Food and Agriculture Organization of the United Nations

Improved Water Resources Monitoring System/ Integrated Water Resources Management at regional level in Lebanon

WATER QUALITY MONITORING

The project

In many areas of the world, including the Near East and North Africa (NENA) region and Lebanon, sustainable and reliable delivery of water for irrigation and municipal use has become increasingly complex. This issue also extends to affect the protection of the ecosystems from water pollution. Particularly, if the overall demand is outstripping supply, the delivery of water is often less about engineering, although it is still required. The issue is more often related to the governance of the resources to manage and protect them from pollution and over-abstraction, resolve conflicts over water, and ensure rights to water are respected. It is also about understanding water flow pathways in complex river basin systems. This is where water monitoring and accounting can play a crucial role to help water management institutions in managing complexity in light of the challenges facing the water sector.

In this context, the Food and Agriculture Organization of the United Nations, in collaboration with the North Lebanon Water Establishment (NLWE), which represents the Ministry of Water and Energy, is implementing the GCP/LEB/029/SWI project **'Improved Water Resources Monitoring System/Integrated Water Resources Management at regional level in Lebanon'**, funded by the Swiss Government. The main objective of the project is to strengthen Lebanon's water institutions improving their performance at regional level, thereby helping them to address the sector challenges for sustainable use of water resources.

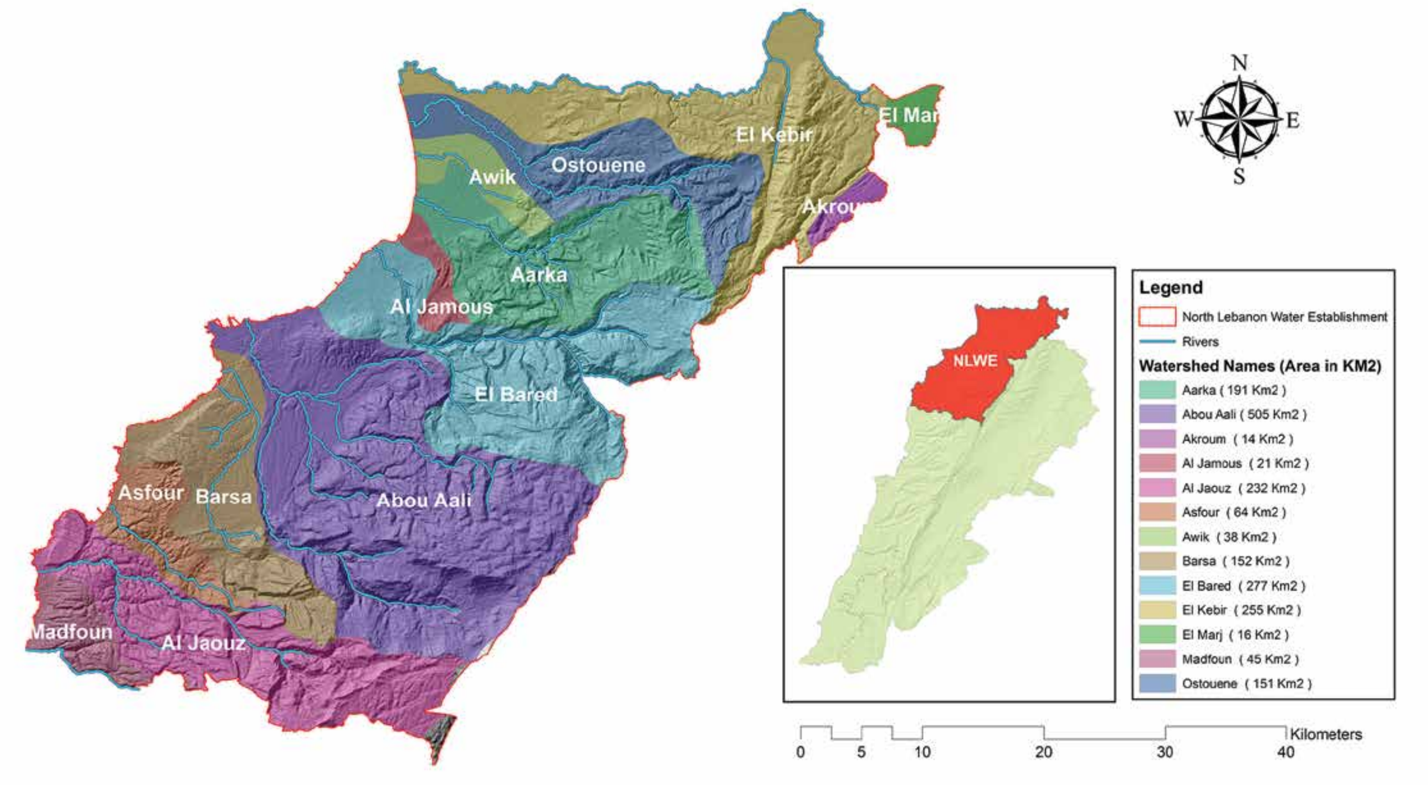
In particular, output (2) of the project, 'Established water quality monitoring at key locations within a pilot watershed', aims at supporting improved management of environmental priorities at water establishment/watershed level (both surface and ground water) through the following activities:

