Rehabilitation and waste management of El-Bared canal irrigation system to reduce source-to-sea pollution and improve livelihoods in the Akkar Region of Lebanon

The project

In Lebanon, like in many places in the world, adequate and reliable management and collection of waste have become increasingly complex and problematic. This issue anticipates cascading and spill-over effect on livelihood, environment, and agriculture. The most common scenario is the involuntary disposal of waste into irrigation canals and its consequent accumulation through villages and ultimately the sea. Moreover, the population growth in Lebanon spurted due to humanitarian crises in neighboring countries and the insufficient waste collection capacity amplify the problem, exacerbating the severe accumulation of solid waste. These dynamics mainly threaten water resources, endangered by faster spreading pollution.

The enhancement of the environmental performance of the irrigation systems in Lebanon, therefore, urgently requires the rehabilitation of the irrigation canals and the proper removal of solid waste that they contain. In addition, and to ensure an effective and efficient monitoring and control of water quality and waste-management, it is fundamental to strengthen the capacity of the authorities in charge and advocate the adverse effect of this problem amongst directly involved communities while providing them with means of alleviation.

In this context, the Food and Agriculture Organization of the United Nations (FAO), in collaboration with the North Lebanon Water Establishment (NLWE), which represents the Ministry of Water and Energy, is implementing a project titled “Rehabilitation and waste management of El-Bared canal irrigation system to reduce source-to-sea pollution and improve livelihoods in the Akkar Region of Lebanon”, financed by the
Government of Norway. The objective of the project is to determine a direct impact in terms of minimizing the discharge of waste from El-Bared system in Lebanon to the Mediterranean Sea, so to improve the livelihoods of the people depending on the system through rehabilitation of irrigation canal system, solid waste disposal, and improved agricultural output and job creation.

In particular, output (1) of the project “irrigation canal systems in relevant areas are rehabilitated and the trash removal equipment is fully installed and operational through the employment of local labor” aims at rehabilitating the irrigation canal system in El Bared irrigation schemes and equipping them with solid waste removal structures through a number of activities, including:

- rehabilitation of the irrigation canals (repair and maintenance of canals, outlets and delivery system) across the lower reaches of El-Bared irrigation canal system making use of local labor with a focus on disadvantaged/refugee communities; and
- improving the removal of solid waste by the installation of trash removal structures (trash traps), sediment extractors and other means across the main canals of El-Bared irrigation canal system making use of local labor with a focus on disadvantaged/refugee communities.

The command area

Akkar can be described as one of the most disadvantaged regions of the country also in terms of infrastructure. The region is witnessing a rapid population growth as the Governorate hosts considerable share of the total number of people displaced from the Syrian Arab Republic. Existing waste-management networks have reached their capacity, spurring the formation of informal dumping in watercourses, including irrigation canals. This has led to severe accumulation of solid waste in these courses and hence contamination of water resources.

Pollution levels now pose a threat to public health and result in major economic and environmental losses. Improvement of irrigation systems extended to solid waste-management is thus fundamental for the development of the region, taking into consideration the lack of effective monitoring and control of water quality.

The enhancement of the environmental performance of the irrigation systems in the region urgently requires the rehabilitation of the irrigation canals and the proper removal of solid waste that they contain.
The mosaic-type landscape of the region is dominated by agriculture, but agriculture sustains a critical loss of natural resource and infrastructure due to the urban encroachment, environmental pollution, and climate change. The dependence on irrigation is well demonstrated by the fact that 43 percent of the 42,000 cultivated area in North Lebanon is equipped for irrigation.

One of the largest catchments is El Bared, supplying both mountainous and coastal areas. Two multipurpose dams are deployed along the El-Bared River to control the flow, generate hydropower and store water for irrigation. The downstream dam discharges water into the river stream and two adjacent, peri-urban irrigation schemes, El-Minieh and Akkar. Akkar main canal is an 11 km long, concrete-lined conveyance structure, turning into a small natural stream in the northernmost part of El-Bared catchment. With its 1,500 ha gross area, Akkar irrigation scheme stretches along the Mediterranean Sea, and irrigation canals and drains run directly into the sea.

The performance of Akkar canal is largely affected by its poor condition, given the sediment deposit, solid waste accumulation, cracks and broken panels. The main drivers of such deterioration are the permanent load of high discharge, the rate of urbanization, the human interference, and the lack of sediment and solid waste removal structures. Since its very establishment, the irrigation canal has not been rehabilitated, and maintenance is limited to simple routine works. The resulting deterioration affects both the environment and the water users. On one hand, irrigation network has become the unwitting intermediary of pollution migration, as communities use irrigation canals for solid waste and sewage transport. On the other hand, the damaged infrastructure entails a disadvantage for users who cannot effectively make use of the irrigation system.
Ecosystem degradation and climate change now cast this issue in a new light, as farmers without reliable access to surface water seek alternative sources, such as the already stressed groundwater sources, or remain exposed to rainfall uncertainties. Poor infrastructure is detrimental also to the marine sources, as the contaminated water together with the sediment and solid waste is flushed away to the Mediterranean.

