49
- Above contour line 500 m 91

2.6.4.2 Reference Evapotranspiration

Evaporation and transpiration are the primary abstractions of the hydrological cycle. These abstractions are minor during a runoff event and can be neglected. The bulk of evaporation and transpiration takes place during the time between runoff events, which is usually long. Hence, these abstractions are the most important during this time interval. The combined effect of evaporation and transpiration is called evapotranspiration (ET), defined as the water vapor produced from the basin as a result of the growth of plants. There is an important difference between evapotranspiration and free surface evaporation. Transpiration is associated with plant growth and hence evapotranspiration occurs only when the plant is growing, resulting thereby in diurnal and seasonal variations. Transpiration thus superimposes these variations on the normal annual free water-surface evaporation.

The FAO Penman-Monteith (FAO-PM) method has been considered as a universal standard to estimate ET_0. It considers many meteorological parameters related to the evapotranspiration process (net radiation, air temperature, vapor pressure deficit, wind speed).

The FAO-PM method to estimate ET_0 on daily basis can be derived as (Allen et al., 1998):

$$ET_0 = \frac{0.408\,\delta(R_n - G) + 900 y u_2 (e_s - e_a)/(T + 273)}{\delta + y(1 + 0.34\,u_2)}$$

Where :
ET_0 : reference evapotranspiration [mm day^{-1}],
R_n : net radiation [MJ m^{-2} day^{-1}],
G : soil heat flux density [MJ m^{-2} day^{-1}],
T : mean daily air temperature at 2 m height [°C]
u_2 : wind speed at 2 m height [m s^{-1}],
e_s : saturation vapor pressure [kPa],
e_a : actual vapor pressure [kPa],
es-ea : saturation vapor pressure deficit [kPa],

Δ : slope of the vapor pressure curve [kPa°C^{-1}],
y : psychrometric constant [kPa°C^{-1}].

The water balance and Evapotranspiration values in Table 16 for the study area have been adopted from Bhamdoun and Beirut International Airport CLIMWAT 2.0 for CROPWAT (FAO) database and can be summarized as follows:

Table 16 Effective rain, ET_0 and water balance in GRB

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Eff. Rain	143	128	111	62	28	1	0	1	4	47	89	130	743
ETo	57	58	83	106	139	165	177	173	132	100	71	61	1322
Balance	86	70	28	-44	-111	-164	-177	-172	-128	-54	18	69	

The ET_0/Effective rain balance for the study area is negative from April till October, consequently, the irrigation season for the study area is from early May till early October and lasts approximately 6 months, keeping in mind that April irrigation water requirements are mostly covered by the available field capacity, whereas October requirements is sometimes covered by early rains.

2.6.4.3 GRB global irrigation water requirements

The net water requirements for each dominant crop can be calculated taking into consideration the agroclimatological data, the existing cropping pattern representative of the study area as well as the corresponding crop coefficients Kc for the appropriate growth stage of each cultivated plant in the study area.

In similar cultivation areas, the irrigation gross water requirements of one hectare are close to 7500 m^3/ha/year. Consequently, the total irrigation water requirements for the study area is:

$$7500 \text{ m}^3\text{/ha/year x 110 ha} = 825{,}000 \text{ m}^3\text{/year}$$

The above value represents irrigation water requirement (demand). The effective water use is likely to deviate from this value and to be around 70%, hence 575,000 m^3/year due to water scarcity.

3 Water Quality Sampling Campaign

3.1 Description

A sampling campaign for water quality check was carried out on the 15th of December 2022 by NDU Laboratory team in coordination with BTD and ACTED. This section will only present a brief summary of the campaign including main results. The complete report is attached in Appendix A.

The first campaign was made over the start of winter season to show compliance with established criteria. A second campaign will be carried out in mid-season and compared to the first campaign results to highlight any seasonal variability.

The sampling plan and location were prepared in a way to guarantee representative samples, thus providing an accurate description of the overall quality of the water in GRB.

Furthermore, sampling sites were located in areas that are safe to access, accessible under all conditions of flow, and well mixed to ensure a homogenous sampling collected is easily identifiable for later sampling.

Permanent sampling locations were chosen by BTD to ensure that representative samples can be compared over time.

Table 17 and Figure 18 show the coordinates and Name of the points chosen for sampling in Ghadir River.

Table 17 Coordinates and location of the chosen points for sampling

Number	Name	Latitude	Longitude
1	Jeser Al Aramel	33.81853474	35.51131075
2	Aser Zaaiter	33.82323273	35.52477982
3	Wadi chahrour/ sofla	33.82099338	35.54734499
4	Kfarchima-Lecico	33.82221055	35.53391979
5	Tiro-Airport	33.81952526	35.50077919
6	Costa Brava Beach	33.80324696	35.48022329

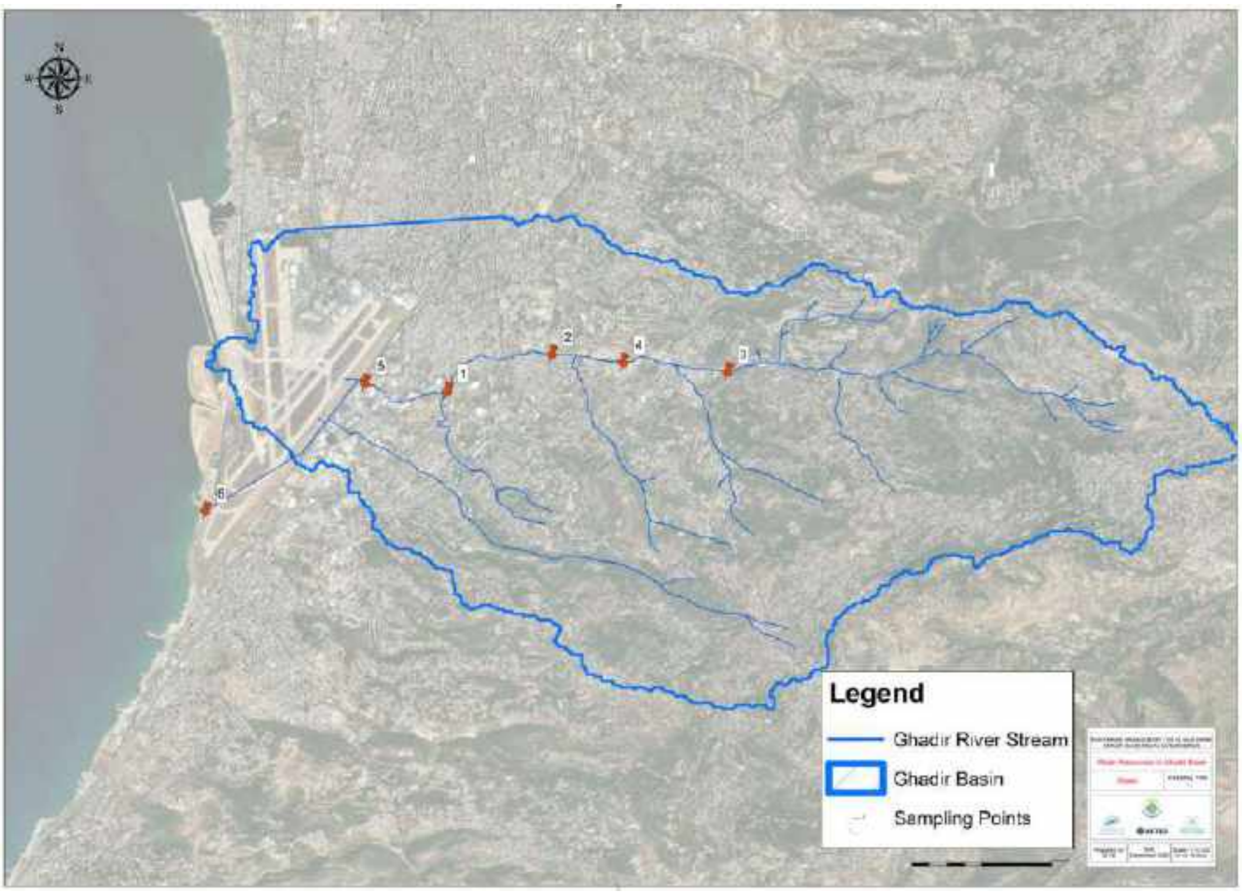

Figure 18 Water quality sampling sites location


Figure 19 Water sampling at Jeser el Aramel

3.2 Results

Below is a summary of all the results got from testing Ghadir river (Table 18). Highlighted in red are the values that exceed the WHO standards for the tested quality parameter.

Table 18 Summary of the results

Test/Point	Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Pt 6
Turbidity (NTU)	3439	3858	3567	3764	1630	3604
pH (pH)	7.25	7.3	7.5	7.8	7.3	6.9
RDO (mg/L)	0.09	1.803	0.944	0.042	0.976	0.046
A-Conductivity (µS/cm)	1192	715	778	738	3469	9084
S-Conductivity (µS/cm)	1398	813	840	805	3933	9938
Salinity (PSU)	0.71	0.402	0.416	0.399	2.1	5.66
TDS (mg/L)	909	528	544	523	2558	6459
TS (ppt)	2203	1488	1609	2098	5145	8891
Temp(°C)	17.26	18.7	21.2	20.7	19.1	20.8
Nitrate (mg/L)	1.79	1.59	1.62	2.19	1.93	1.34
Lead (mg/L)	0.1	<0.1	0.38	0.1	1.61	1.62
Cadmium (mg/L)	0.094	0.1	0.088	0.1	0.19	0.22
Barium (ppm)	0.1	0.2	0.3	0.002	0.2	1.6
Mercury (ųg/L)	0.02	0.04	0.02	0.06	0.09	0.11
Sodium (ppm)	17	9	10	10.7	70	185
Potassium (ppm)	8	2.8	3.4	3.5	7.8	16
Lithium (ppm)	0	0.001	0	0	0.1	0.1
Calcium (ppm)	20.8	11.9	14.4	13.2	32.4	68
Phosphorus (mg/L)	4.58	3.28	3.16	2.77	3.21	3.39
Chloride (mg/L)	>200	97	153	109	>200	>200
Ammonia (mg/L)	1.64	<1	3.54	<1	11.5	18.6
Sulfate	199	145	180	169	>200	>200
Fluoride	1	0.8	1	0.9	0.9	0.9
DO	0.19	0.3	0.28	0.17	0.33	0.37
BOD	411	356	375	399	601	622
COD	731	522	613	650	832	982
Total Coliform	220	190	130	290	360	410
Fecal	160	130	90	210	310	350
Ecoli	130	110	70	180	250	270

3.3 Discussion

Water samples were collected from Ghadir River during the wet season and tested for physical qualities, chemical contents, and microbiological counts. Six sampling points were selected. Water quality parameters, such as conductivity, DO, BOD, COD, pH, TS, DS, and Fecal Coliform were analyzed. The concentration of lead, cadmium, mercury, barium, lithium, sodium, potassium, chloride, sulfate, fluoride, ammonia, phosphorus, and nitrate was also analyzed at all the points. The examination of the results is shown below:

Measuring **Dissolved Oxygen** (**DO**) in drinking water is an important property of water quality. DO is critical for fish and other aquatic organisms to survive. DO values for Ghadir river, along our reach varied between 0.17 mg/L to 0.37 mg/L. WHO standard for sustaining aquatic life is <4 mg/L, whereas for drinking purposes it is 6 to 8.5 mg/L. Therefore, all the examined points are not suitable for drinking and aquatic life. Very low. Low levels of oxygen (hypoxia) or no oxygen levels (anoxia) means that there are excess organic materials, such as large algal blooms, that are decomposed by microorganisms in the studied river. While each organism has its own DO tolerance range, generally, DO levels below 3 milligrams per liter (mg/L) are of concern, and waters with levels below 1 mg/L, such as in our case, are considered hypoxic and usually devoid of life.

While in the case of **Biological Oxygen Demand (BOD)** concentration, the results recorded values ranging from 356 mg/L and 622 mg/L. Most rivers have BOD_5 below 1 mg/L. Moderately polluted rivers may have a BOD_5 value in the range of 2 to 8 mg/L. High BOD_5 levels (>8mg/L) can be a result of high levels of organic pollution, caused usually by poorly treated wastewater, or from high nitrate levels (EEA, 2001). WHO standard for surface water is 25 mg/L, which is exceeded to a great extent as shown by the values in Table 18. High BOD_5 values were detected at all sites which may be attributed to high levels of Nitrates and phosphates. These high values indicate that sewage or industrial wastewater is penetrating Ghadir river. High biochemical oxygen demand can be caused by: high levels of organic pollution, caused usually by poorly treated wastewater or non-treated wastewater penetrating the river; high nitrate levels, which trigger high plant growth. Both result in higher amounts of organic matter in the river.

Chemical Oxygen Demand (**COD**) is another important parameter of water quality assessment. A standard for surface purposes is 125 mg/L, which is exceeded for all sites in the studied river. Table 12 shows the COD data of six sampling points. The highest levels of COD recorded may be also attributed to raw sewage discharge, and for the same reasons stated in the BOD examination.

Concerning the **pH** which is an indicator of the acidic or alkaline condition of water status, the standard for any purpose is 6.5-8.5, in that respect; the values of our sampled water conform with the standards because the values vary between 6.9 and 7.8. All sites exhibited values of pH within the limits of the natural values that support aquatic life.

Adding to the above, the value of **electric conductivity** (**EC**) of Ghadir river varied between 715 and 9084 µs/cm. Conductivity depends on the number of ions present in water. The conductivity is very high for most of the points and exceeded the acceptable standards for rivers and surface water (< 1500 µs) for points 1,5, and 6. A main observation from the results is that conductivity is directly influenced by TDS, the higher the TDS the higher the EC (Lawson, 2011).

Likewise, **total solids concentrations** in the wet season varied between a minimum of 1488 mg/L at point 2 and a maximum of 8891 mg/L at point 6. Many factors contribute to high levels of total solids in water, with soil erosion being a major contributor. An increase in the water flow rate or a decrease in stream bank vegetation can speed up the process of soil erosion, thus contributing to the levels of suspended particles such as clay and silt. Human activity is also responsible for high TS levels in Ghadir river. Common human pollution contaminants include pesticides, lead, bacteria, and mercury.

Concerning **Dissolved Solids (DS)**, the standard for drinking water is 500 mg/L. The minimum and maximum values obtained from the samples in the wet season are 523 at point 4 mg/L and 6459 mg/L at point 6. In this respect, we can conclude that Ghadir river water quality is not acceptable. High levels of TDS at some points are caused by the presence of potassium, chlorides, and sodium and by toxic ions (lead arsenic, cadmium, and nitrate), and result in an undesirable taste that could be salty, bitter, or metallic, discolor the water, and create an unpleasant odor. (Lawson, 2011).

Similarly, the WHO standard for **ammonia** in the surface water is 1.5 mg/L. The results yielded from the test results showed higher values for most of the sites (1,3,5 and 6) reaching 18.6 mg/L at the last point, which means it is very dangerous in terms of ammonia pollution. These high levels of ammonia might be attributed to agricultural runoff in addition to raw sewage discharge. Likewise, ammonia peak might be associated with a nutrient influx in streams with little to no flow and low DO content (Ryan et al. 2002). Ammonia levels above the recommended limits may harm the whole aquatic life. Ammonia toxicity is thought to be one of the main causes of unexplained losses in fish hatcheries. Excess ammonia may accumulate in the organism and cause an alteration of metabolism or increases in body pH.

Adversely, the levels of **nitrate** exhibited a similar fluctuation among the sites ranging all within the acceptable levels (5 mg/l).

Apart from the above, we have traced **metal detection** in the water. These chemicals are classified as being potentially hazardous and toxic to most forms of life. Results reported that trace metals' concentrations for **lead, mercury, and cadmium** were very high at all points and mostly elevated at points 4, 5, and 6. The above results imply that the river is receiving mercury and lead from the direct discharge of industrial wastes directly into the river. The elevated concentration of these toxic compounds in the water can be detrimental to people's health. For example, even in small doses, lead exposure can cause brain and nervous system damage, while PFAS exposure is linked to cancer, thyroid disease, and other health problems.

Moreover, some of the chemical elements like **Sodium, potassium, lithium, and calcium** are essential as micronutrients for the life processes in animals and plants (Kar et al., 2008). Fortunately, acceptable concentrations were found in GRB.

Similarly, **phosphorus** concentrations recorded values greater than 2.77 mg/L for all the sampled Comparing these results with WHO limits, they exceed the acceptable level of phosphorus (1mg/L) in rivers. The high level of phosphate at all these sites might be due to anthropogenic sources, mainly, agricultural runoff, animal waste, raw sewage, or different types of rubbish that are thrown into the river. Excess phosphate in surface runoff might lead to cultural eutrophication. During this phenomenon, PO_4^{3-} in freshwater leads to a favorable condition for algae and weed growth, which ultimately brings a rapid reduction in the ecosystem through oxygen depletion.

Similarly, **chloride** concentration documented values varying from 97 at point 2 to >200 mg/L at points 1,5, and 6. Compared with WHO guidelines, the level of chloride at the latter sites confirms that there are industrial effluents or urban runoff at the location of the sample.

The **sulfate** recorded a mean value of less than 199 mg/L for sites 1 to 4. Compared with WHO guidelines, the results fall within the acceptable range (<200 mg/L), however at sites 5 and 6, the concentration of sulfate exceeded the acceptable level. Acid drainage, fertilizer leaching from agricultural soils, wetland drainage, and agricultural and industrial wastewater runoff as well as sea level changes are the main direct and indirect sources of the anthropogenic $SO^{4}{}_{2-}$ input to Ghadir river.

Moreover, **fluoride** concentrations were recorded at all sites, yet no marked variation was observed. Acceptable values were found at all sites.

Apart from the physical and chemical parameters, the water was tested for microbiological pollutants. The results of the six sampling points show that all sites are bacteriologically contaminated to an extreme extent. Total, fecal, and E-coli were detected at all sites and were too numerous indicating the critical condition of excessive microbiological contamination. The presence of fecal coliform bacteria in very high levels indicates potential health risks to swimmers and implies the unsuitability of the water at these critical points for specific water most domestic water uses. The source of organic and microbial pollutants present in the water can be accounted for by the seepage of industrial wastewater into the river and support the presence of agricultural runoff, and animal waste, raw sewage, (Amacha et al., 2012).