- definition of monitoring water quality parameters to be tested in laboratory;
- collection of water samples at key location of the targeted area for both surface and ground water; and
- provision of a monitoring tool for NLWE and related training of professional staff (e.g. employment of water quality data to assess water quality risk, development of water quality plans, etc.).

The command area

The project follows a pilot approach, whereby the regional Water Establishment has been selected through a rapid assessment driving to the greatest possible impact. Based on well-defined selection criteria, including water availability, level of irrigation development, water quality status, scope for institutional capacity building and scalability, the North Lebanon Water Establishment (NLWE) was chosen. The authority of the Establishment extends to the complex hydrological systems and diverse topography of Northern Lebanon. Amongst the involved watersheds, El-Bared is the second largest one, with its 277 km2 catchment area.

Figure 1: Watersheds in North Lebanon



Source: Google Earth Pro v7.3.3.7786 (2020). Lebanon. 34°29'30 N, 35°58'33 E, elevation 40 m modified to comply with UN. 2020. Map of Lebanon, 4282 United Nations January 2010. https://www.un.org/Depts/Cartographic/map/profile/lebanon.pdf

From the eastern to the western part of the watershed, the land use significantly changes. While the areas at higher altitudes are predominantly occupied by natural vegetation, expansion of built-up and urban areas became particularly challenging along coastal areas. The speed of urban area growth exceeds the capacity of natural resources to provide equal benefits for all. Above all, water resources are under the greatest pressure to meet environmental, economic and social objectives. Even if theoretical availability is sufficient to cover all demands, rapidly declining water quality spurs a knock-on effect across the watershed. Amongst many, agricultural and environmental demands are the most affected.

The selected command area, covering Akkar and irrigation schemes, is supplied by various irrigation water sources, including surface water from El-Bared River, springs and wells. The immense agricultural potential is well-known; however, it faces multiple challenges driven by urbanization, natural resource exploitation, environmental degradation and climate change. The water quality in the irrigation schemes is impacted by different sources of contamination, amongst which is the uncontrolled sewage discharge and the solid waste. The main and lower-level canals of Akkar and Minieh irrigation schemes are involuntarily connected to sewage and storm water infrastructure, proving to be hazardous to the environment, agriculture and human health. Moreover, solid waste is often disposed directly into the irrigation canals, thus spreading through the adjacent water networks and eventually reaching agricultural lands.

Agriculture is a sector that both drives and sustains the water quality deterioration. On one hand, crops naturally absorb some of the pollutants, but water quality parameters such as dissolved salts, certain toxic ions, abnormal pH can lead to significant crop damage. On the other hand, agriculture largely contributes to water pollution, whereby excessive use of crop production inputs such as chemical fertilizers and pesticides, as well as veterinary medicines, are the major pollutants of water resources.

Introducing a water quality monitoring system is a key strategy for achieving major progress in sustainable natural resource management and preserving environmental conditions.