Rehabilitation of the irrigation canal to enable the deployment of waste removal structures and the improvement of conveyance efficiency is the first practical step to halt the cascade of adverse effects. A well-maintained irrigation infrastructure is also fundamental to supplying reliable and good quality surface water for farmers. Beyond the obvious benefits, improved canal performance has virtual benefits, such as shifting farmers away from groundwater exploitation by enhanced access to surface water.

**The approach**

There is an ample number of performance assessment and benchmarking methodologies in support of irrigation system rehabilitation. Most of these methods involve expert observations and in-situ measurements to perform indicator calculation. While conventional approaches provide standard practices to conduct the assessment, there is now an increasingly growing interest to deploy remote and automated approaches. On this ground, a remote rapid assessment procedure (RE-RAP) is designed by employing remote-sensing technology, which requires only high resolution, drone photos of the canal to carry out the condition assessment.

Transitioning from conventional methods to remote assessments have, then, further gains, such as enhanced human and financial resources efficiency, consistent results and reduced human bias throughout the assessment procedure, increased scalability by covering inaccessible area, increased flexibility and optimized conditions for the implementation.

---

**Turning challenges into opportunity**

COVID-19 tore through the world in 2020. In turn, countries went into a global lockdown to contain the harmful effects. Beyond the impact on the health sector, the crisis exacerbated the socio-economic challenges and forced the partial suspension of many economic activities.

The crisis triggered non-conventional approaches to avoid more severe consequences. The disrupted trade flows set a renewed focus on the need for improving domestic production, thus requiring increased productivity of agriculture sector. As irrigation is key to enhance productivity, the development of irrigated agriculture is a possible way to mitigate the impacts on food security.

To respond to the critical questions of this trying period, the project went the extra mile to develop remote methodology for the condition assessment of irrigation canals and hence to pave the way for a technically sound rehabilitation work in Akkar. Well aware of the unpredictability of the trajectories, the methodology was established and piloted in a way that it allows its transfer and scale-out to a broad scale of irrigation systems worldwide.
A systematic approach is adopted to acquire remote photos of the whole canal length, develop and calibrate the remote methodology for the assessment, and quantify the damages prior to the rehabilitation work. RE-RAP is trialed in Akkar irrigation system to draw lessons on the applicability of the methodology. The implementation is divided into five steps.

**Figure 4.** Remote rapid assessment procedure main implementation steps.

1. Prerequisites
2. Remote survey
3. Image analysis
4. Crowdsourcing
5. Damage quantification

**Prerequisites**

If repair works and rehabilitation are at issue, mechanical cleaning as routine maintenance work is required to obtain clear overview of the condition flaws. The conditions of the canal can be inadequate for further interventions, due to heavily silting of sewage disposal and poor maintenance throughout years. Heavy loads of deposited silts and debris also make it difficult to operate the canal at full capacity and most of the irrigation outlets in the downstream end of the canal can be running under capacity.

The first step of the condition assessment and the consequent rehabilitation is the removal of silt and deposited debris. Mechanical cleaning has multiple benefits, as it reveals the underlying concrete surfaces for visual inspection to assess the extent of damage while helping in restoring the water flow to feed the canal outlets at the far end of canal.

To demonstrate the crucial importance of routine cleaning through the pilot in Akkar irrigation scheme, discharge curves at the headworks were calibrated before and after the works. The evident increase in canal capacity is a vast contribution to the enhancement of irrigation management and practices, which has an immediate effect on irrigation practices and satisfaction with irrigation services.
Remote survey

Drone survey is conducted during the canal closure period to acquire digital orthophotos of the canal and hydraulic.

The duration and ground sample distance (GSD) of the flight, and resolution of the digital photos can be adjusted in order to optimize the required resources and time.

If visual interference is encountered, such as dense vegetation or shading structure, the drone can be replaced with a high-resolution handheld digital camera.

Image analysis

The image analysis is based on a computer algorithm which is developed to convert the digital red-green-blue (RGB) photos to greyscale.

The image histogram binarization technique is applied to differentiate two distinct classes: damaged section and undamaged section. Then, the algorithm calculates the area of damage surface by counting the number of pixels in the class and converting them into the unit of square meter.
The inclined surfaces of canal sides are orthogonally projected to account for the inclination angle between the camera and the lining of canal sides. In case of complex canal systems with no prior knowledge of the scales and dimensions, the image analysis can be complemented with topographical survey.

The purpose of the topographic survey is to create a baseline spatial dataset to validate the accuracy of drone orthophotos and to provide as-built drawings that are used during the rehabilitation of the canal.

The topographic survey data is overlaid on the drone photos and the differences in the location of sampled features such as bridge corners and outlet locations are measured to validate the accuracy of drone photos.
Crowdsourcing

The purpose of data crowdsourcing is to validate the results by means of physical verification in the field. Spot checks of the extent of damage are performed and verified against the result obtained from the image analysis. In addition, to prioritize rehabilitation of the severely damaged reaches of the canal, the condition of canal lining is evaluated and graded according to pre-set assessment criteria.