According to the WHO standards and the European Economic Community, fecal coliforms in river water are should not exceed 100 FC/100 ml (Servais et al. 2007). Several health outcomes such as gastrointestinal infections might be associated with fecally polluted water which may result in a significant burden of disease (WHO 2001).

To sum up, the results from data analysis show that, the water is certainly unfit for drinking purposes without any form of treatment, but for various other surface water usage purposes, it still could be considered quite acceptable. But as we know, once a trend in pollution sets in, it generally accelerates to cause greater deterioration. So, a few years from now, serious water quality deterioration could take place.

3.4 Conclusion

The water quality of the Ghadir River was analyzed. The physical, bacteriological, and chemical composition of the river was studied in the wet season. All sites exhibited values of pH within the limits of the natural values that support aquatic life. The levels of TDS were fluctuating among the sites with the highest values recorded at site 6 which is extremely violating the guideline and implies seawater and wastewater intrusion. Higher BOD_5 values were detected at sites 5 and 6 which may be attributed as well to seepage of industrial and raw sewage water. The levels of nitrate exhibited a clear fluctuation among the sites ranging yet falling below the limit for surface water. The estimated indices at sites 5 and 6 exhibited the worst water quality conditions among the studied sites.

WHO specifies guidelines and imperative values for drinking and aquatic life were used. This assessment was adopted as the Lebanese Ministry of Environment (MOE) Standards for surface water, do not include all of the parameters reported here.

Results revealed that the water quality of the Ghadir river is very polluted and generally affected by activities related to industrial wastes and raw sewage wastes.

4 WEAP Modeling

Water Evaluation and Planning (WEAP) is a software tool for integrated water resources planning that provides a comprehensive, flexible and user-friendly framework for planning and policy analysis. The primary support for development was provided by The Stockholm Environment Institute, while a number of agencies, including the US Army Corps, UN, World Bank, USAID, US EPA, IWMI, Water Research Foundation and the Global Infrastructure Fund of Japan have provided project support.

It has been applied in water assessments in dozens of countries, including: the United States, Mexico, Brazil, Germany, Ghana, Burkina Faso, Kenya, South Africa, Mozambique, Egypt, Israel, Oman, Central Asia, India, Sri Lanka, Nepal, China, South Korea, and Thailand.

WEAP operates in many capacities:

Water balance database	Scenario generation tool	Policy analysis tool
WEAP provides a system for maintaining water demand and supply information.	WEAP simulates water demand, supply, runoff, streamflows, storage, pollution generation, treatment and discharge and instream water quality.	WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems.

The goal of the model for GRB is to establish the baseline scenario for current water resources management (WRM) in the area, contemplating both water sources and demands. This model will shed a light into current and projected unmet demands and serve as a baseline on which to build upon different scenarios for WRM.

With this in mind, it is therefore necessary to input all the different water demands, mainly domestic consumption and irrigation requirements, and all the different water sources that are comprised of groundwater abstractions and springs diversions.

4.1 Data input and modeling

4.1.1 Time horizon

The time horizon for the project has been set to 2020 – 2035. The model has been subdivided into 12-time steps per year, using a calendar month partition and including leap days as well.

As a consequence, the year 2020 will be used as the Current Accounts Year in which all parameters and variables are defined. These will be projected throughout 15 years to establish the baseline scenario. In general, unless specified otherwise, parameters will remain constant; and variables will only be modified if they are related to the progression of time, like for instance when considering population growth.

The following sections will provide a brief description of these variables and parameters related to water supply and demand.

4.1.2 Water Distribution Systems

In order to articulate on an efficient manner between the current assignment and the Updated NWSS 2020, it was decided that water supply and demand will be organized according to water distribution systems.

As it was mentioned before, the study of GRB involves 11 water systems that are totally or partially within the basin. Each system consists of one or more villages from Baabda and Aley regions, as seen in Figure 16.

4.1.3 Water Demand

Domestic water demand has been included in the model, following the water distribution systems criteria. Additionally, irrigation water demand has been incorporated through an irrigation node. These water demand nodes, will be later joined to their respective sources through transmission links.

4.1.3.1 Domestic water demand

Within the barycenter of each water system area, a single node was input containing the sum of the domestic water demand for the diverse villages that are part of this system. Figure 20 shows the 11 water systems which were labelled in a standardized way to aid to a later visualization of results. This labelling can be found in Table 19.

In terms of the water demand, formulas and populations were followed as described previously in section 2.5.

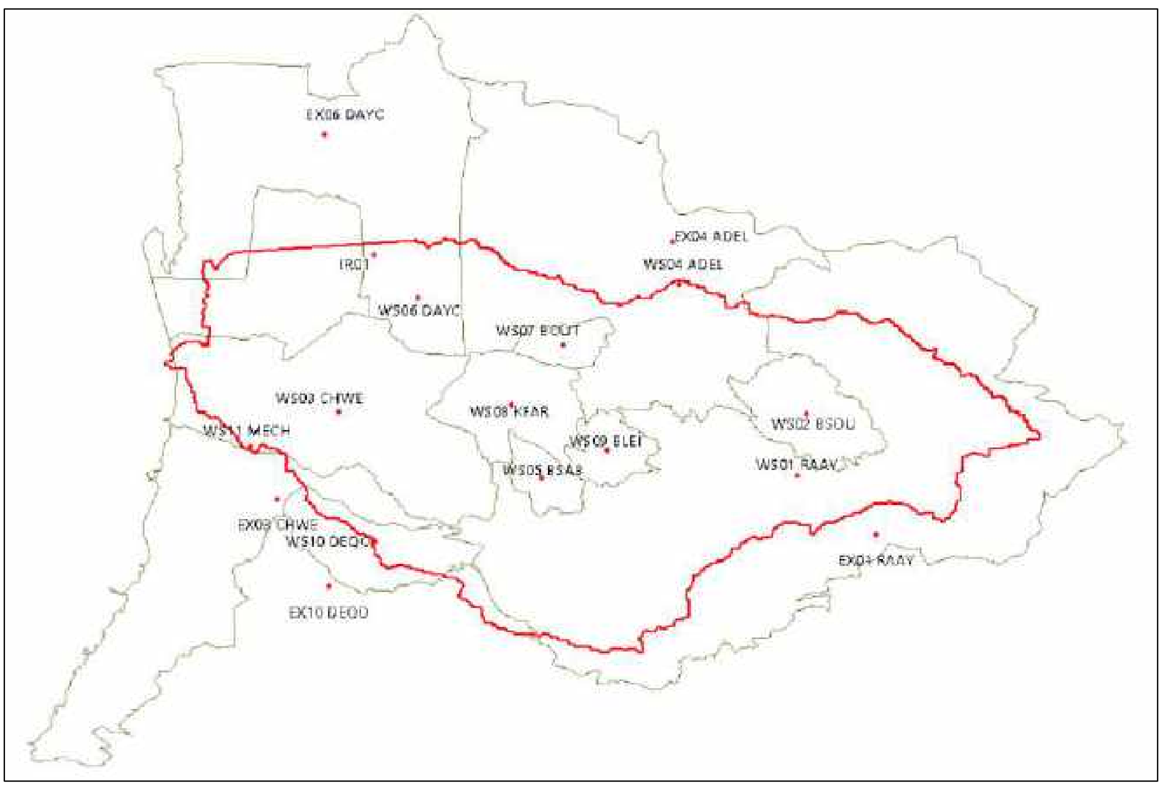

Figure 20 Water Demand nodes representing water distribution systems (WS) and irrigation (IR) nodes within WEAP

Table 19 WEAP ID for Water Systems

ID	Water System Name	ID	Water System Name
WS01 RAAY	Raayan	WS07 BOUT	Boutchay
WS02 BSOU	Bsous	WS08 KFAR	Kfarchima
WS03 CHWE	Choueifat	WS09 BLEI	Bleibel
WS04 ADEL	Ain El Delbe	WS10 DEQO	Deir Qoubel
WS05 BSAB	Bsaba	WS11 MECH	Mechref wells
WS06 DAYC	Daychouniyeh		

Considering that this model will be later used to include different scenario explorations, the urban demand by water system was disaggregated as much as possible by the use of Key Assumptions. This will later provide more flexibility to change these variables and analyze their impact. Some considerations to be noticed:

- Population from all the water systems was identified as urban for demographic purposes.
- Domestic and Non-Domestic consumption were included as Key Assumptions.
- Physical losses were included as a Key Assumption implemented within the transmission links between supply and demand. Theoretically, the losses are not part of the demand but is an issue of the network that connects supply with demand. These networks are symbolized as transmission links.
- Urban Growth Rate was included as a Key Assumption to be used for computation of future populations following inbuilt formulae that matches the Updated NWSS 2020 exponential proposition.

4.1.3.2 Irrigation water demand

An irrigation node has been introduced to take into consideration the irrigation demand. In this case, the irrigation node was placed in the northern section of the basin with an irrigated area of 110 Ha.

To obtain the water demand for the sector, the areas relate to an average water demand per hectare that amounts to 7500 m^3/ha/month. This value was introduced as a Key Assumption to be used for the node.

4.1.4 Water Supply

Within this model, three different types of water sources can be identified: Springs, Groundwater Abstractions and River Water Intakes. The latter one is not a current source.

4.1.4.1 Springs

As described in section 2.5.1, 4 springs representing external water systems have been included within the model. A standardized label was input as well following the identification in Table 20. Due to their location, these springs are external to the GRB with the exception of Deir Qoubel which falls close to the boundary and happens to be out of service.

Table 20 WEAP ID for Springs

Code	Spring Name
SP01 RAAY	Raayan spring
SP02 ADEL	Ain el Delbe spring
SP03 DAYC	Daychounieh spring
SP04 DEQO	Deir Qoubel spring

Spring elements have been introduced as a node of “Other Supply” as it does not fall into the category of “Groundwater node, Reservoir or Catchment”. Within WEAP, this type of nodes is limited within their functionality for which a modeling intervention had to be implemented.

This intervention consisted of adding to each spring a river element which will complete the required functionality. As an example, this arrangement can be seen in Figure 21 representing the spring Daychounieh (SP03 DAYC) which is a source for the Daychounieh water system (WS06 DAYC). Each one of these springs has a similar arrangement. For each one of these, the corresponding discharge has been input in m^3/s.

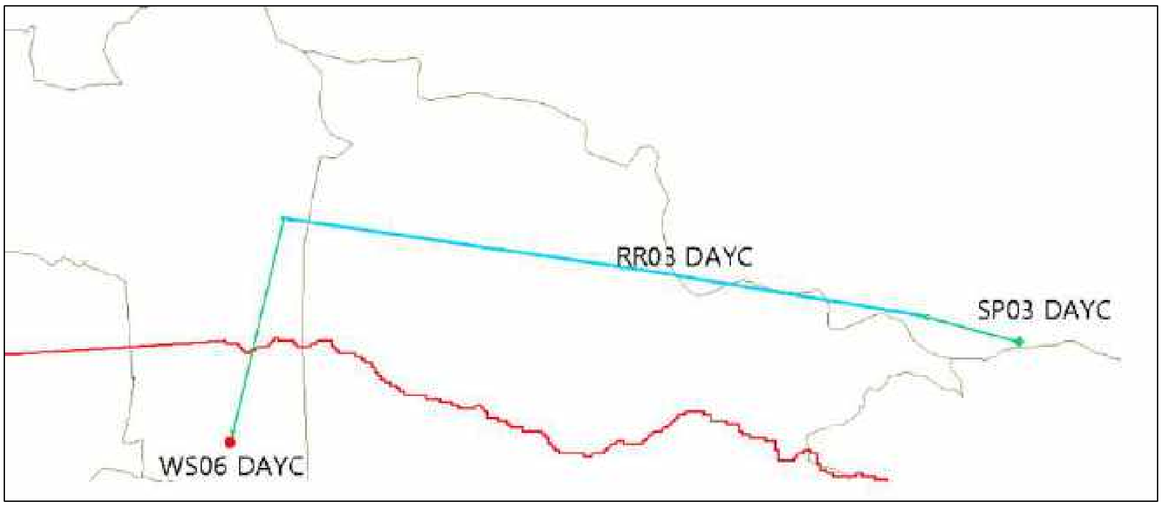

Figure 21 Arrangement for spring sources in WEAP

4.1.4.2 Groundwater Abstraction

As described in section 2.5.1, 30 public wells falling within the basin have been included in the model, each one of these represented as an individual groundwater node. Additionally, two more nodes were added to represent the Mechref wells, which are external to the basin, and the private wells used for irrigation. A standardized label was input as well following the identification in Table 21. The location of the wells can be seen in Figure 22.

Table 21 WEAP ID for Wells

Code	Well Name	Code	Well Name
WE01 BAAB	Jamhour	WE17 ZAKK	Zakka
WE02 JAMH	Wede Chahrour 2	WE18 DEQ2	Deir Qoubel 2 - School well
WE03 CHA2	Wadi Chahrour 1 Well	WE19 DEQ3	Deir Qoubel 3
WE04 CHA1	Bleibel	WE20 DEQ1	Deir Qoubel Well
WE05 BLEI	Betchay well 1	WE21 ANTO	Antounieh
WE06 BETC	Bsaba Well	WE22 KANA	Kanaan Well
WE07 BSAB	Bsous Well	WE23 OUSS	Oussaily Well
WE08 BSOU	Al rayess well	WE24 HOUM	Houmal
WE09 ARAY	Kartoun Well	WE25 AAAN	Ain Aanoub (Maaroufiye)
WE10 KART	Choueifat well richani	WE26 BDED	Bdedoun
WE11 CHOU	Haret El Qobbe	WE27 QMA3	Qmatiye
WE12 HEQO	Haret El Qobbe - Qobbeh (Choueifat)	WE28 QMA1	Qmatiyeh 1
WE13 QOBB	Richane (Chouaifet)	WE29 QMA2	Qmatiyeh 2
WE14 RICH	Saab 1	WE30 KAHA	Kahaleh
WE15 SAA1	Jamhour	*WX01 MECH*	*Mechref Wells*
WE16 SAA2	Saab 2	*WP01*	*Private wells*

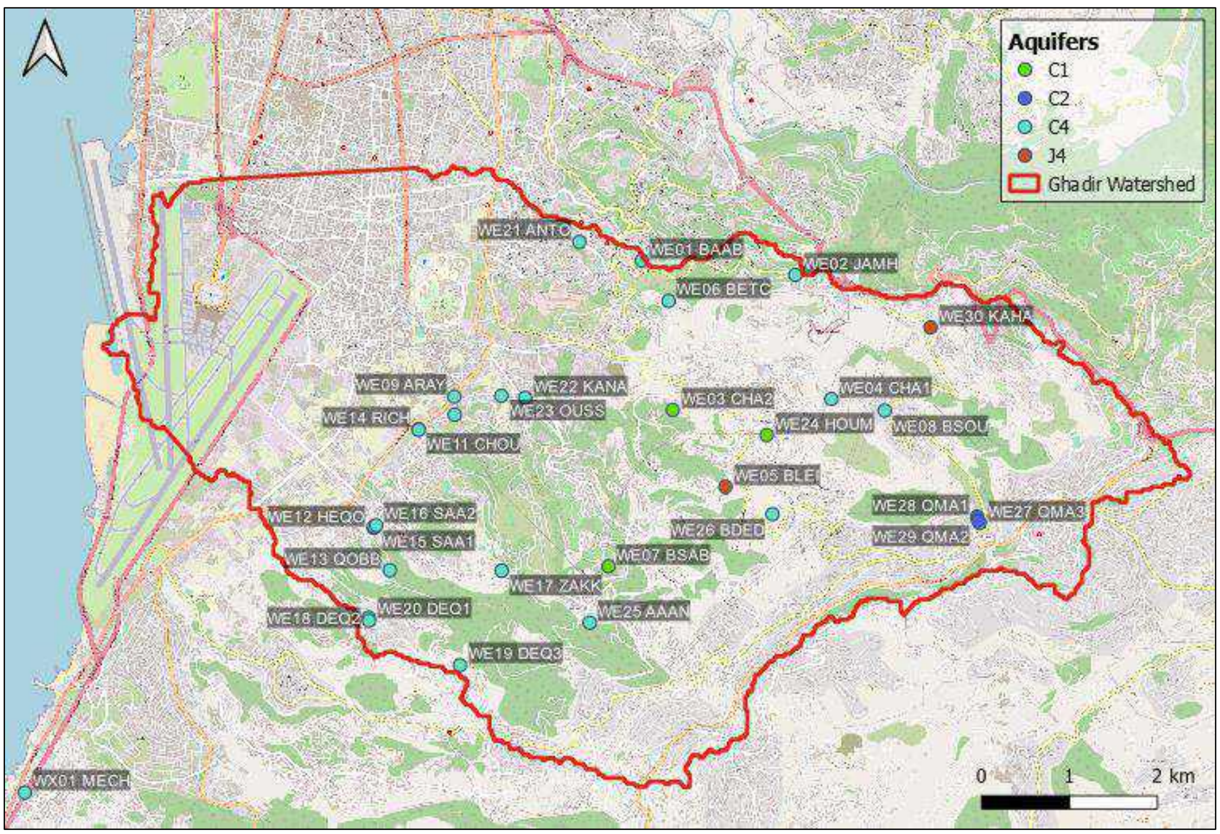

Figure 22 Well location classified according to exploited aquifer

The main estimated parameters and characteristics of each of these aquifers can be found in Table 22. Storage capacity and initial storage have been averaged from a range of values that were estimated (see section 2.3). The number of public wells in service is not limited only to the wells presented in Table 21, but also includes wells that supply water systems outside Ghadir.