Figure 2: Polluted irrigation canal outlets

The approach

In order to address water quality-related issues in the area, creating a robust water quality monitoring system that enables data acquisition and analysis comes first. The obtained information can then be used to develop strategies to preserve water quality. To design such a monitoring system, the planning phase evolved through the following steps:

Definition of parameters → Definition of key monitoring sites → Creating monitoring protocol based on need assessment → Providing laboratories with needed equipments to operate the monitoring system

1. Based on the assessment of the water resources and agricultural water uses in the area, relevant quality parameters have been defined. Each parameter has a significant role, which might be either positive or negative under different conditions. Although heavy metals are fundamental for crop production, for instance, an excessive amount leads to undesirable accumulation, even to toxicity. The major challenge is, thus, to define the acceptable minimum and maximum thresholds and monitor their concentration accordingly. The identified parameters are grouped into physical, chemical, and biological categories. Physical parameters indicate properties detectable by the senses, while chemical ones determine the amounts of mineral and organic substances. Furthermore, biological parameters involve testing of faecal pollution.

Physical
- pH
- Temperature
- Colour and smell

Chemical
- Electical conductivity (EC)
- pH
- Soluble cations
  - Natrium
  - Potassium
- Soluble anions
  - Bicarbonate
  - Chlorine
- Heavy metals
  - Lead
  - Iron
  - Zinc

Biological
- Biochemical oxygen demand (BOD) / Chemical Oxygen Demand (COD)
- Total Coliform
- Fecal Coliform
- E-coli

In order to support the interpretation of results, thresholds have been defined for each parameter based on national and international standards of concentration limits, and they are based on annual irrigation rate of 10 000 m^3/ha.

Table 1: Acceptable threshold of concentration per parameters

Test	Threshold	Comments
Electrical conductivity (EC)	2.0 dS/m	> 4 dS/m (toxic)
Total dissolved solids (TDS)	700 mg/L	2000 mg/L (toxic)
Sodium Adsorption Ratio (SAR)	7	>9 (toxic)
pH	6.5-8.4	Normal range
Bicarbonate (HCO-3)*	300 mg/L	>500 mg/L (check RSC)
Chloride (Cl-)	200 mg/L	>300 mg/L
Residual chlorine		>0.05 mg/L (damage some crops)
Sulphate (SO42-)	400 mg/L	Normal
Nitrate-nitrogen (NO3-N)	5-30 mg/L	Contributes to algal growth and eutrophication
Phosphorus (P)	<2 mg/L	Contributes to algal growth and eutrophication
Boron (B)	<2mg/L	>4 mg/L(toxic)
Cadmium (Cd)	0.02 mg/L	>0.04 mg/ L (reduces quality of crop)
Nickel (Ni)	0.02 mg/L	>0.04 mg/ L (reduces quality of crop)
Mercury (Hg)	0.01 mg/L	>0.04 mg/ L (reduces quality of crop)
Lead (Pb)	0.02 mg/L	>0.04 mg/ L (reduces quality of crop)
Turbidity	35 NTU	>70 NTU (causes blockage for drip irrigation)
Arsenic (As)	0.1 mg/L	>0.2 mg/ L (toxic)
Cobalt (Co)	0.05 mg/L	>0.1 mg/ L (toxic)
Chromium (Cr)	0.10 mg/L	>0.2 mg/ L (toxic)
Copper (Cu) in calcareous soil	0.20 mg/L	>0.4 mg/ L (toxic)
Iron (Fe) in calcareous soil	1.5 mg/L	>3 mg/ L (very high)
Manganese (Mn) in calcareous soil	0.2 mg/L	>0.4 mg/ L (very high)
Molybdenum (Mo)	0.01 mg/L	>0.02 mg/ L (very high)
Selenium (Se)	0.02 mg/L	0.04 mg/ L (toxic)
Zinc (Zn) in calcareous soil	2.0 mg/L	>4 mg/ L (very high)