Table 22 Hydrogeological formation and aquifers characteristics

Symbol	Formation Name	Public wells in service	Outcrop Area (km^2)	GW Recharge (% of Rainfall)	Storage Capacity (MCM)	Initial Storage (MCM)
C1	Chouf	7	3.8	19	83	65
C2	Abeih-Mdairej	3	15.4	17	N/A	N/A
C4	Sannine	23	10.8	37	90	71
J4-J7	Jurassic	3	0.01	N/A	843	843
Q	Quaternary	0	14.5	5	118	51

Groundwater abstraction nodes were included in WEAP, using transmission links to represent the flow going to the respective water systems. As it was mentioned in 2.5.1, part of the abstracted water is used for supplying the villages that fall within the area delimited by GRB (inner villages), while another part of the abstraction supplies the villages falling outside GRB (outer villages) that correspond to the same water system.

To represent these villages that belong to the same water system but fall outside the basin area, external demand nodes were added without an assignation of demand to these. From the wells, two separate transmission links represent the water transfer from the abstraction to the inner and outer villages, respectively.

This representation can be seen as an example in Figure 23, where the red line symbolizes the northern limit of the GRB. WS04 ADEL represents the demand of the inner villages, while EX04 ADEL the outer ones for Ain El Delbe water system. It can be seen that wells WE01, WE02, WE03 and WE04 have two transmission links supplying the inner and outer villages respectively, considering the diverted flow rates presented in section 2.5.1.

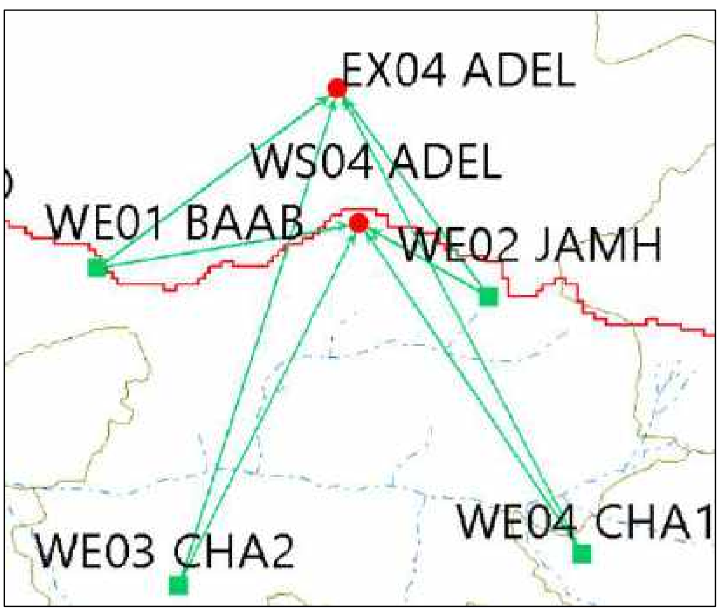

Figure 23 Wells configuration in WEAP

The corresponding maximum flow rates abstracted to supply the inner and outer villages of each water system were added into the transmission links as maximum flow volumes, including as well a 33% loss rate, to account for leakages in the distribution. Following the updated NWSS 2020, the daily water demand amounts to 150 l/cap/day while losses are estimated to 50 l/cap/day making it equivalent to a ratio of 33% of the demand.

On the other hand, key assumptions were used to represent the characteristics of each aquifer. These key assumptions include Outcrop Area, Recharge, Maximum Storage, Initial Storage and Number of Wells.

Since many wells belong to the same aquifer, the recharge and storage parameters are shared between them. Therefore, to reflect this, these parameters were divided by the number of wells within each aquifer to represent the individual effect of each one to later aggregate to show the collective aquifer withdrawal. Particularly, as a simplification all the private wells were included in the Quaternary aquifer.

Additionally, in order to be able to estimate the recharge, an average precipitation value was computed for each month from the available rainfall records. These records are described in next section.

4.1.4.3 River Water Intakes

As mentioned, currently there are no river water intakes to be considered as a supply for the upper-mentioned water systems. Nevertheless, a hydrological modeling was performed to characterize the availability and variability of the resource.

4.1.4.3.1 Basic hydro-meteorological data and approach

The attainable precision and reach of a hydrological model rely on the available data that serves as its foundation. In this case, the determining factors were the availability of data from both the pluviometric and hydrometric stations, as shown in Figure 24.

- Pluviometric data from Beirut International Airport station, covering Jan-2000 to Dec-2018 with monthly rainfall data as well as other parameters related to temperature, humidity and wind factors.
- Hydrometric measurements in Ghadir Station, covering from Sep-2000 to Aug-2016, with monthly average discharge.

Taking this into consideration, an upslope area was calculated upstream the hydrometric station to define the draining sub-catchment from which rainfall generates the discharge. Figure 25 shows the representation within WEAP of such catchment and the location of the hydrometric station along Ghadir.

As a general approach, it was decided to model the catchment using a Rainfall-Runoff simplified coefficient method which would allow a gross calibration and sufficient precision. As an advantage, the simplicity of the method avoids the need of estimating the unknown parameters that are required for more complex methods like the soil-moisture one for example. The time period was set to be in a hydrological year basis, starting from **Sep-2000 until Aug-2016** to use all the hydrometric measurements in the calibration and a separate WEAP model area was created just to focus on calibration of parameters.

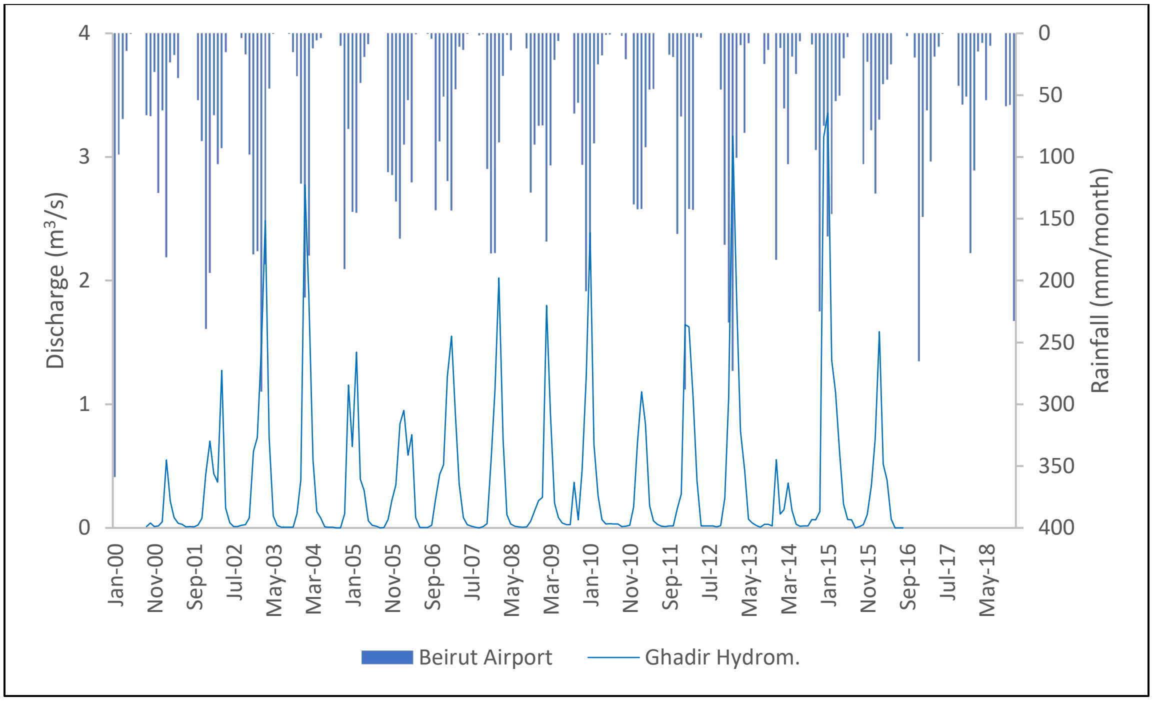

Figure 24 Ghadir, rainfall vs discharge

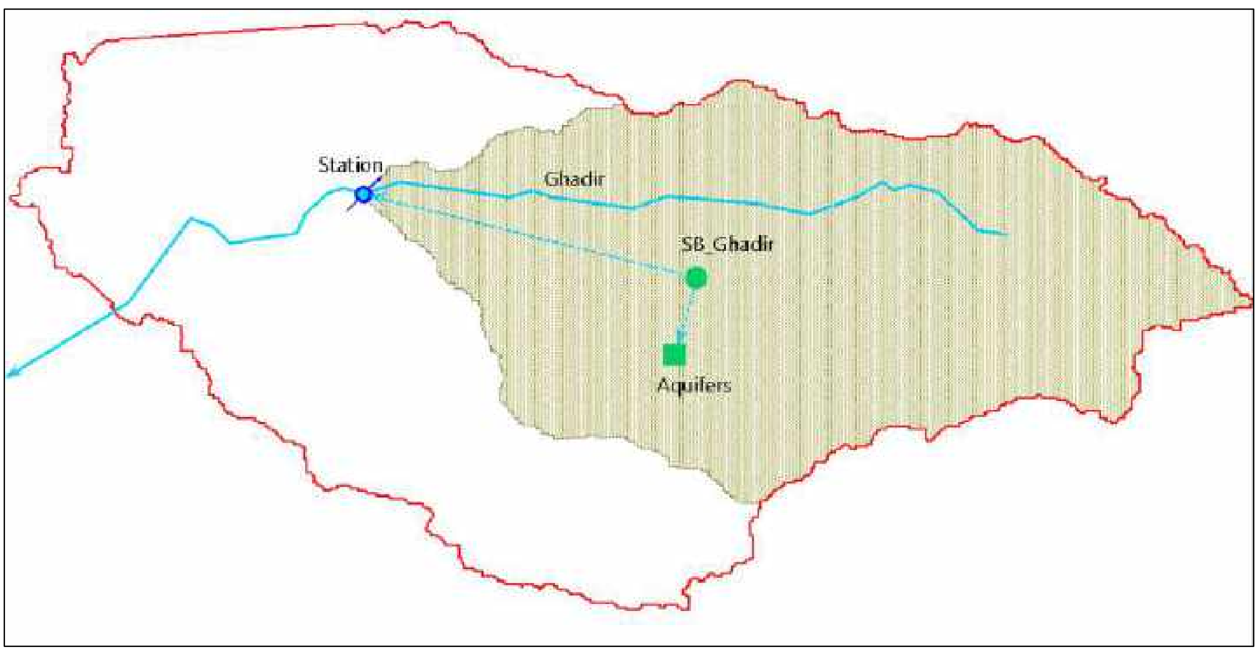

Figure 25 WEAP representation of sub-catchment

Other required parameters for the simplified coefficient method include Reference Evapotranspiration, Runoff-Groundwater split, and Land Use data. The latter one, relates to Area, Crop coefficient (Kc) and Effective Precipitation.

Reference Evapotranspiration (ETRef)

Reference Evapotranspiration (RET or ETRef) was obtained from WaPOR (FAO) datasets on a monthly basis from 2009. The WaPOR database (WAter Productivity through Open access of Remotely sensed derived data) is a comprehensive database that provides information on biomass (for food production) and evapotranspiration (for water consumption) for Africa and the Near East in near real-time covering the period from 01-January-2009 to present (FAO, 2020a).

The WaPOR offers continuous data at a 10-day average time step for Africa and the Near East at three spatial resolutions. The continental-level data (250m) covers continental Africa and large parts of the Near East (L1). The national-level data (100m) covers 21 countries and four river basins (L2). The third level (30m) covers eight irrigation areas (L3). The WaPOR RET data has a spatial resolution of 20 km.

In the case of Ghadir sub-basin, the trends in two adjacent pixels were considered weighting the area falling within them. Figure 26 shows the variation related to Ghadir subbasin for one of the pixels and Figure 27 the averaged values used as an input in WEAP calculations.

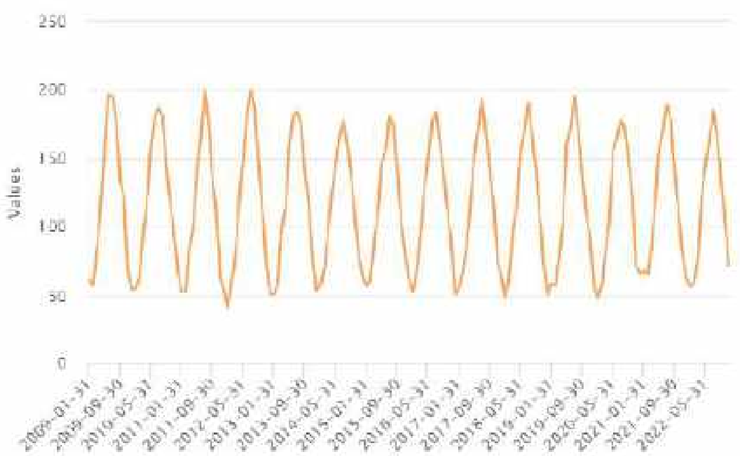

Figure 26 Monthly Reference Evapotranspiration for Ghadir subbasin

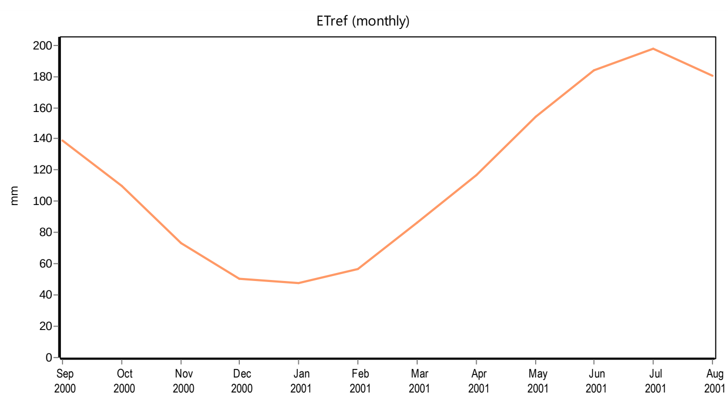

Figure 27 Monthly average values of ETRef used in WEAP

Runoff-Groundwater Split

Taking into account that the remainder of the effective precipitation will be either infiltrating or generating the runoff that turns into river flow, the last parameter to set and calibrate is the Runoff-Groundwater Split. A first iteration was set to be that a 5% of this remainder goes into surface runoff and a 95% to infiltration. However, after many manual calibration runs, the final split was set for each month as described in the following table.

Table 23 Runoff-Groundwater Split

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Runoff	1.6%	0.2%	0.2%	0.6%	0.9%	1.0%	1.8%	3.6%	13.2%	0%	0%	0%
Groundwater	98.4%	99.8%	99.8%	99.4%	99.1%	99.0%	98.2%	96.4%	86.8%	100%	100%	100%

It is important to notice that given the simplicity of the model, these values are over-fitted for this precise method and subbasin, influenced as well by the way in which data was provided as an input, its consistency and scarcity. An extrapolation to other areas is not possible and the physical sense of the groundwater/runoff split is not to be evaluated directly from this calibration results as it is a loose representation of the hydrological cycle for a limited period of time. Results of the model will be shown in the next section.

4.2 Results Exploration

This section will explore the main results obtained for the baseline modeling of GRB.

4.2.1 Results of Hydrological model

Following the iterative calibration process described in section 4.1.4.3 River Water Intakes, results for runoff generation were compared against streamflow measurements from Ghadir hydrometric station (see Figure 25).

Since the objective of the model is to assess water resources, the main results of interest are the monthly discharged averaged throughout the years. Figure 28 and Table 24 show the comparison of the resulting hydrograph from WEAP simulation, as opposed to the actual measurements in Ghadir hydrometric station.

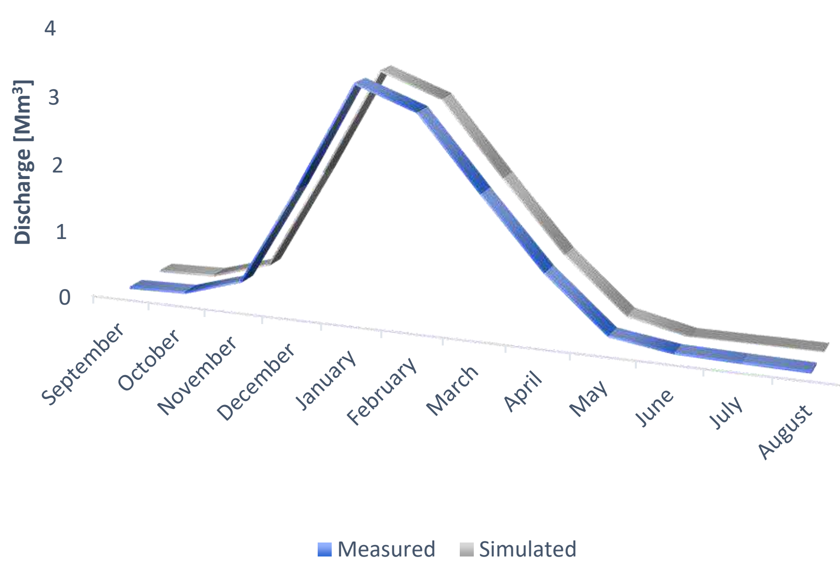

Figure 28 Hydrograph comparison of discharge volume in million cubic meters

Table 24 Hydrograph comparison of discharge volume in million cubic meters

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Measured	0.09	0.12	0.38	1.85	3.42	3.09	2.02	1.00	0.20	0.07	0.04	0.03
Simulated	0.09	0.11	0.38	1.87	3.43	3.09	2.02	1.00	0.20	0.00	0.00	0.00

It can be seen from the model that measured flows during June, July and August are quite small and the simplified method struggles to obtain these due to the mismatch between rainfall data and averaged evapotranspiration values given as an input. Nevertheless, the overall difference is not significative. The model performance is summarized in Table 25.

Figure 29 shows the monthly calculations for the given time period. It is possible to see that the obtained values are within the order of magnitude, however there is a certain dispersion when looking at some specific months. For the purposes of this model, these types of results are acceptable.

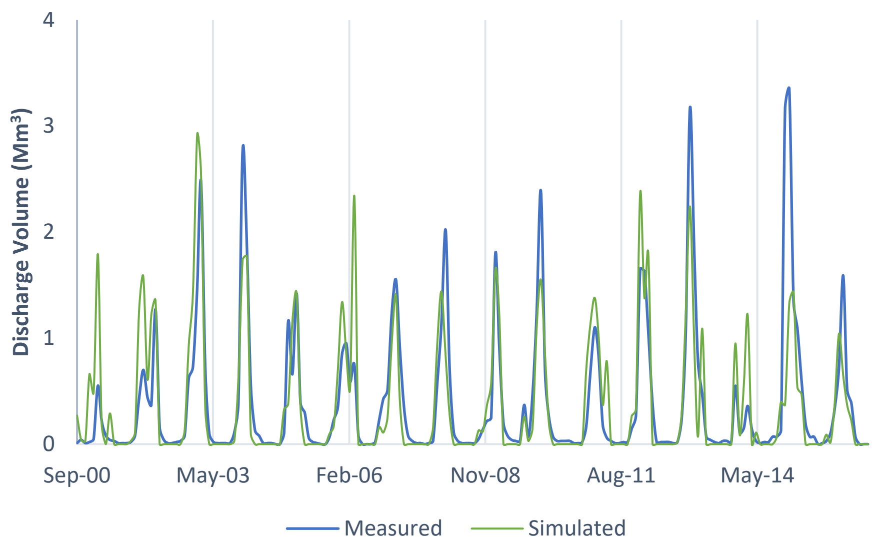

Figure 29 Monthly Hydrograph comparison in million cubic meters

Table 25 Statistical computation of hydrological model error

Param	Time Period	NSE	KGE	NRMSE	PBIAS	RSR	LNS	RMSE [MCM]	MAE [MCM]	r	r^2
Value	01-16	0.54	0.75	110%	-0.88%	0.68	0.46	1.1	0.58	0.76	0.57

4.2.2 Results of WEAP Node based model

With regards to the node-based model, many different outputs can be explored from WEAP. Considering the data input, the most relevant one to the objective of the model is the interaction between supply and water demand.

Figure 30 presents the full WEAP model scheme including all nodes, links and rivers.

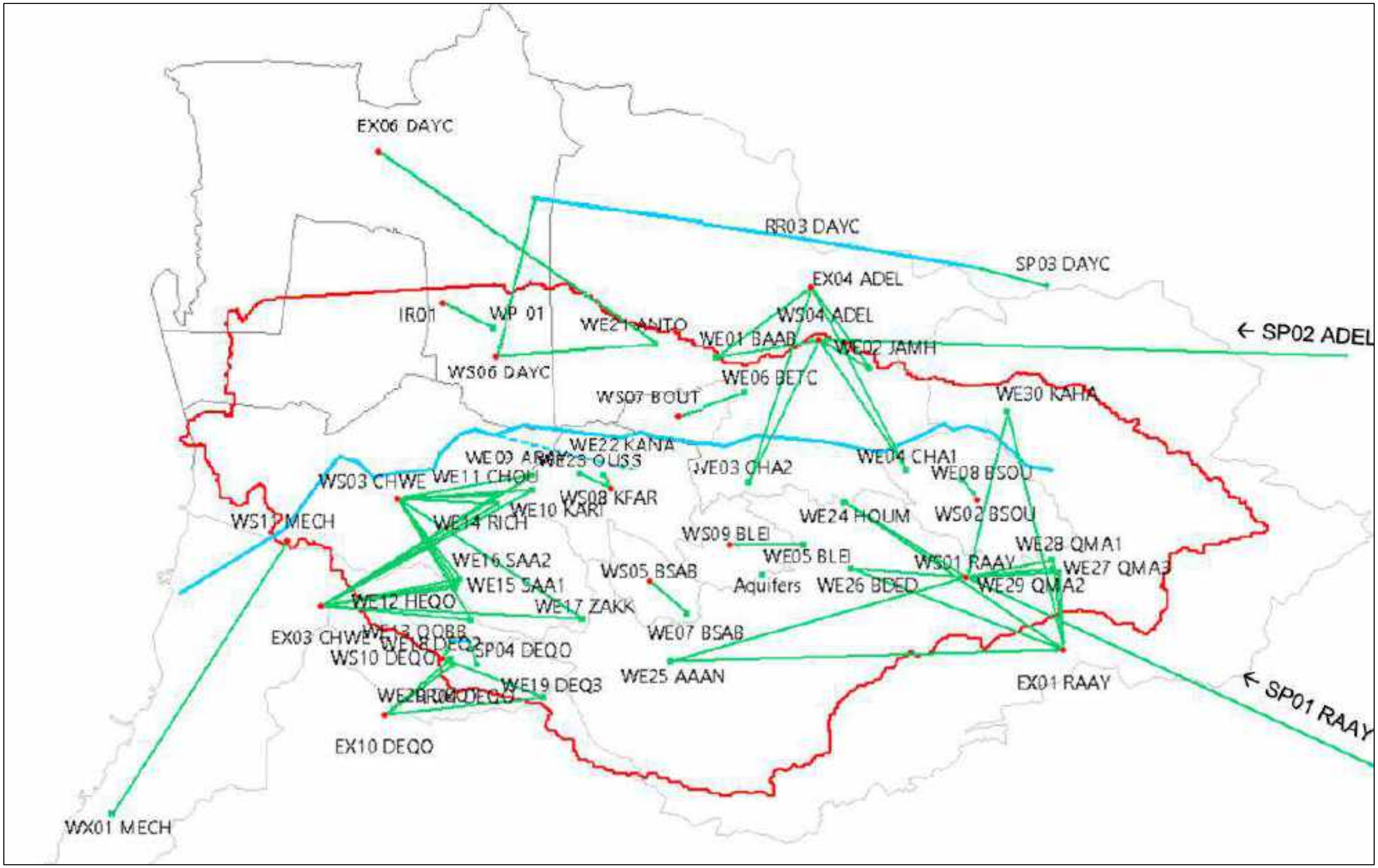

Figure 30 WEAP node-based representation for GRB

4.2.2.1 Demand coverage for baseline scenario

One of the main outputs to analyze is the demand coverage considering the current and projected sources and demands. Figure 31 shows the percentage of demand covered for 2020 for the eleven Water Systems of GRB.

Since most of the values used for the input are on a yearly basis, the demand coverage does not vary significantly throughout the year.

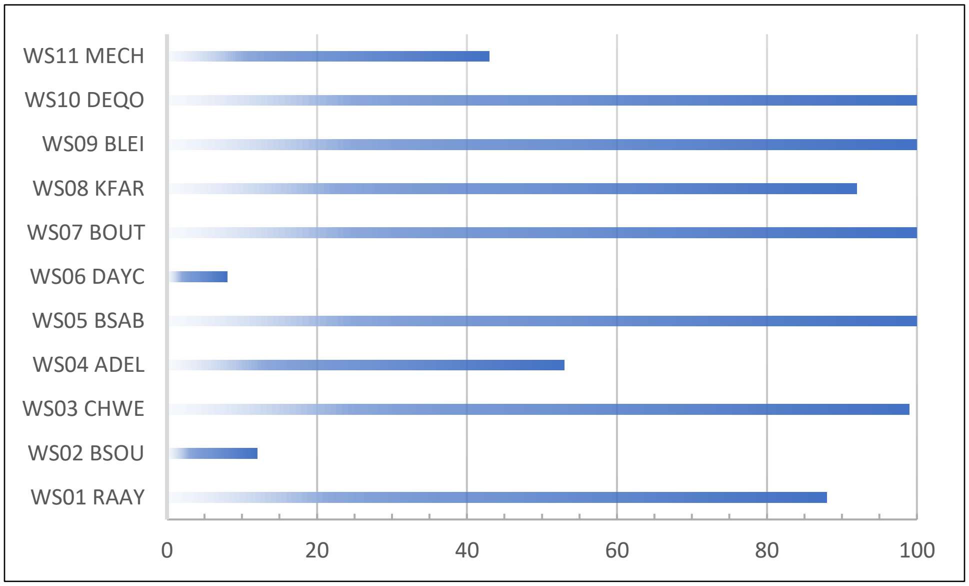

Figure 31 Demand coverage in 2020 for Ghadir Water Systems [%]

The demand coverage of the irrigation sector has a variation throughout the year and can be seen in Figure 32 as the demand for irrigation goes from May until October.

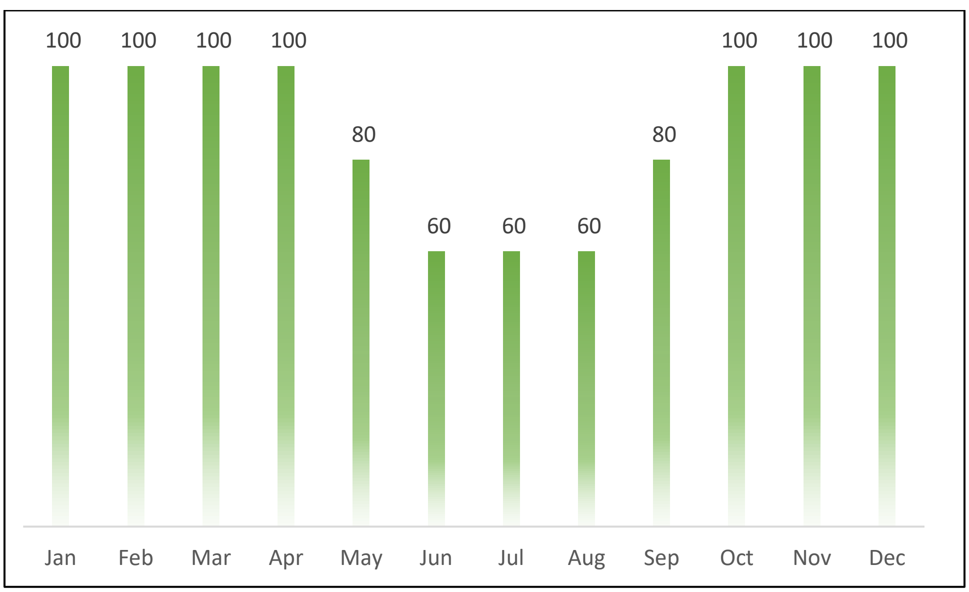

Figure 32 Irrigation demand coverage [%]

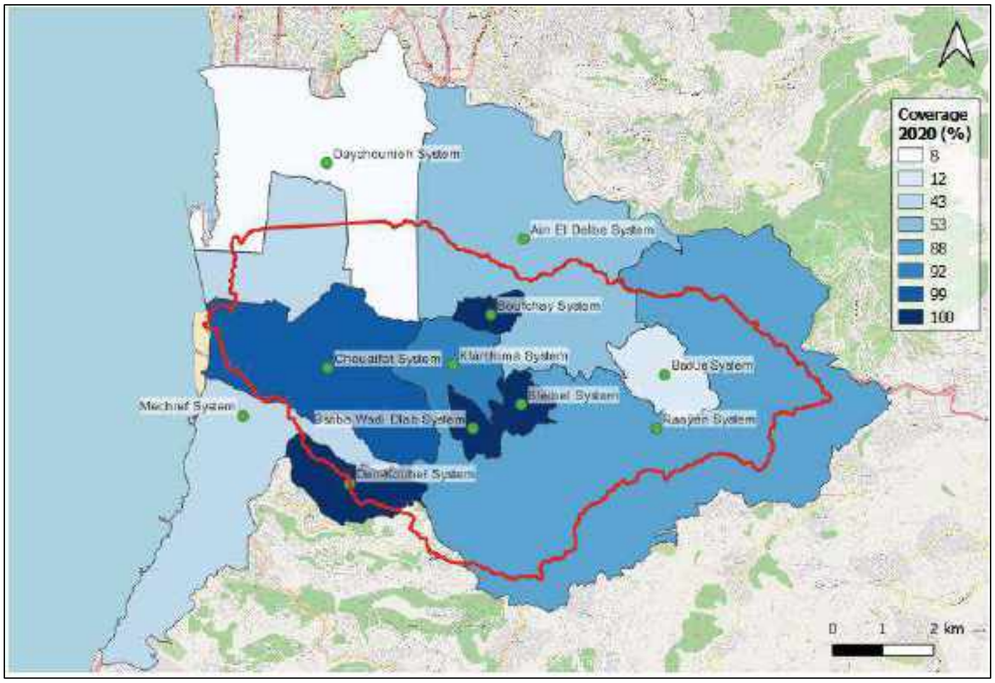

Figure 33 Water distribution systems demand coverage map for 2020

4.2.2.2 Demand Coverage for half supply scenario

As it was mentioned, the abstraction rates included in the model consider a scenario where wells are operating on a 24-hour basis. However, this situation is not realistic with the current operation mode. Therefore, a realistic scenario is presented where supplies are reduced to half, both for wells and springs. A key assumption was included within this scenario and set to be 50%. Figure 34 shows how this reduction impacts further the demand coverage of many water systems.

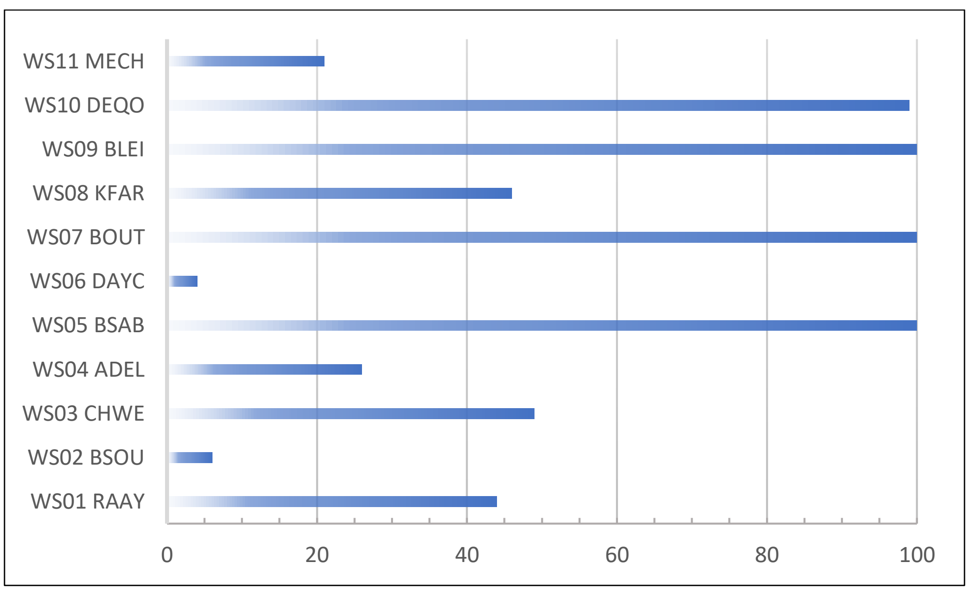

Figure 34 Demand coverage in 2020 for Ghadir Water Systems half supply scenario [%]

In an analog way, irrigation coverage naturally drops to 33% as opposed to the previous 66% shown in Figure 32.

5 Ghadir River Basin Management Assessment

During the first phase of this study, the water and environmental resources of GRB were quantitively and qualitatively assessed for the baseline period between the years 2000 and 2020.

Previous relevant studies were reviewed, mainly the geological and hydrogeological description, the agricultural situation, the findings of the NWSS on the water balance of the water distribution systems located within Ghadir i.e. water demand, water supply sources, deficit and excess, etc., and the wastewater situation. The concept design for the training of Ghadir river related to the flooding of the downstream urban area of Ghadir was also reviewed. Hydrometeorological data were also collected and analysed. And cartographic data were compiled in a comprehensive GIS database which included the basin boundary, Landuse, geological and hydrogeological maps.

The current physical condition of the stream was assessed during the site visit and sampling campaigns conducted on November and December 2022. Several building encroachments were observed with sewer effluent directly flowing into it along the stream. Eroded soil and transported garbage were also observed especially at narrow corridors and shallow culverts.

In addition to physical pollution, the sampling campaign results revealed that the water quality of the Ghadir river is very polluted and generally affected by activities related to industrial wastes and raw sewage wastes.

The state of the water resources in GRB has been assessed for the baseline period based on the outputs of a detailed WRMM developed in WEAP21 software. The baseline assessment investigated water availability, water demand, and unmet demand (per sector) in the basin.

Based on the model results for the baseline year 2020, the water demand of 7 water systems are covered above 80% in case of on a 24-hour basis operation but only 4 water systems above 80% on a 12-hour basis operation. Daychounieh, Mechref Wells and Bsous systems are the most uncovered systems.

The total annual unmet demand for 24-hour operation is approximately 25,250 m^3/day or 9.2 Mm^3/year, which represents 40% of the total required water supply for GRB. This basically means that, on average, only 13.4 Mm^3/year or 60% of the water needs are covered by the available water resources in Ghadir. As for a half supply scenario with 12-hour operation, the total unmet demand is 15.8 Mm^3/year which represents 70% of the total required water supply.

In the second phase of the project, the WEAP model will be used to simulate future distribution scenarios with the purpose of improving the conservation and management of the river basin and optimize the economic, environmental, and social benefits of the river taken into consideration suggestions from the participatory approach and proposed projects from the Updated NWSS 2020.

Water balance will be developed, assessed, and translated into policy relevant targets to further support the design corresponding PoM, then propose an action plan in coordination with key stakeholders in the region.

6 Appendix

A. Water quality sampling campaign report

AL GHADIR RIVER
WATER QUALITY MONITORING

JANUARY 2023

NDU Team Members
Dr. Jacques Harb/Quality Assurance-Reporting
Dr. Claudette Hajj/Monitoring and Testing
Mr. Elie Lahoud/Sampling

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1 Overview of the followed Monitoring Process in Al Ghadir River

Notre Dame University of Louaize (NDU) team abided by the EPA (2013) guidelines during the monitoring and testing of the water quality in Al Ghadir River. The monitoring steps followed by NDU are presented in Figure 1 below.