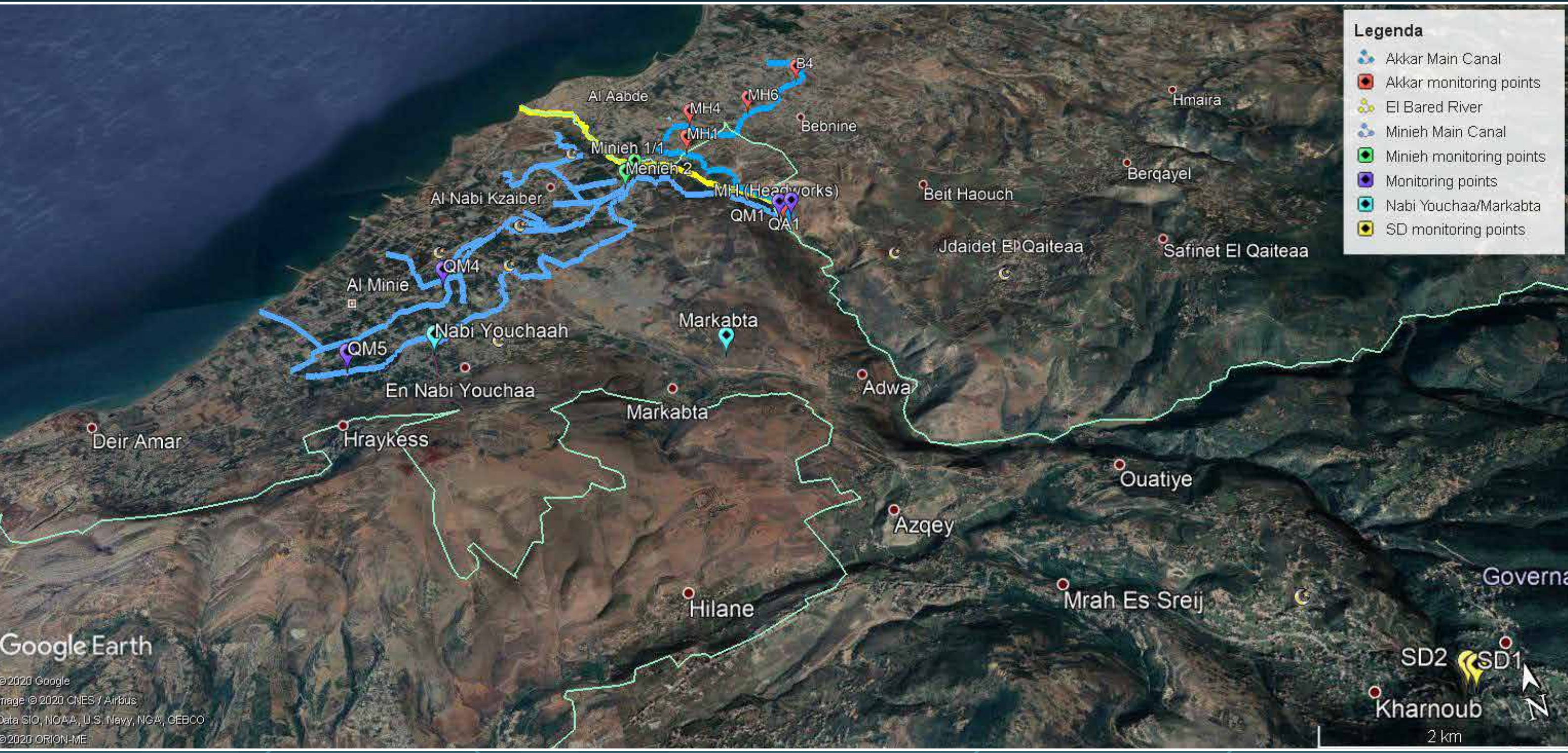
2. As a second step, key monitoring sites have been defined according to site selection criteria:

- cover the entire area, from source to fields;
- define the proximity of potential point source and diffuse pollution;
- provide accessibility for sampling;
- consider the risk of contamination to agricultural production;
- optimize the number of sites according to the density of pollution sources;
- ensure integration with other monitoring systems (discharge, water use); and
- estimate the cascading effect of contamination along the network.

Based on the selection criteria, the water quality network has resulted into 15 sampling sites, as a first phase, which cover the irrigation system from source of the water to users:

- Sites at source: Two sites from Syr Al Dennieh, a major spring feeding into the watershed of Nahr El-Bared; one site at Nabi Youchaa, nearing the main communal well; one site at Markabta spring, supplying water to areas at higher altitude.
- Sites at distribution point: Three sites at the head work of Nahr El-Bared dam, distributing water to both Minieh and Akkar (Bibnieh and Mhamara).
- Sites in delivery network: Seven sites, 4 in Minieh and 3 in Akkar, located along the main canals of Nahr El-Bared.