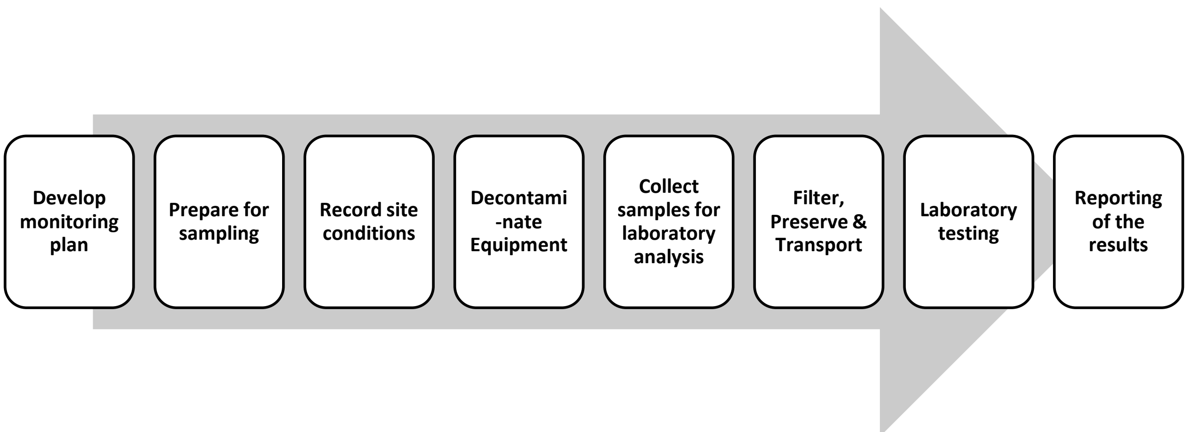

Figure 1 Stages of monitoring Process followed by NDU Team

1.1 Developing the Monitoring Plan

To guarantee that monitoring of Al Ghadir river basin is relevant, accurate, targeted, and cost-effective, a monitoring plan was developed by Notre Dame University after coordination with BTD. The last documents contained all the details of the actions, responsibilities, and timeframes that enables a delivery that meets the project objectives. Figure 2 shows the elements of the monitoring plan.

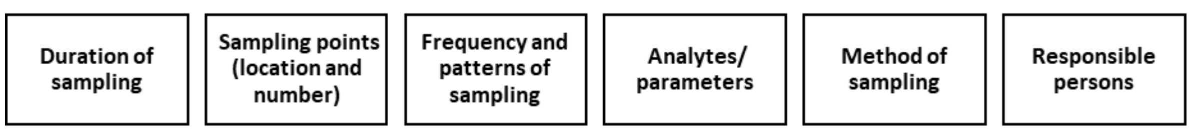

Figure 2 Elements of the Monitoring Plan

To accurately reflect the quality of the water in Al Ghadir, sampling was planned in a way that reflects water quality during both the dry and the wet seasons. The locations of 6 samples were chosen by BTD and GVC. The first sampling from Al Ghadir river took place on 15th of December 2022.

1.1.1 Duration of sampling

Sampling was made over the wet season from the Al Ghadir river to show compliance with established criteria. The sampling was made over 4 hours. Sampling in Al Ghadir can deliver information regarding the variability in the water due to random and systematic influences.

1.1.2 Sampling Locations

The sampling plan to monitor water composition in Al Ghadir river was prepared in a way to guarantee that samples are collected at sites and times that provide a representative sample, thus providing an accurate description of the overall quality of the water in the river.

Furthermore, sampling sites were located in areas that are safe to access, accessible under all conditions of flow, and well mixed to ensure a homogenous sampling collected is easily identifiable for later sampling.

Furthermore, sampling sites were located in areas that are safe to access, accessible under all conditions of flow, and well mixed to ensure a homogenous sampling collected is easily identifiable for later sampling.

Permanent sampling locations were chosen by BTD to ensure that representative samples can be compared over time.

Table 1 and Figure 1 show the coordinates and Name of the points chosen for sampling in Al Ghadir River.

Table 1 Coordinates and location of the chosen points for sampling

Number	Name	Latitude	Longitude
1	Jeser Al Aramel	33.81853474	35.51131075
2	Aser Zaaiter	33.82323273	35.52477982
3	Wadi chahrour/ sofla	33.82099338	35.54734499
4	Kfarchima-Lecico	33.82221055	35.53391979
5	Tiro-Airport	33.81952526	35.50077919
6	Costa Brava Beach	33.80324696	35.48022329

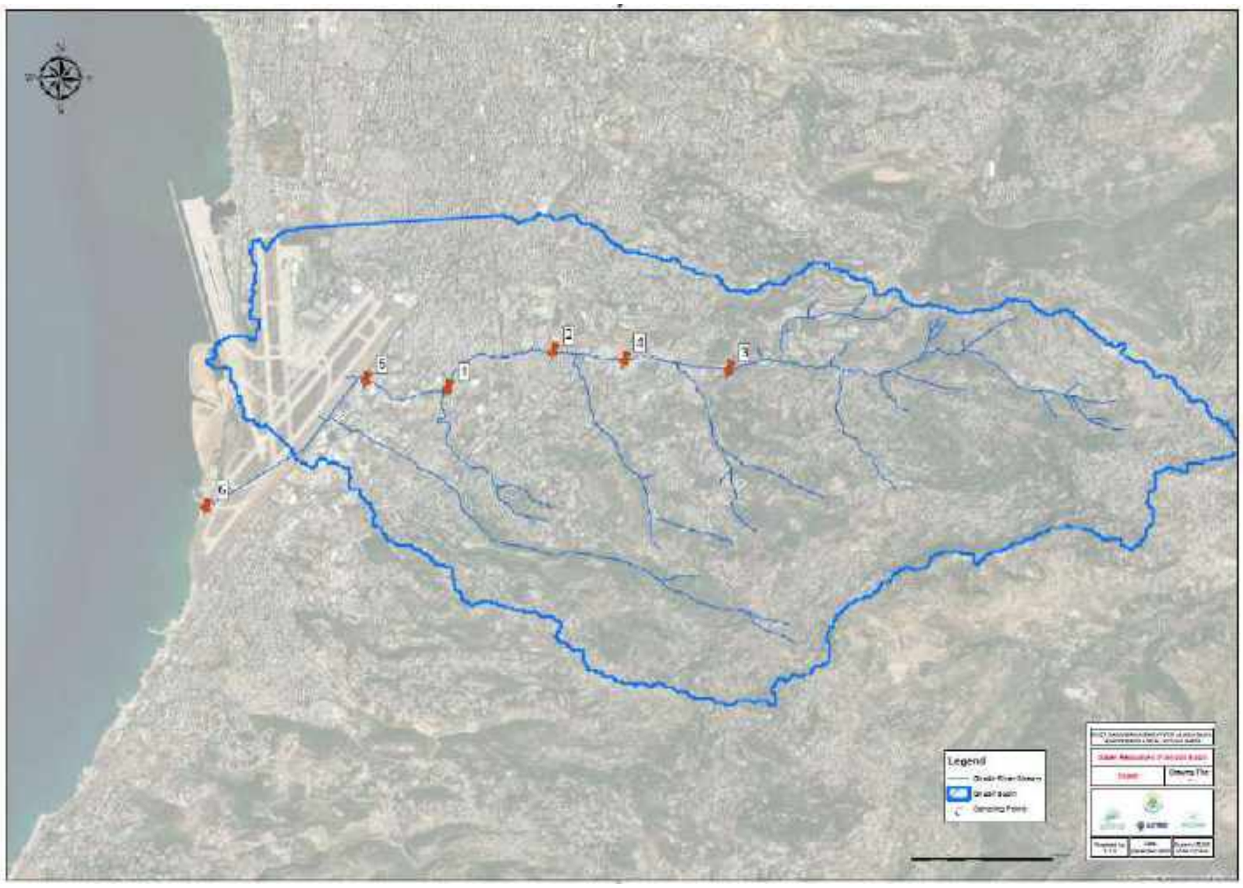

Figure 3 Representation of the different sampling locations

1.1.3 Water sampling and Procedures

The number of samples needed to determine the composition of water defines the accuracy/precision of the project (Griffiths, 2012). During the Al Ghadir first visit on December 15th (2022), six sampling points were chosen by BTD and agreed upon by the ACTED team. The grab sampling technique was used in Al Ghadir This method is recommended when the parameters to be tested are not expected to greatly vary over time.

Grab samples were chosen for this trip as they are considered samples that provide a ‘snapshot’ of the water quality characteristics at the time of sampling (dry season). Therefore, grab sampling was used as it shows the concentrations at the Ten points location (differently) and time of sampling. Nonetheless a high number equal to ten samples was used to show the nature of change over time. The sampling of all the ten points in al Ghadir was performed in one day over five hours. This method helps in showing the worst-case scenario situations, eg in the presence of surface scums of algae or oil and greases, or even very high pollution.

A sample of water was taken directly from the river at all the points using both plastic and glass containers.

Sub-surface samples were taken from approximately 15 to 20 cm depth, as the water was very shallow in the river, with care taken to ensure that no floating films or organic material were collected unless they were of specific interest. NDU team tried to collect the sample at a reasonable distance from the edge. In all points, NDU team collected the samples directly into the sample container without using intermediate containers.

1.1.4 Sampling frequency and patterns of sampling

NDU team agreed with the stakeholders that two sampling campaigns will occur in Al Ghadir River. The first during December (2022) and the second will be taken during a later stage. This sampling frequency (twice a year in two different seasons) ensures that the characteristics of the waters are adequately described resulting in a good understanding of the system and potentially accurate reporting of compliance or noncompliance with the standards (Hespanhol, & Prost, 1994).

1.1.5 Analytes

The choice of analytes with ACTED team depended on the contaminants present in Al Ghadir River and the criteria against which the monitoring is to be evaluated.

Table 2 below includes the final list of analytes to be examined on Al Ghadir river:

Table 2 Final list of analytes

Turbidity (NTU)	Phosphorous (mg/L)
pH (pH)	Chloride (mg/L)
ORP (mV)	Ammonia (mg/L)
RDO (mg/L)	Sulphate
Conductivity (µS/cm)	Fluoride
TDS (ppt)	Lithium
TS (ppt)	Calcium
Temp (°C)	Potassium
Nitrate (mg/L)	Sodium
Lead (mg/L)	DO
Cadmium (mg/L)	BOD
Barium (ɥg/L)	COD
Mercury (ɥg/L)	Total Coliform
Ecoli	Fecal Coliform

2 Planning the Sampling Event

Careful planning and preparation of the sampling event amongst NDU, BTD, and ACTED is important and help to save time and resolve the number of problems that might occur during sampling. Overall, the sampling event was very smooth, and no unexpected hurdle occurred. This was the result of careful preparation of the trip that constitutes of the following:

2.1 Logistics

The basic steps followed by NDU for planning the sampling event are as follows:

1. NDU team reviewed the monitoring plan before the trip, including monitoring locations, number of samples required, sampling methods, and Occupational Health, Safety and Welfare (OHS&W) issues.
2. NDU team informed the personnel at NDU laboratories of the intended schedule.
3. NDU team prepared a list of the needed logistics such as the containers of suitable material and volume that contain preservatives. Table 3 shows a sample of the table that describes the followed procedure to do the testing.
4. BTD team scheduled the monitoring event. NDU team planned for the day including planning how and when NDU will transport the samples back to the laboratory. NDU team prepared a template to be taken on-site that aimed to show how samples are to be preserved and delivered to the laboratory as quickly as possible and within recommended holding times. This is especially relevant for samples with holding times of 24 hours or less (see Table 3).
5. NDU team checked all equipment required for the sampling event. It ensures that the equipment is operational and calibrated and checked one day before the sampling event. Moreover, Dr. Claudette Hajj and her team from NDU have decontaminated the equipment and the sample containers to be used or even reused between samples.

Table 3 Containers, Preservation Methods and Holding times

Analyte	Container Type	Volume (ml)	Filling Technique	Preservation	Holding time
Conductivity	Glass or Plastic	100	Fill container completely to exclude air	Not required	24 Hrs.
BOD	Glass	1000	Do not pre-rinse container with sample	Refrigerate and store in the dark	24 Hrs.
PH	Glass or Plastic	100	N.A.	Refrigerate	6 Hrs.
Solids	Glass or Plastic	500	Fill a container to exclude air	Refrigerate	24 Hrs.
Turbidity	Glass or Plastic	100	Fill container completely to exclude air	Not required	24 Hrs.
Metals	Glass or Plastic	100	N.A.	Acidify with nitric acid to pH 1 to 2	1 month
Fecal,E coliforms	Sterilized Glass or plastic,	200	Do not completely fill a container	Refrigerate	preferably < 6 hrs.

Figure 4 Autoclaving the Containers

2.2 Preparation of the Equipment before and during the Sampling

Major items of equipment that were prepared by the NDU team before the sampling process are:

1. Prepare and print the Records of observations and actions sheet. Table 4 was prepared to guarantee that a complete record of each sampling site and event is kept.

Table 4 Records of observations and actions sheet Sample

Sampling summary

Sampler	Claudette	Project number	Acted- Trip 1
Date	August 31, 2022	Time (begin and end)	11:39 am

Site information

Site ID	Point 4	GPS	Table 1
Location	Al Assi	Photo numbers	

Field observations

Weather	Temperature	31 C	
	Wind and direction Cloud cover/rain	Not present-Sunny	
Water	Tide/depth	1m	
	Flow Choppy/mixed/calm	Flow	
Observations examples	Surface film?	Yes	
	Algae/phytoplankton? Debris? Odour?	No Yes Yes	
Other/additional			

During every sampling event, observations of field conditions that could assist in the interpretation of monitoring data were recorded by NDU team. This provides useful information about the water being sampled, which can help diagnose the source and potential impact of pollutants found by chemical analysis.

Examples of such field conditions recorded by the NDU team are as follows:

- Presence of Wind and Rain: YES/**NO**
- Shading from clouds and vegetation YES/**NO**
- Any abnormalities that indicate pollution or affect water quality, such as the absence of flow, presence of surface scum, **watercolor or odors**, excessive algal or plant growth, dead fish, or invertebrates should also be noted. The above was recorded at each point.

The team recorded the bad sewage smell of the water at most points. Also, the presence of solids such as cans and trashes were observed at all points, particularly at points 1, 2 5, and 6.

2. Prepare and print all Chain of Custody forms that includes all the details about each sample (sampler name, time, date, type of tests, preservation method used, container type and size, type of analysis needed) and labels and packed them for the trip.
3. Use Navigational aids (NAVA 400 GPS) to accurately locate the sampling site for future reference.
4. Decide before the trip on the field testing meters.

Decide on the analytes that quickly degrade after they are sampled and therefore must be tested in the field. Some field measurements were undertaken in situ. The following analytes were measured in the field as concentrations of these analytes can be significantly changed during transport and storage:

- Dissolved oxygen (DO)
- Temperature
- PH
- Conductivity
- Redox (reduction/oxidation potential)
- Turbidity
- Chlorine
- Salinity

The above analytes were measured using multi-parameter meters. Field meters were calibrated one day before use. In particular, dissolved oxygen, pH, and turbidity that drift from day to day were calibrated using a standard solution twice during the sampling day.

5. To preserve the integrity of the sample, the team ensured appropriate sample containers for each of the various parameters. The sample containers and preservation methods are presented in Table 2.
6. Prior to heading to the site, the team decontaminated the sampling equipment. All sampling equipment presents a risk of cross-contamination and therefore are thoroughly cleaned between samples with ethanol and distilled water. Moreover, multiple-use equipment is decontaminated prior to each sampling and between the collection of samples.
7. Most types of the sample require chilling as a means of preservation. NDU team prepared the needed esky. Samples are stored on ice in a car refrigerator, and the temperature maintained between 1°C and 4°C by adding two packs of ice every 2 hrs.

2.3 Collection of samples for analysis

Samples were collected using grab sampling from all the points in triplicates as shown in figures 7 to 12. Before the samples collection, the team made sure that the equipment is inert, and does not cause contamination or interference with the sample.

As organics have a tendency to adsorb to plastic, stainless steel equipment such as buckets and sampling rods were used. Glass sample containers were used in most cases, additional samples were taken in plastic containers. The team followed EPA Appendix 2 for information on the type of sampling container (eg glass, plastic), typical required volume, filling technique and preservation requirements for common analytes.

2.4 Sample Identification, Transport, and Storage

Samples were labelled by NDU team so they can be readily identified at all times. Sample containers were marked using permanent markers in such a way that they can be identified and distinguished from other samples in the laboratory. Care was taken when packing samples, as they are often subject to vibration during transport. Sample labels have specified a clear and unique identifying code that can be cross-referenced to the monitoring location and time of sampling and includes: the date, time, location, name of sampling site, and name of a sampler.

Figure 5 Sampling directly into the container

Figure 6 Filling and Labeling of the Samples on Site

During sample transport and storage, the NDU team followed key precautions to ensure effective transport and storage:

- Samples are appropriately packed to avoid breakage and cross-contamination.
- Ensure the time between sampling and analyzing not to exceed holding time.
- Sample containers are sealed, carefully packed with appropriate packing material, chilled or frozen (as required), and transported in an appropriate cooler or fridge.

2.5 Lab testing

Table 5 shows the test methods used at NDU labs to perform the needed testing. The procedure followed in these sections were accurately followed.

Table 5 Test methods

Parameter	Test Method
BOD 5	EMDC1 1173: Part 3 ± Five-day BOD Method
COD	EMDC1 1173: Part 4 ± Dichromate Digestion Method
PH	EMDC1 1173: Part 2 ± Electrometric Method
Temperature	EMDC1 1173: Part 1 ± Electrometric Method
Total Suspended Solids	EMDC1 1173: Part 1 ± Gravimetric Method
TS	EMDC1 1173: Part 3 ± Gravimetric Method
Turbidity	APHA Standard Methods:2130 B. Nephelometric Method
Chlorides (Cl -)	APHA Standard Methods: 4110 B. Ion Chromatography with Chemical Suppression of Eluant Conductivity
Cadmium	EMDC1 1173: Part 7 ± Flame Atomic Spectrometry Absorption Spectrometry
Barium (Ba)	EMDC1 1173: Part 7 ± Direct Nitrous Oxide-Acetylene Flame Atomic Absorption
Fluorides (F-)	APHA Standard Methods: 4110 B. Ion Chromatography with Chemical Suppression
Lead	EMDC1 1173: Part 7 ± Flame Atomic Absorption Spectrometry
Mercury (Hg)	EMDC1 1173: Part 10 ± Cold-Vapor Atomic
Nitrates (NO3 -)	APHA Standard Methods: 4110 B. Ion Chromatography with Chemical Suppression
Phosphorus	EMDC1 1173: Part 6 ± Colorimetric
Lithium	EMDC1- Flame photometry
Calcium	EMDC1 Flame photometry
Sodium	EMDC1 Flame photometry
Potassium	D992 Flame photometry
Nitrate	D1254 11C2: Flame Atomic Absorption Spectrometry
Ammonia	D1426: Flame Atomic Absorption Spectrometry
Total Coliform Organism	ISO 6222:1999, Microbiological method

3 Lab Results

Results obtained following the physical, biological and chemical testing of data collected (see Table 6 to Table 13), indicating a neutral PH.

Total Dissolved Solids are a measure of all ions in a solution (TDS). TDS measurements were greater than 500 mg/L for all the samples and could reach a very high value of 7275 mg/L at point 5. DO was found to be very low for all the points varying between 0.04 to 1.8mg/L. Dissolved oxygen is a key indicator of water quality. It is essential for fish and other aquatic organisms to survive, therefore when the water has a low dissolved oxygen level (<6.5 mg/L), water conditions become lethal. When DO levels drop below 5 mg/L, as in the case of the AL Ghadir river, any aquatic life present is put under extreme stress. If DO levels remain below 1-2 mg/L longer than a few hours, it results in fish death. It primarily results from excessive algae growth caused by phosphorus.

Below are the results of the field measurement:

Table 6 Results of Point 1

Point Number	**Point Name**			**Nb of readings**
1	**Jeser Al Aramel**			**3**
Report Properties	Start Time = 2022-08-31 08:46:48 Duration = 00:00:20			
Sample Number	1a	1b	1c	**Average**
Turbidity (NTU)	3497	3342	3478	**3439**
RDO (mg/L)	0.091	0.089	0.089	**0.0901**
A-Conductivity (µS/cm)	1190	1193	1193	**1192**
S-Conductivity (µS/cm)	1396	1400	1400	**1398**
Salinity (PSU)	0.705	0.708	0.708	**0.707**
TDS (ppt)	907	901	910	**909**
TS	2188	2210	2208	**2203**
pH (pH)	7.26	7.24	7.2	**7.25**
Temperature (°C)	17.27	17.26	17.26	**17.26**
Nitrate (mg/L)	1.61	1.8	1.96	**1.79**
Lead (mg/L)	0.1	0.1	0.1	**0.1**
Cadmium (mg/L)	0.09	0.09	0.102	**0.094**
Barium (mg/L)	0.1	0.1	0.1	**0.1**
Mercury (ɥg/L)	0.02	0.02	0.02	**0.02**
Sodium (ppm)	15	19	17	**17**
Potassium (ppm)	7.8	8.2	8.0	**8**
Lithium (ppm)	0	0	0	**0**
Calcium (ppm)	20.2	21.4	20.7	**20.8**
Phosphorous (mg/L)	4.40	4.60	4.44	**4.58**
Chloride (mg/L)	>200	>200	>200	**>200**
Ammonia (mg/L)	1.49	1.82	1.61	**1.64**
Sulfate	196	203	198	**199**
Fluoride	1	1	1	**1**
DO	0.19	0.19	0.19	**0.19**
BOD	394	430	382	**411**
COD	753	711	730	**731**
Total Coliform	220	210	230	**220**
Fecal	160	155	165	**160**
E coli	130	130	130	**130**

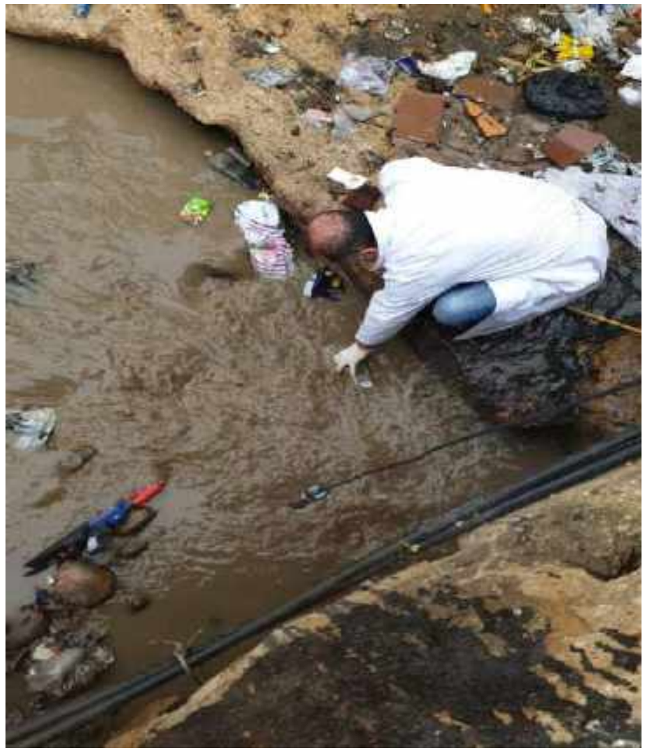

Figure 7 Sampling at point 1

Table 7 Results of Point 2

Point Number		**Point Name**		**Nb of readings**
2		**Aser Zaaiter**		**3**
Sample Number	2a	2b	2c	Average
Turbidity (NTU)	3749	3897	3930	**3858**
RDO (mg/L)	1.800	1.810	1.799	**1.803**
A-Conductivity (µS/cm)	713	716	717	**715**
S-Conductivity (µS/cm)	811	813	815	**813**
Salinity (PSU)	0.401	0.402	0.403	**0.402**
TDS (ppt)	527	528	529	**528**
TS	1495	1550	1419	**1488**
pH (pH)	7.3	7.3	7.3	**7.3**
Temperature (°C)	18.7	18.7	18.7	**18.7**
Nitrate (mg/L)	1.69	1.85	1.83	**1.79**
Lead (mg/L)	<0.1	<0.1	<0.1	**<0.1**
Cadmium (mg/L)	0.1	0.1	0.1	**0.1**
Barium (mg/L)	0.2	0.2	0.2	**0.2**
Mercury (ųg/L)	0.04	0.04	0.04	**0.04**
Sodium (ppm)	9	7	10	**9**
Potassium (ppm)	2.8	2.8	2.7	**2.8**
Lithium (ppm)	0.001	0.001	0.001	**0.001**
Calcium (ppm)	11.2	12.6	11.9	**11.9**
Phosphorous (mg/L)	3.4	3.1	3.34	**3.28**
Chloride (mg/L)	97	92	102	**97**
Ammonia (mg/L)	<1	<1	<1	**<1**
Sulfate	150	146	139	**145**
Fluoride	0.8	0.7	0.8	**0.8**
DO	0.3	0.3	0.3	**0.3**
BOD	360	357	351	**356**
COD	525	524	517	**522**
Total Coliform	190	180	200	**190**
Fecal	130	130	130	**130**
E coli	110	110	110	**110**

Figure 8 Sampling at point 2

Table 8 Results of Point 3

Point Number	Point Name			Nb of readings
3	**Wadi Chahrour al Sofla**			**3**
Sample nb	3a	3b	3c	**Average**
Turbidity (NTU)	3644	3615	3442	**3567**
RDO (mg/L)	0.950	0.941	0.942	**0.944**
A-Conductivity (µS/cm)	775	781	780	**778**
S-Conductivity (µS/cm)	835	842	841	**840**
Salinity (PSU)	0.414	0.418	0.417	**0.416**
TDS (ppt)	540	546	547	**544**
TS	1622	1599	1606	**1609**
pH (pH)	7.5	7.5	7.5	**7.5**
Temperature (°C)	21.2	21.2	21.2	**21.2**
Nitrate (mg/L)	1.59	1.63	1.64	**1.62**
Lead (mg/L)	0.38	0.38	0.37	**0.38**
Cadmium (mg/L)	0.087	0.088	0.088	**0.088**
Barium (mg/L)	0.3	0.3	0.3	**0.3**
Mercury (ųg/L)	0.02	0.02	0.02	**0.02**
Sodium (ppm)	10	10	9	**10**
Potassium (ppm)	3.4	3.3	3.4	**3.4**
Lithium (ppm)	0	0	0	**0**
Calcium (ppm)	14.4	14.3	14.3	**14.4**
Phosphorous (mg/L)	3.11	3.17	3.20	**3.16**
Chloride (mg/L)	147	152	160	**153**
Ammonia (mg/L)	3.63	3.59	3.49	**3.54**
Sulfate	171	188	180	**180**
Fluoride	1	1	1	**1**
DO	0.28	0.28	0.28	**0.28**
BOD	366	386	373	**375**
COD	621	630	588	**613**
Total Coliform	140	120	130	**130**
Fecal	90	90	90	**90**
E coli	70	70	70	**70**

Figure 9 Sampling at point 3

Table 9 Results of Point 4

Point Number	Point Name			Nb of readings
4	**Kfarchima-Lecico**			**3**
Sample Nb	4a	4b	4c	**Average**
Turbidity (NTU)	3917	3679	3695	**3764**
RDO (mg/L)	0.043	0.043	0.041	**0.042**
A-Conductivity (µS/cm)	735	738	741	**738**
S-Conductivity (µS/cm)	802	805	808	**805**
Salinity (PSU)	0.398	0.399	0.400	**0.399**
TDS (ppt)	522	523	525	**523**
TS	2106	2105	2083	**2098**
pH (pH)	7.8	7.8	7.8	**7.8**
Temperature (°C)	20.6	20.7	20.7	**20.7**
Nitrate (mg/L)	2.23	2.18	2.16	**2.19**
Lead (mg/L)	0.1	0.1	0.1	0.1
Cadmium (mg/L)	0.1	0.1	0.1	0.1
Barium (mg/L)	0.002	0.002	0.002	**0.002**
Mercury (ųg/L)	0.06	0.06	0.06	**0.06**
Sodium (ppm)	10.7	10.6	10.8	**10.7**
Potassium (ppm)	3.5	3.5	3.5	**3.5**
Lithium (ppm)	0	0	0	**0**
Calcium (ppm)	13.3	12.5	13.8	**13.2**
Phosphorous (mg/L)	2.91	3.01	2.39	**2.77**
Chloride (mg/L)	111	108	106	**109**
Ammonia (mg/L)	<1	<1	<1	<1
Sulfate	160	177	167	**169**
Fluoride	1	0.9	0.8	**0.9**
DO	0.20	0.16	0.15	**0.17**
BOD	400	386	411	**399**
COD	649	670	631	**650**
Total Coliform	270	290	300	**290**
Fecal	210	210	210	**210**
E coli	180	180	180	**180**

Figure 10 Sampling point 4

Table 10 Results of Point 5

Point Number		Point Name		Nb of readings
5		**Tiro-Airport**		**3**
Sample Nb	5a	5b		**Average**
Turbidity (NTU)	1611	1611	1669	**1630**
RDO (mg/L)	1.058	0.820	1.050	**0.976**
A-Conductivity (µS/cm)	3509	3463	3435	**3469**
S-Conductivity (µS/cm)	3954	3902	3942	**3933**
Salinity (PSU)	2.12	2.09	2.11	**2.10**
TDS (ppt)	2575	2536	2562	**2558**
TS	5110	5195	5130	**5145**
pH (pH)	7.3	7.3	7.3	**7.3**
Temperature (°C)	19.1	19.1	19.1	**19.1**
Nitrate (mg/L)	1.86	1.90	2.03	**1.93**
Lead (mg/L)	1.62	1.58	1.60	**1.61**
Cadmium (mg/L)	0.17	0.19	0.22	**0.19**
Barium (mg/L)	0.2	0.2	0.2	**0.2**
Mercury (ɥg/L)	0.09	0.09	0.09	**0.09**
Sodium (ppm)	74	73	63	**70**
Potassium (ppm)	7.9	7.7	7.7	**7.8**
Lithium (ppm)	0.10	0.1	0.1	**0.1**
Calcium (ppm)	31.3	33.2	32.7	**32.4**
Phosphorous (mg/L)	2.99	3.24	3.4	**3.21**
Chloride (mg/L)	>200	>200	>200	**>200**
Ammonia (mg/L)	11.5	12	11	**11.5**
Sulfate	>200	>200	>200	**>200**
Fluoride	0.9	0.9	0.9	**0.9**
DO	0.29	0.39	0.31	**0.33**
BOD	618	595	595	**601**
COD	829	848	819	**832**
Total Coliform	350	370	360	**360**
Fecal	310	310	310	**310**
E coli	260	250	240	**250**

Figure 11 Sampling point 5

Table 11 Results of Point 6

Point Number		Point Name		Nb of readings
6		Costa Brava Beach		3
Sample nb	**6a**	**6b**	**6c**	**Average**
Turbidity (NTU)	3663	3547	3602	**3604**
RDO (mg/L)	0.050	0.046	0.042	**0.046**
A-Conductivity (µS/cm)	9049	9107	9095	**9084**
S-Conductivity (µS/cm)	9900	9964	9951	**9938**
Salinity (PSU)	5.64	5.68	5.67	**5.66**
TDS (ppt)	6434	6476	6468	**6459**
TS	8844	9119	8844	**8891**
pH (pH)	6.9	6.9	6.9	**6.9**
Temperature (°C)	20.5	20.5	20.5	**20.5**
Nitrate (mg/L)	1.41	1.22	1.39	**1.34**
Lead (mg/L)	1.60	1.64	1.62	**1.62**
Cadmium (mg/L)	0.22	0.21	0.23	**0.22**
Barium (mg/L)	1.6	1.6	1.6	**1.6**
Mercury (ųg/L)	0.11	0.11	0.11	**0.11**
Sodium (ppm)	182	184	189	**185**
Potassium (ppm)	16	16	16	**16**
Lithium (ppm)	0.1	0.1	0.1	**0.1**
Calcium (ppm)	61	77	66	**68**
Phosphorous (mg/L)	3.30	3.37	3.50	**3.39**
Chloride (mg/L)	>200	>200	>200	**>200**
Ammonia (mg/L)	17	17.9	20.9	**18.6**
Sulfate	>200	>200	>200	**>200**
Fluoride	0.9	0.9	0.9	**0.9**
DO	0.33	0.32	0.46	**0.37**
BOD	638	627	601	**622**
COD	966	1013	967	**982**
Total Coliform	390	440	400	**410**
Fecal	340	350	360	**350**
E coli	270	270	270	**270**

Figure 12 Sampling point 5

Water safety and quality are fundamental to human development and well-being. Providing access to safe water is one of the most effective instruments in promoting health and reducing poverty. To analyze the water quality in the Al Ghadir river we need to compare our lab results values to the water standards that are intended to protect public health. Recognizing this, we are abiding by World Health Organization (WHO) normative "guidelines" that present an authoritative assessment of the health risks associated with exposure to health hazards through water and of the effectiveness of approaches to their control.

WHO Water quality guidelines specify the conditions water must meet to protect those specific uses. Measuring Al Ghadir river water results against water quality standards shows which bodies of water or which exact location needs restoration and protection and dictates how we set limits on pollutant discharges from public and private facilities.

Below, Table 12 shows the WHO Standards Limit for surface water. Our value from AL Ghadir water testing will be compared to these limits to examine it is quality.

Table 12 WHO Standards Limit Table (Boyd,2019)

Chemical Product	WHO Limit	Chemical Product	WHO Limit
Ph	6.5-8.45	CL- (mg/L)	250
Temp °C	15-21	F^{-} (mg/L)	1.5
EC (ɥS/cm)	1500	$PO_4{}^{3-}$ (mg/L)	1
TDS (mg/L)	500	Ca^{2+} (mg/L)	200
BOD (mg/L)	25	Mercury (mg/L)	0.002
COD (mg/L)	25	Barium (mg/L)	1.3
Na^{2+} (mg/L)	150	Cadmium (mg/L)	0.005
$K+^{+}$(mg/L)	12	Lead (mg/L)	0.015
NH_4^{+} (mg/L)	1.5	Total Nitrogen	50
SO_4^{2-} (mg/L)	250	NO_3^{-} (mg/L)	50

Below is a summary of all the results got from testing AL Ghadir river (Table 13). Highlighted in red are the values that exceed the WHO standards for the tested quality parameter.