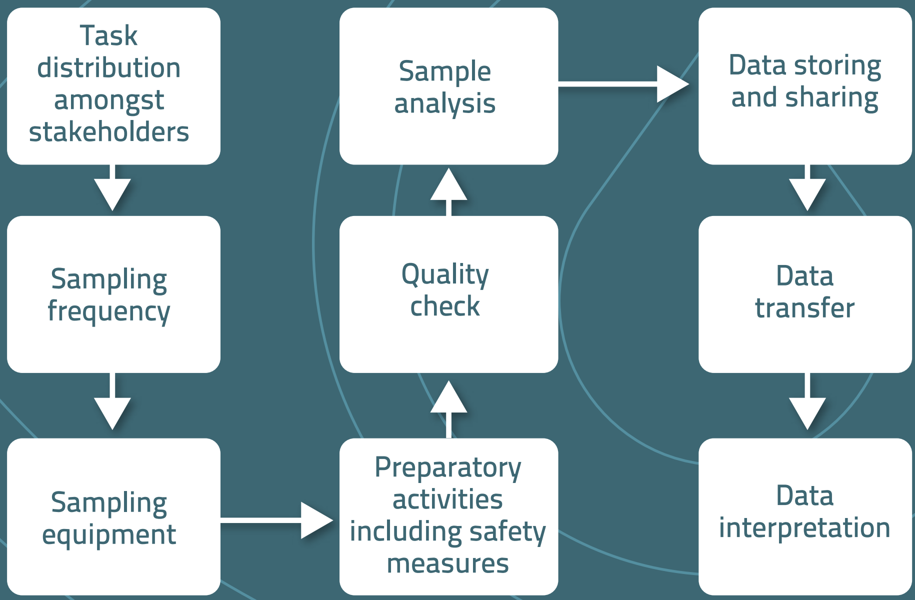
Figure 3: Water quality sampling sites



Source: Google Earth Pro v7.3.3.7786 (2020). Lebanon. 34°29'30 N, 35°58'33 E, elevation 40 m modified to comply with UN. 2020. Map of Lebanon, 4282 United Nations January 2010. https://www.un.org/Depts/Cartographic/map/profile/lebanon.pdf

During site selection phase, special emphasis has been placed on the requirement to integrate the results of different monitoring systems, namely discharge, water use and water quality monitoring. Their data qualities have significant spatio-temporal differences. While water quantity assessment depends on frequent time-step of measurement, for instance, water quality parameters are less variable, thus requiring less frequent measurement. Further complicating matters include the monitoring of water use, which can be calculated only at seasonal time-step. However, the site selection process attempted to approximate the monitoring sites of the different monitoring systems in order to enable comprehensive assessment of specific areas.

3. With the aim to ensure the reliability of monitoring results, a sampling and analysis protocol has been established and distributed to relevant stakeholders. This step is particularly important since different laboratories are responsible for different monitoring sites. Given the fact that the monitoring sites are in a single watershed with adjacent irrigation network, the complex monitoring system tightly weave interdependence between the different laboratories. Little uncertainty in sampling and analysis might lead to inconsistency in overall data assessment. Such a sampling and analysis protocol requires the knowledge of the following procedures (overleaf):



Finally, this well-crafted and detailed process has led to the compilation of comprehensive monitoring databases that provide readily available information to decision-makers and may return timely warning.

4. Water quality monitoring in the area has imperative ground of urgency due to the excessive deterioration of water resources. The sustainability of the monitoring system is, therefore, a substantial requirement to ensure long-term data acquisition. The involved four laboratories, Tripoli, Minieh, Donnieh and Halba, must be properly equipped to maintain the monitoring activity.

Figure 4: Water quality sampling in monitoring site

Figure 5: On-job training on equipment use in involved laboratories

A series of laboratory inventories have been carried out to assess the infrastructure and human capacities. Finally, each laboratory has properly been refurbished and equipped with the following instruments and materials to enable regular monitoring:

- BOD/COD system;
- Flame photometer system;
- Portable spectrophotometer;
- pH/EC/Temperature meter (multi meter);
- Water turbidity meter;
- Extraction columns for lead analysis;
- Vacuum filtration system; and
- Various reagents.

Throughout the project implementation, the samples' analysis is supervised by senior experts and scientists in order to prepare professional staff to take over the monitoring activity and return valid and reliable results to the central monitoring system.

The outcome

The interpretation of results must be properly framed in the context of agricultural water use, since a simple comparison of acceptable threshold and measured values is not sufficient to understand the underlying mechanism of water resource deterioration. Assessing the fluctuation of the values, conducting simultaneous measurement in each monitoring site, evaluating the environment of the sampling site, as well as the timing of sampling, play an important role in establishing cause-effect relationships.

In order to understand the cause of potential pollution, the monitoring sites at water sources have been analysed in the first step. As for groundwater sources, the tables indicate that the content of the Markabta spring and Nabi Youchaa (new and old wells) are very low in K, Na, and Cl. The major constituents are HCO3- in addition to Ca and Mg. Moreover, they are free from contamination of bacteria (Coliform, Fecal coliform, and E-Coli). The quality of the water of these two sources is excellent and suitable for drinking and irrigation.

Figure 6: Supervision of laboratory analysis

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Table 2: Results of quality analysis at water source

Site	Parameter	Date (2019)				
		June	July	August	September	October
Markabta	Na+ (mg/l)	5.2	5.8	5.7	4.8	8
	K+ (mg/l)	1	1.2	0.8	1.9	2.6
	Cl- (mg/l)	7	15	17	17	17
	HCO3- (mg/l)	124				
	Total coliform (CFU/100ml)				7	2
	Fecal coliform (CFU/100ml)				0	0
	E-Coli (CFU/100ml)				0	0
Nabi Youchaa	Na+ (mg/l)	8.4	8.7	8.7	7.5	12.2
	K+ (mg/l)	1.8	1.8	1.7	3.7	5
	Cl- (mg/l)	25	25	23	23	23
	HCO3- (mg/l)	143				
Nabi Youchaa (new well)	Total coliform (CFU/100ml)				49	21
	Fecal coliform (CFU/100ml)				6	10
	E-Coli (CFU/100ml)				0	0
Nabi Youchaa (old well)	Total coliform (CFU/100ml)				0	
	Fecal coliform (CFU/100ml)				0	
	E-Coli (CFU/100ml)				0	

The picture is somewhat different in downstream monitoring points. The displayed values of chemical analysis show the level of pollution of the water samples from the source to the irrigation canals in July. Since none of the observed values has had higher than acceptable limits, the water resources can be considered acceptable for irrigation in the summer period, although in some spots along the canal pollution with heavy metals has been observed. The general salinity level is also considerably lower than acceptable limits.

Table 3: Results of chemical analysis in July in monitoring locations from source to distributaries

Sample #	pH	EC	Na	K	Ca	Mg	CO3	HCO3	Cl-	Fe	Zn	Cu	Mn	Ni	Pb
		(µS/cm)	(mg/L)							(µg/L)					
HD	7.4	376	5.6	1.2	22	15	0	115	15	26.6	0	3.81	0.57	0.33	0.19
Mkbta	7.23	419	9.7	1.4	37	5	0	124	30	5.26	0	2.84	0.34	13.85	0.20
QA1	7.25	373	5.4	1.2	39	13	0	108	10	22.74	0	3.68	0.21	3.37	0.20
MH1	7.47	370	5.3	1	30	13	0	109	10	25.03	0	3.36	0.33	0.34	0.20
MH6	7.51	385	5.7	1.3	25	13	0	108	10	23	0	4.58	0.83	0.53	0.16
B4	7.15	401	7.1	1.6	46	12	0	108	12	31.88	0.12	5.11	0.95	0.94	0.19
QM1	7.36	386	5.5	1.2	29	14	0	108	9	17.95	0	4.56	0.16	0.2	0.19
Minieh 1/1	7.47	359	5.2	1.3	28	12	0	109	11	3.83	0	23.08	0.14	0.51	0.21
Minieh 2	6.72	361	5	1.2	26	12	0	97	9	17.1	0.52	4.91	0.25	0.57	0.14
QM4	7.79	375	6.2	2.3	40	11	0	112	10	4.5	0.4	4.8	0.02	12.16	0.23
QM5	7.85	396	5.5	1.5	41	11	0	100	10	14.53	0.24	4.18	0.64	0.54	0.23
SD1	6.91	215	1.6	0.3	29	5	0	72	5	47.5	0	0.6	0	0	0.6
SD2	7.01	274	2	0.4	34	7	0	77	6	46.2	0	0.7	0	11.3	0.5
Yhsh	7.83	542	13.7	2.2	27	16	0	143	25	45.86	0	3.8	0.8	245	0.5