Table 13 Summary of the results

Test/Point	Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Pt 6
Turbidity (NTU)	3439	3858	3567	3764	1630	3604
pH (pH)	7.25	7.3	7.5	7.8	7.3	6.9
RDO (mg/L)	0.09	1.803	0.944	0.042	0.976	0.046
A-Conductivity (µS/cm)	1192	715	778	738	3469	9084
S-Conductivity (µS/cm)	1398	813	840	805	3933	9938
Salinity (PSU)	0.71	0.402	0.416	0.399	2.1	5.66
TDS (mg/L)	909	528	544	523	2558	6459
TS (ppt)	2203	1488	1609	2098	5145	8891
Temp(°C)	17.26	18.7	21.2	20.7	19.1	20.8
Nitrate (mg/L)	1.79	1.59	1.62	2.19	1.93	1.34
Lead (mg/L)	0.1	<0.1	0.38	0.1	1.61	1.62
Cadmium (mg/L)	0.094	0.1	0.088	0.1	0.19	0.22
Barium (ppm)	0.1	0.2	0.3	0.002	0.2	1.6
Mercury (ųg/L)	0.02	0.04	0.02	0.06	0.09	0.11
Sodium (ppm)	17	9	10	10.7	70	185
Potassium (ppm)	8	2.8	3.4	3.5	7.8	16
Lithium (ppm)	0	0.001	0	0	0.1	0.1
Calcium (ppm)	20.8	11.9	14.4	13.2	32.4	68
Phosphorus (mg/L)	4.58	3.28	3.16	2.77	3.21	3.39
Chloride (mg/L)	>200	97	153	109	>200	>200
Ammonia (mg/L)	1.64	<1	3.54	<1	11.5	18.6
Sulfate	199	145	180	169	>200	>200
Fluoride	1	0.8	1	0.9	0.9	0.9
DO	0.19	0.3	0.28	0.17	0.33	0.37
BOD	411	356	375	399	601	622
COD	731	522	613	650	832	982
Total Coliform	220	190	130	290	360	410
Fecal	160	130	90	210	310	350
Ecoli	130	110	70	180	250	270

4 Discussion and Interpretations

Water samples were collected from Al-Ghadir River during the wet season and tested for physical qualities, chemical contents, and microbiological counts. Six sampling points were selected. Water quality parameters, such as conductivity, DO, BOD, COD, pH, TS, DS, and Fecal Coliform were analyzed. The concentration of lead, cadmium, mercury, barium, lithium, sodium, potassium, chloride, sulfate, fluoride, ammonia, phosphorus, and nitrate was also analyzed at all the points. The examination of the results is shown below:

Measuring **Dissolved Oxygen** (**DO**) in drinking water is an important property of water quality. DO is critical for fish and other aquatic organisms to survive. DO values for Al-Ghadir river, along our reach varied between 0.17 mg/L to 0.37 mg/L. WHO standard for sustaining aquatic life is <4 mg/L, whereas for drinking purposes it is 6 to 8.5 mg/L. Therefore, all the examined points are not suitable for drinking and aquatic life. Very low. Low levels of oxygen (hypoxia) or no oxygen levels (anoxia) means that there are excess organic materials, such as large algal blooms, that are decomposed by microorganisms in the studied river. While each organism has its own DO tolerance range, generally, DO levels below 3 milligrams per liter (mg/L) are of concern, and waters with levels below 1 mg/L, such as in our case, are considered hypoxic and usually devoid of life.

While in the case of **Biological Oxygen Demand (BOD)** concentration, the results recorded values ranging from 356 mg/L and 622 mg/L. Most rivers have BOD_5 below 1 mg/L. Moderately polluted rivers may have a BOD_5 value in the range of 2 to 8 mg/L. High BOD_5 levels (>8mg/L) can be a result of high levels of organic pollution, caused usually by poorly treated wastewater, or from high nitrate levels (EEA, 2001). WHO standard for surface water is 25 mg/L, which is exceeded to a great extent as shown by the values in Table 13. High BOD_5 values were detected at all sites which may be attributed to high levels of Nitrates and phosphates. These high values indicate that sewage or industrial wastewater is penetrating Al-Ghadir river.   High biochemical oxygen demand can be caused by: high levels of organic pollution, caused usually by poorly treated wastewater or non-treated wastewater penetrating the river; high nitrate levels, which trigger high plant growth. Both result in higher amounts of organic matter in the river.

Chemical Oxygen Demand (**COD**) is another important parameter of water quality assessment. A standard for surface purposes is 125 mg/L, which is exceeded for all sites in the studied river. Table 12 shows the COD data of six sampling points. The highest levels of COD recorded may be also attributed to raw sewage discharge, and for the same reasons stated in the BOD examination.

Concerning the **pH** which is an indicator of the acidic or alkaline condition of water status, the standard for any purpose is 6.5-8.5, in that respect; the values of our sampled water conform with the standards because the values vary between 6.9 and 7.8. All sites exhibited values of pH within the limits of the natural values that support aquatic life.

Adding to the above, the value of **electric conductivity** (**EC**) of Al-Ghadir river varied between 715 and 9084 µs/cm. Conductivity depends on the number of ions present in water. The conductivity is very high for most of the points and exceeded the acceptable standards for rivers and surface water (< 1500 µs) for points 1,5, and 6. A main observation from the results is that conductivity is directly influenced by TDS, the higher the TDS the higher the EC (Lawson, 2011).

Likewise, **total solids concentrations** in the wet season varied between a minimum of 1488 mg/L at point 2 and a maximum of 8891 mg/L at point 6. Many factors contribute to high levels of total solids in water, with soil erosion being a major contributor. An increase in the water flow rate or a decrease in stream bank vegetation can speed up the process of soil erosion, thus contributing to the levels of suspended particles such as clay and silt. Human activity is also responsible for high TS levels in Al-Ghadir river. Common human pollution contaminants include pesticides, lead, bacteria, and mercury.

Concerning **Dissolved Solids (DS)**, the standard for drinking water is 500 mg/L. The minimum and maximum values obtained from the samples in the wet season are 523 at point 4 mg/L and 6459 mg/L at point 6. In this respect, we can conclude that Al-Ghadir river water quality is not acceptable. High levels of TDS at some points are caused by the presence of potassium, chlorides, and sodium and by toxic ions (lead arsenic, cadmium, and nitrate), and result in an undesirable taste that could be salty, bitter, or metallic, discolor the water, and create an unpleasant odor. (Lawson, 2011).

Similarly, the WHO standard for **ammonia** in the surface water is 1.5 mg/L. The results yielded from the test results showed higher values for most of the sites (1,3,5 and 6) reaching 18.6 mg/L at the last point, which means it is very dangerous in terms of ammonia pollution. These high levels of ammonia might be attributed to agricultural runoff in addition to raw sewage discharge. Likewise, ammonia peak might be associated with a nutrient influx in streams with little to no flow and low DO content (Ryan et al. 2002). Ammonia levels above the recommended limits may harm the whole aquatic life. Ammonia toxicity is thought to be one of the main causes of unexplained losses in fish hatcheries. Excess ammonia may accumulate in the organism and cause an alteration of metabolism or increases in body pH.

Adversely, the levels of **nitrate** exhibited a similar fluctuation among the sites ranging all within the acceptable levels (5 mg/l).

Apart from the above, we have traced **metal detection** in the water. These chemicals are classified as being potentially hazardous and toxic to most forms of life. Results reported that trace metals' concentrations for **lead, mercury, and cadmium** were very high at all points and mostly elevated at points 4, 5, and 6. The above results imply that the river is receiving mercury and lead from the direct discharge of industrial wastes directly into the river. The elevated concentration of these toxic compounds in the water can be detrimental to people's health. For example, even in small doses, lead exposure can cause brain and nervous system damage, while PFAS exposure is linked to cancer, thyroid disease, and other health problems.

Moreover, some of the chemical elements like **Sodium, potassium, lithium, and calcium** are essential as micronutrients for the life processes in animals and plants (Kar et al., 2008). Fortunately, acceptable concentrations were found in Al Ghadir.

Similarly, **phosphorus** concentrations recorded values greater than 2.77 mg/L for all the sampled Comparing these results with WHO limits, they exceed the acceptable level of phosphorus (1mg/L) in rivers. The high level of phosphate at all these sites might be due to anthropogenic sources, mainly, agricultural runoff, animal waste, raw sewage, or different types of rubbish that are thrown into the river. Excess phosphate in surface runoff might lead to cultural eutrophication. During this phenomenon, PO_4^{3-} in freshwater leads to a favorable condition for algae and weed growth, which ultimately brings a rapid reduction in the ecosystem through oxygen depletion.

Similarly, **chloride** concentration documented values varying from 97 at point 2 to >200 mg/L at points 1,5, and 6. Compared with WHO guidelines, the level of chloride at the latter sites confirms that there are industrial effluents or urban runoff at the location of the sample.

The **sulfate** recorded a mean value of less than 199 mg/L for sites 1 to 4. Compared with WHO guidelines, the results fall within the acceptable range (<200 mg/L), however at sites 5 and 6, the concentration of sulfate exceeded the acceptable level. Acid drainage, fertilizer leaching from agricultural soils, wetland drainage, and agricultural and industrial wastewater runoff as well as sea level changes are the main direct and indirect sources of the anthropogenic SO42- input to ALGhadir river.

Moreover, **fluoride** concentrations were recorded at all sites, yet no marked variation was observed. Acceptable values were found at all sites.

Apart from the physical and chemical parameters, the water was tested for microbiological pollutants. The results of the six sampling points show that all sites are bacteriologically contaminated to an extreme extent. Total, fecal, and E-coli were detected at all sites and were too numerous indicating the critical condition of excessive microbiological contamination. The presence of fecal coliform bacteria in very high levels indicates potential health risks to swimmers and implies the unsuitability of the water at these critical points for specific water most domestic water uses. The source of organic and microbial pollutants present in the water can be accounted for by the seepage of industrial wastewater into the river and support the presence of agricultural runoff, and animal waste, raw sewage, (Amacha et al., 2012).

According to the WHO standards and the European Economic Community, fecal coliforms in river water are should not exceed 100 FC/100 ml (Servais et al. 2007). Several health outcomes such as gastrointestinal infections might be associated with fecally polluted water which may result in a significant burden of disease (WHO 2001).

To sum up, the results from data analysis show that, the water is certainly unfit for drinking purposes without any form of treatment, but for various other surface water usage purposes, it still could be considered quite acceptable. But as we know, once a trend in pollution sets in, it generally accelerates to cause greater deterioration. So, a few years from now, serious water quality deterioration could take place.

5 Conclusion

The water quality of the Al-Ghadir River was analyzed. The physical, bacteriological, and chemical composition of the river was studied in the wet season. All sites exhibited values of pH within the limits of the natural values that support aquatic life. The levels of TDS were fluctuating among the sites with the highest values recorded at site 6 which is extremely violating the guideline and implies seawater and wastewater intrusion. Higher BOD_5 values were detected at sites 5 and 6 which may be attributed as well to seepage of industrial and raw sewage water. The levels of nitrate exhibited a clear fluctuation among the sites ranging yet falling below the limit for surface water. The estimated indices at sites 5 and 6 exhibited the worst water quality conditions among the studied sites.

WHO specifies guidelines and imperative values for drinking and aquatic life were used. This assessment was adopted as the Lebanese Ministry of Environment (MOE) Standards for surface water, do not include all of the parameters reported here.

Results revealed that the water quality of the AL Ghadir River is very polluted and generally affected by activities related to industrial wastes and raw sewage wastes.

6 Quality Assurance and Performance

Quality assurance (QA) plan contains the policies, procedures and actions established to provide and maintain a degree of confidence in data integrity and accuracy. For the monitoring trip to AL Ghadir River to successfully meet its objectives, NDU took rigorous and thorough steps to ensure that its testing campaign is reliable. The team followed EPA standards for monitoring and sampling procedures. The QA system shown in Table 14 was followed.

Moreover, Water sampling quality control ensures that the monitoring data taken sufficiently represents the in-situ conditions of the Al Ghadir River. Any significant change of contamination to the sample due to containers, handling and transportation is identified through the incorporation of QC. Therefore, all labs tests at NDU were taken in triplicates and a comparison of the results was examined. In all cases no outliers was found, and the average was taken for all the parameters

Table 14 Quality control in monitoring

Monitoring Step	QC protocols	Purpose	Refer to Compulsory
Develop monitoring plan	Various, including control sites, multiple sample locations, duplicate samples, sampling times	Ensure the sample collected is representative of the body from which it was taken	Section 1 in this report
Sample collection	Appropriate containers, filling, and preservation techniques	Minimize changes to sample (physical and chemical)	Section 2
	Sample blanks—field, transport, equipment, and container	Quantify contamination of samples during the sampling process	Section 3
	Decontamination of sampling equipment	Minimize contamination	Section 3
Field testing	Equipment calibration	Minimize and quantify bias and error in-field equipment	Section 3
Transport and storage	Appropriate preservation techniques	Minimize physical and chemical changes to sample	Section 4
Analysis	NDU lab accredited by ABET for required analysis	Ensure the laboratory undertakes appropriate QC including spikes, calibration of equipment, and make sure the results are reported in triplicates	Section 5 and 6
Reporting	Peer review validation	Validate that sampling is undertaken as per the monitoring plan and by sampling guidelines	Section 5 to 7

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B.First Participatory Workshop Report

Challenges

Municipalities

- Problem with intermixing of rainwater and wastewater and the need for separation.
- Illegal construction within Ghadir river bed.
- Industrial pollution along the riverbed – need to revise CDR studies for this issue.
- No integration between ministries (MoE, MoEW, and MoI) and the need for collaboration.
- Insufficient cleaning of Ghadir riverbed.
- Problem with leachate generated from Costa Brava landfill.
- Inadequate capacity of the existing sewer lines in the area and the need for new survey and increase the hydraulic capacity of the system.

Research Institutes and Academia

- Identify and locate primary point sources of pollution and address priorities (e.g., industries, farmers, etc.)
- Absence of government in regards to alleviating pollution on Ghadir river and proposition towards micro and decentralized management. Recommendation to install several small-scale WWTPs to limit pollution and reduce load on the existing central preliminary Ghadir WWTP.
- Absence of identification of project stakeholders and no reliance in specific criteria during solution discussions.
- Problem with salt water intrusion into the many private wells in the watershed area leading to contaminated water not suitable for domestic usage – recommendation to head towards usage of surface water sources and groundwater aquifer recharge.

Environmental Activists and Organizations

- Problem with industrial pollution and necessity to do preliminary or secondary treatment for each industry prior discharge into the wastewater network or the surface water.
- Absence of municipal roles and their financial weakness.
- Decentralized vs. centralized wastewater solutions – a study of cost/benefit and requirement of proper alternative analysis and selection criteria.

Suggested Solutions

Group A:

- Definition and delineation of the public Ghadir riverbed border/domain.
- Removal of all illegal structures within the river domain and assignment and implementation of penalties.
- Updating of the already assigned solutions (from studies with the CDR) and their compilation
- Better involvement and inclusion of the municipalities and locate funding sources
- Division of the problem into subparts and solving one subpart after the other
- Awareness campaigns
- As a temporary and immediate solution, proposition to construct retainment structures to protect the illegal houses within the river domain from heavy flash floods during the rainy season.

Group B:

- Creation of a committee that is responsible for planning and assigning of solution for the industrial pollution in the area
- Awareness campaigns
- Legal Accountability
- Complete surveying of illegal structures within the riverbed domain
- Investing in rainwater harvesting projects
- Groundwater recharge
- Excavation of additional pathways for the river to disperse and divide the flow and therefore reduce the intensity and concentration of the floods.

Group C:

- Maintenance of the existing wastewater network and installation of new networks to increase the connection coverage rate to Ghadir WWTP and upgrading of the plant to include additional secondary and tertiary treatment stages.
- Construction of a system of decentralized small-scale WWTPs and finding of mutual benefits
- Increase awareness campaigns

C.Geological sections

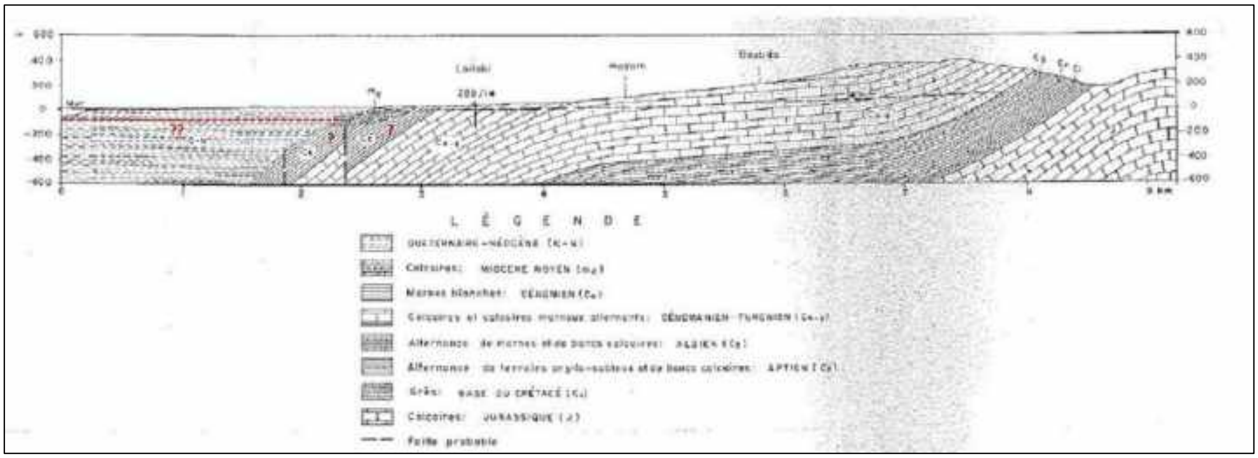

Figure A 1 Geological section crossing through the study area (modified from UNDP, 1970)