The results of biological analysis on faecal pollution have been well beyond acceptable levels. The principal risk of high faecal contamination is that of infectious disease. Comparing the results of the counts at the source with the counts in the irrigation canals, it becomes clear that heavy load of biological contamination exists all along the river, and irrigation canals, as well as at the dam. This level of contamination poses several risks to human safety and agriculture. At current stage, the water cannot be recommended for the irrigation of fresh vegetables.

Table 4: Biological analysis in monitoring locations from source to distributaries

Site	Parameter (CFU/100ml)	September	October
QM1-QM5	Total coliform	28 000->500 000	276 000-1 186 000
	Fecal coliform	9 000-369 500	66 000-616 000
	E-Coli	4 000-350 500	48 000-632 000
QA1-B4	Total coliform	90 000->200 000	205 000->200 000
	Fecal coliform	9 500-110 000	115 000-195 000
	E-Coli	3 000-54 000	100 000-145 000
Headwork	Total coliform	95 000	-
	Fecal coliform	26 500	-
	E-Coli	5 000	-
SD1	Total coliform	1 017 000	1 056 000
	Fecal coliform	700 000	276 000
	E-Coli	600 000	212 000
SD2	Total coliform	560 000	960 000
	Fecal coliform	250 000	356 000
	E-Coli	220 000	330 000

Evidently, the main cause of such high-level faecal contamination is the uncontrolled sewage discharge from households. The domestic plumbing systems are directly connected to irrigation canals, thus, conveying untreated wastewater into the irrigation water. The higher the population density, the higher the contamination.

Figure 7: E-Coli contamination in Akkar and Minieh

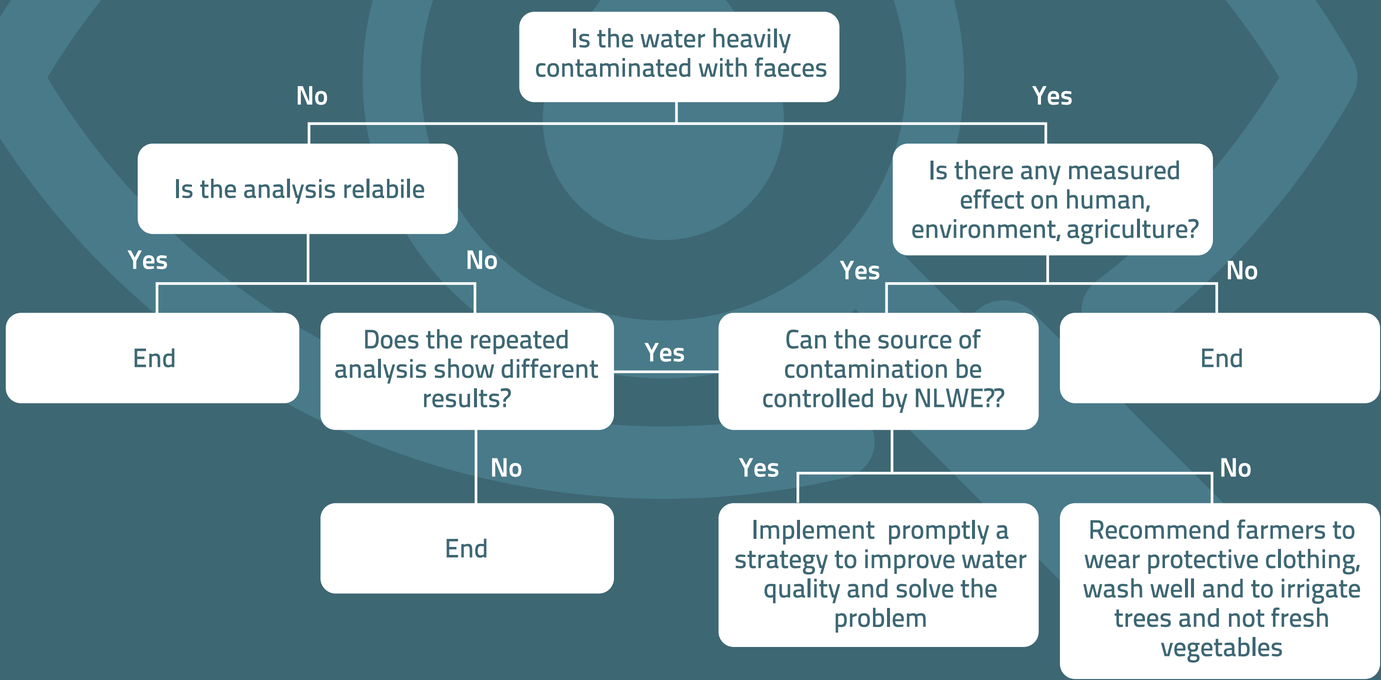
Source: Google Earth Pro v7.3.3.7786 (2020). Lebanon. 34°29'30 N, 35°58'33 E, elevation 40 m modified to comply with UN. 2020. Map of Lebanon, 4282 United Nations January 2010. https://www.un.org/Depts/Cartographic/map/profile/lebanon.pdf

Figure 8: Fecal coliform contamination in Akkar and Minieh

Figure 9: Total coliform contamination in Akkar and Minieh

Source (both maps): Google Earth Pro v7.3.3.7786 (2020). Lebanon. 34°29'30 N, 35°58'33 E, elevation 40 m modified to comply with UN. 2020. Map of Lebanon, 4282 United Nations January 2010. https://www.un.org/Depts/Cartographic/map/profile/lebanon.pdf

A decision-support tree has been established to guide authorities in managing water contamination. Such a planning method can guide decision-makers to evaluate the situation and find well-performing strategies.



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The lessons learned on best practices

The first phase of the project drew lessons from the implementation and results of water quality analysis. Such lessons can be categorized under three dimensions: agricultural, social and environmental.

Agricultural	Social	Environmental
Water quality monitoring is key to maximize the agricultural benefits and minimize the adverse impact of pollution on agriculture Agriculture, in return, is responsible for water quality deterioration. In order to eliminate the agriculture-driven pollution, a protocol of optimal input use should be established while providing trainings for farmers The current faecal contamination poses risks to field workers. Until contamination is not controlled, workers should be supplied with protective clothing Due to faecal contamination, water is not recommended for irrigation in many parts of the system. Likewise, fresh vegetable irrigation should be avoided until contamination is not controlled	The back-and-forth interaction between water quality and human safety must be recognized. While human interference is the major cause of water contamination in the area, the high concentration of bacteriological pollution is the principal risk to human health Sewage discharge into irrigation canals must be eliminated in the area to avoid bacteriological contamination, and the potential spreading of infectious diseases As the causes and impacts are increasingly multifaceted, preserving water quality requires a wide collaboration amongst stakeholders, such as water users, communities, and authorities	Water quality monitoring is the cornerstone of a more sustainable natural resource management that is in line with environmental objectives Water contamination has cascading effects across the watershed. Heavily contaminated water affects the natural resources, in particular land and soil, forests and marine life

Figure 10: Training of laboratory staff

Lessons-learnt related to water quality monitoring are critical to maintain the achieved results. Training of professional staff is key to reach long-term sustainability of established remote-based system and maintain its gains.

The long-term vision of the project anticipates the scaling-up of implemented and demonstrated practices, both within the boundaries of the NLWE and beyond, extending to other establishments. Dissemination is a built-on complex strategy with multiple publication outlets to reach wide audiences. The scaling-up is phased into three successive steps:

Piloting	▪ **Select pilot sites based on multiple-criteria** ▪ **Design and implement novel approaches** ▪ **Draw lessons from implementation**
Learning	▪ **Train professional staff on traditional and non-traditional methods** ▪ **Extend the training to potential stakeholders at national level**
Scaling-up	▪ **Demonstrate results and assess replicability** ▪ **Implement the developed approach**

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