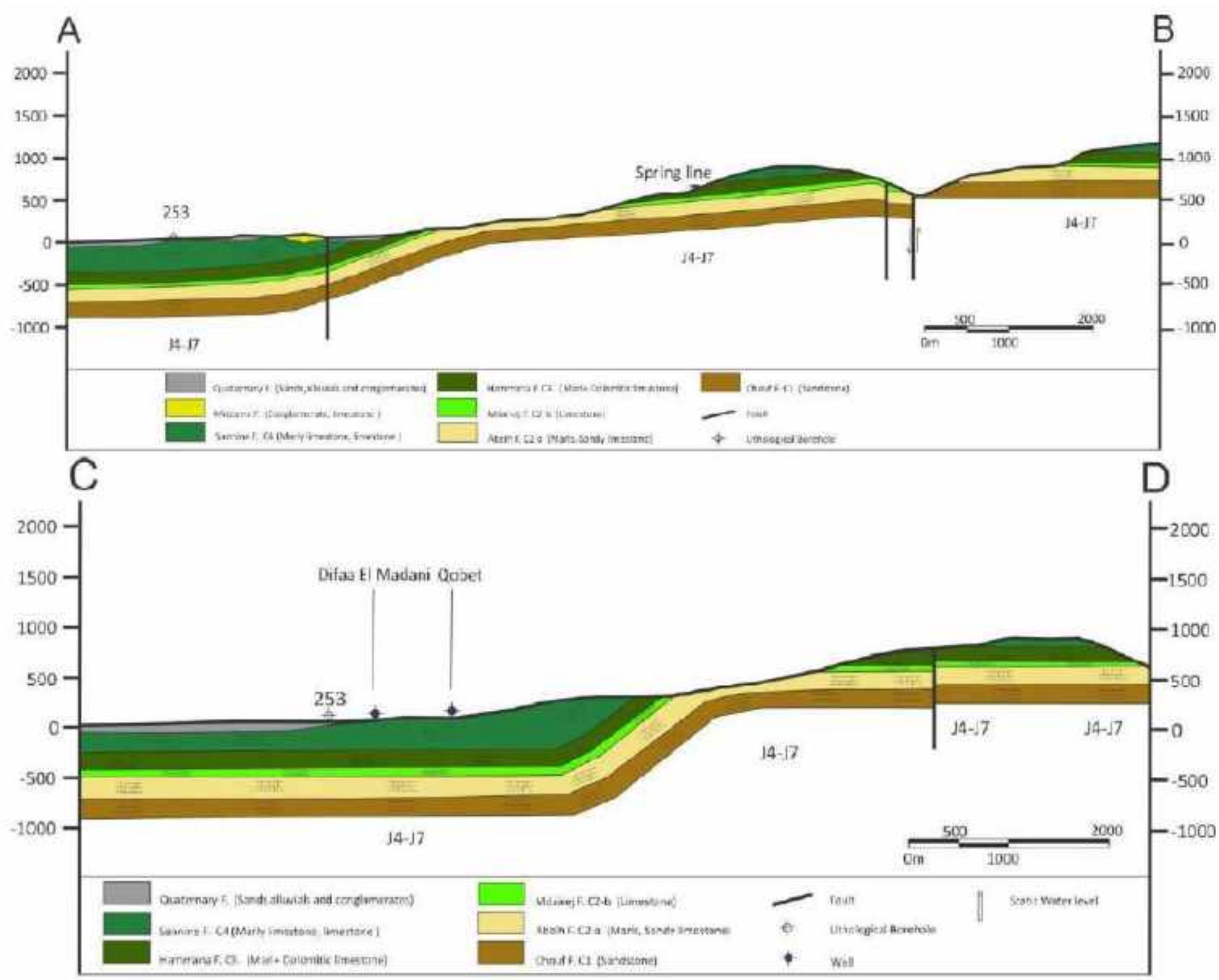

Figure A 2 Geological cross sections AB & CD (Doummar et al., 2015)

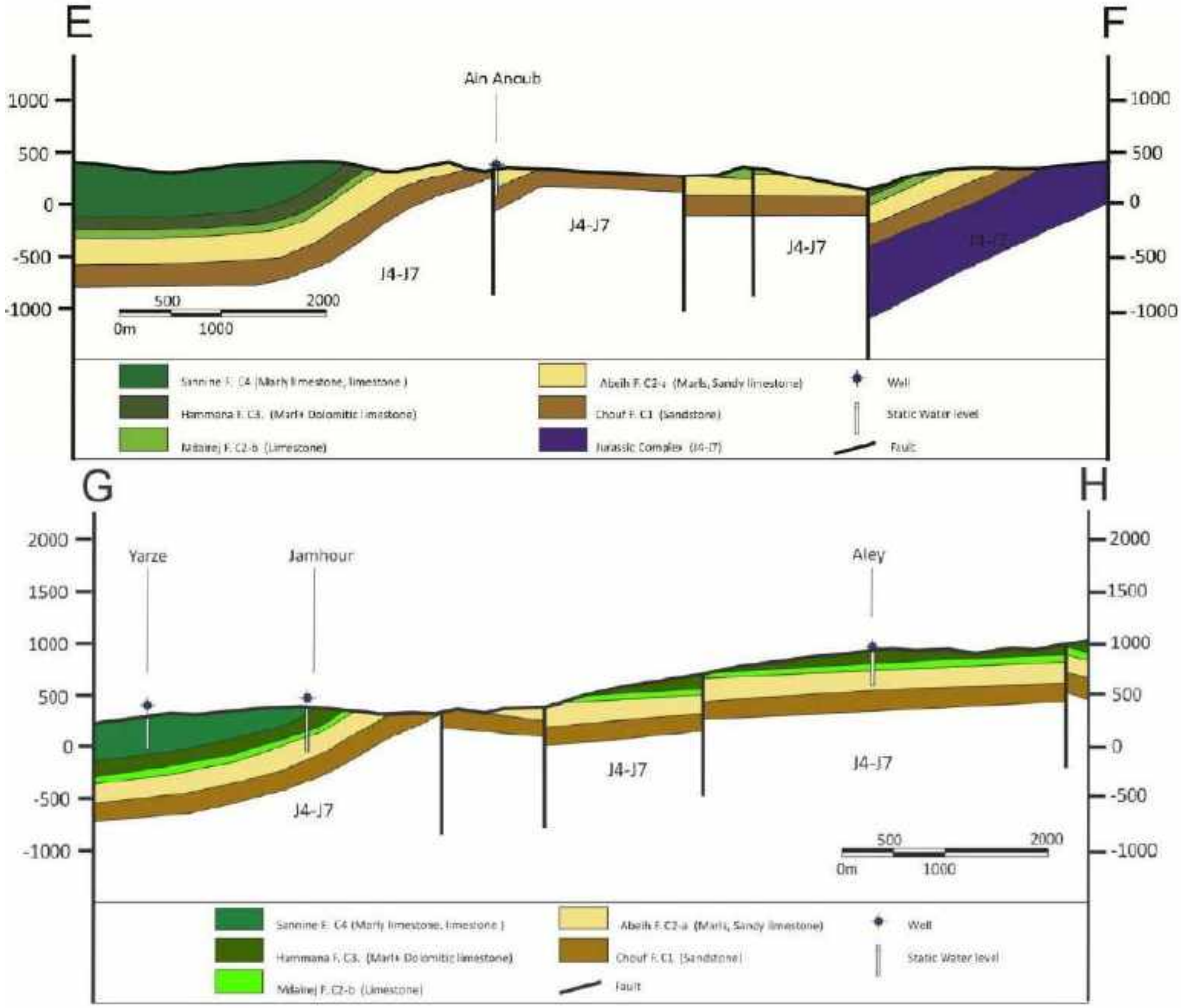

Figure A 3 Geological cross sections EF & GH (Doummar et al., 2015)

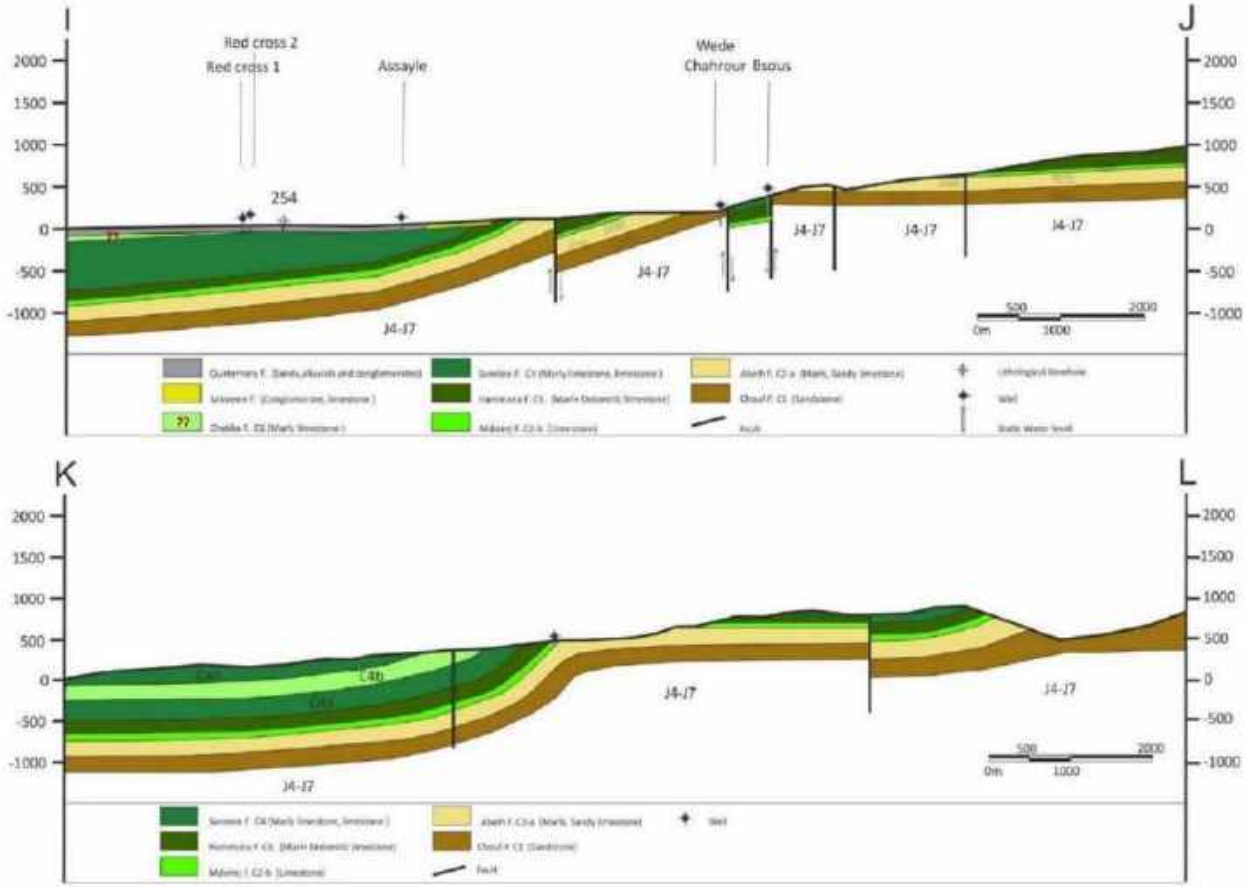

Figure A 4 Geological cross sections IJ & KL (Doummar et al., 2015)

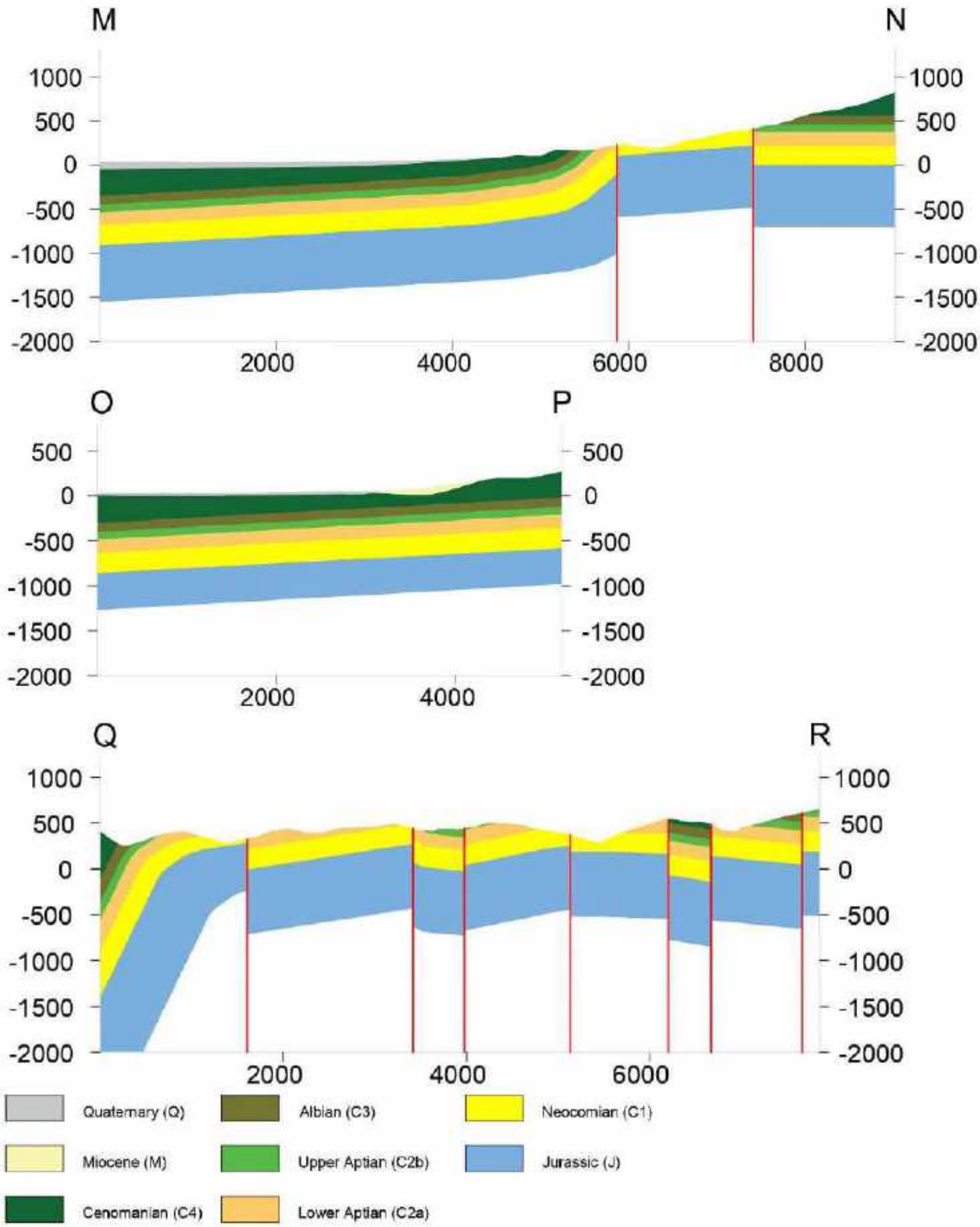

Figure A 5 Geological cross sections MN, OP & QR generated for the sake of this project (note: red vertical lines represent faults)

D.Maps

N
W
E
S
Legend
Ghadir River Stream
Ghadir Basin
RIVER BASIN MANAGEMENT FOR AL ASSI BASIN, GHADIR BASIN AND AL OSTUAN BASIN
Water Resources in Ghadir Basin
Ghadir
Drawing Title: -
HawkaMaa - EU
ACTED
BUREAU TECHNIQUE POUR LE DEVELOPPEMENT
Prepared by: B.T.D
Date: December 2022
Scale=1/15,000 on A0 Printout
Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

N
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M
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G
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ad
Qd
M2a
C1
R
QL
I
C
J
QL1
J4
C2b
O
Q
C4
C2a
N
C3
H
Q
K
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E
D
Ghadir River Basin
Geological Sections
Faults
Geological Formation
Q: Pebbles and sand
ad: Alluvial deposits, sandy alluviums, argillaceous colluvium
Qd: Sand dunes
QL: Brown soils, decalcified red soils, terrigenous alluvium
QL1: Red soils
M2a: Breccia and conglomerate
C4: Alternating limestones and marly limestones finely bedded
C3: Green marls and alternating limestone units
C2a: Argillaceous sandstones
C2b: Marls, marly limestones and dolomites
C1: Pink quartz sandstone, sandstone rich in lignites
J4: Massive grey limestones
RIVER BASIN MANAGEMENT FOR AL ASSI BASIN, GHADIR BASIN AND AL OSTUAN BASIN
Water Resources in Ghadir Basin
Ghadir
Drawing Title:
-
HawkaMaa - EU
ACTED
BUREAU TECHNIQUE POUR LE DEVELOPPEMENT
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Date: December 2022
Scale=1/15,000 on A0 Printout
Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community


N
W
E
S
Legend
LUC
Medium density Urban fabric
Dense Urban Fabric
Dense Mixed Wooded Lands
Airport
Industrial or Commercial Areas
Scrubland with some dispersed bigger trees
Dense Pines
Clear Grassland
Olives
Fruit Trees
Clear Pines
Diverse Equipment
Field Crops in Small Fields/Terrace
Clear Mixed Wooded Lands
Abandoned Agriculture Land
Low Density Urban Fabric
Scrubland
Others
1 0.5 0 1 Kilometers
RIVER BASIN MANAGEMENT FOR AL ASSI BASIN, GHADIR BASIN AND AL OSTUAN BASIN
Water Resources in Ghadir Basin
Ghadir
Drawing Title: -
HawkaMaa - EU
ACTED
BUREAU TECHNIQUE POUR LE DEVELOPPEMENT
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Scale=1/15,000 on A0 Printout
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community


N
W
E
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Ghadir WWTP
Khalde PS
daouha PS
PS
Legend
Pumping Station
Waste Water Treatment Plant
Ghadir Basin
Ghadir River Stream
Sewer Pipes
1
0.5
0
1 Kilometers
RIVER BASIN MANAGEMENT FOR AL ASSI BASIN, GHADIR BASIN AND AL OSTUAN BASIN
Water Resources in Ghadir Basin
Ghadir
Drawing Title:
-
HawkaMaa - EU
ACTED
BUREAU TECHNIQUE POUR LE DEVELOPPEMENT
Prepared by: B.T.D
Date: December 2022
Scale=1/15,000 on A0 Printout
Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

N
W
E
S
Daychounieh System
Mechref System
Ain El Delbe System
Raayan System
Boutchay System
Chouaifat System
Kfarchima System
Bsous System
Bleibel System
Bsaba Wadi Dlab System
Deir-Koubel System
Bchamoune System
Raayan System
Mechref System
Legend
Ghadir River Stream
Ghadir Basin
Water Systems
RIVER BASIN MANAGEMENT FOR AL ASSI BASIN, GHADIR BASIN AND AL OSTUAN BASIN
Water Resources in Ghadir Basin
Ghadir
Drawing Title: -
HawkaMaa - EU
ACTED
BUREAU TECHNIQUE POUR LE DEVELOPPEMENT
Prepared by: B.T.D
Date: December 2022
Scale=1/15,000 on A0 Printout
Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community


N
W
E
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Legend
Ghadir River
Cultivated area located below contour line 250m (129 ha)
Cultivated area located between contour line 250m & 500m (141 ha)
Cultivated area located above contour line 500m (77 ha)
Ghadir Basin
1
0.5
0
1 Kilometers
RIVER BASIN MANAGEMENT FOR AL ASSI BASIN, GHADIR BASIN AND AL OSTUAN BASIN
Water Resources in Ghadir Basin
Ghadir
Drawing Title:
-
HawkaMaa - EU
ACTED
BUREAU TECHNIQUE POUR LE DEVELOPPEMENT
Prepared by:
B.T.D
Date:
December 2022
Scale=1/15,000
on A0 Printout
Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

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