Damage quantification

The last step is the assessment and quantification of the identified damages as per the validated image histogram. The chart provides information on the location of the section and the extent of the damaged area, thus allowing the quantification of rehabilitation needs.

Figure 10. Damage levels are used to assess the level of rehabilitation works required.

Good conditions

- Concrete panels are aligned and level, joints are sound.
- No evidence of base course erosion, minor spalling only.
- Rare occurrence of hairline cracks, material firmly held.
- No vegetation growth between the joints.

Fair conditions

- Concrete panels are aligned and level, some joints need resealing.
- Occasional erosion or settlement of base course.
- Minor cracks up to 1 mm wide or spalling may occur.
- No vegetation growth between the joints.

Poor conditions

- Concrete panels deviate occasionally from line and level.
- Clear signs of panel damage and erosion of base and sub-base course.
- Cracks up to 5 mm wide or spalling randomly distributed over the panels show clear risk of progressive failure.
- Frequent joint failures, vegetation ingress between join.

Very poor conditions

- Alignment and level are completely lost for group of panels.
- Multiple panels collapsed, clear evidence of base and sub-base course erosion and settlement.
- Missing parts of concrete panels and excessive cracks show high risk of progressive failure.
- Random vegetation between the cracks.
The outcome

Through the rigorous process of obtaining images and a set of relevant technical information to the assessment, the RE-RAP proves to be robust to quantify the damage and prepare rehabilitation plans. Once the baseline assessment is performed, the RE-RAP calibrated to the given irrigation system can be used to generate benchmark for the consistent condition tracking over time.

Canal rehabilitation based on performance assessment has a wide range of benefits from increased conveyance efficiency to healthier environment. By eliminating seepages and sediment deposit, the water delivery capacity increases thus providing more reliable, adequate and equitable water service for users.

The improved canal condition can significantly extend the lifespan of the irrigation system and reduce the need for re-investment. The balanced performance between upstream and downstream parts reduces the source of friction amongst users and re-integrate the downstream farmers. Improved condition has also positive impact on the environment, as the pollution source of contaminated silt deposit is removed, while good canal conditions enable the installation of further waste removal equipment.

The case of Akkar irrigation canal

The upstream 7 km of El-Bared Irrigation Canal passes through unpopulated agricultural lands where fewer damages are found due to less human interference with the canal infrastructure.

The turning point of condition is the section at 7 km from the headworks, where the frequency of occurrence and amount of damage to the canal lining is more severe due to increased rate of in-built areas.

The pilot case in Akkar irrigation scheme showed that downstream areas are prone to poor canal performance, and any prioritization of rehabilitation works should focus on the canal tail.
## Lessons learned

The pilot case provides lessons learned during the design and implementation of this component of the project. Such lessons can be categorized under three domains.

<table>
<thead>
<tr>
<th>Data collection (Drone image acquisition)</th>
<th>Analysis (Image processing)</th>
<th>Implementation and scaling up</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Drone survey is a rapid and cost-effective way for assessing the condition of an irrigation canal in inaccessible areas.</td>
<td>• Image processing is a computationally intensive and comparatively complex process, but once the methodology is established and calibrated, the process can be automated and iterated as frequently as required.</td>
<td>• The implementation of the developed methodology on pilot scale in Akkar irrigation canal system proved successful and the consequent rehabilitation (civil work) could be implemented based on the acquired rehabilitation plans.</td>
</tr>
<tr>
<td>• Survey protocols must be established prior to the beginning of implementation such as the image spatial and spectral resolution and flight altitude.</td>
<td>• Spatial resolution of image should be rightly chosen to capture the required details of the target surface to achieve the desired results.</td>
<td>• The methodology is flexible and open to both drone and satellite images, to automatically obtaining information and assessments, also for large scale uptake.</td>
</tr>
<tr>
<td>• Image acquisition should be avoided at times of low sun elevation angles (mornings and evenings). During these periods, long shadows of surrounding objects can obscure the view of target surface and may require complex processing to eliminate the effect of shadows.</td>
<td>• Validation of image processing result is an important step in the developed methodology. Validation points should be selected at well-defined locations spread uniformly across the study area.</td>
<td>• The methodology supports replicability, and the algorithm can be implemented through a software package for technology transfer and large-scale uptake and distribution.</td>
</tr>
<tr>
<td>• Scheduled closure period of canal is the best time for drone survey. During this time, the absence of water and floating objects make it easier to capture the real target surface.</td>
<td>• Image processing works on the principle of image segmentation and can eliminate the biasness that may arise due to manual assessment.</td>
<td>• The methodology is capable to process big data and generate results at large scale to increase number of beneficiaries.</td>
</tr>
<tr>
<td>• Drone survey should be an integral part of the annual infrastructure benchmarking programs to keep record of the condition of the infrastructure.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Facts and figures

Canal coverage
11.2 km

Validation points
30

Drone image data
10 GB

Optimum image resolution
10 m

Drone photos
8,000+

Damaged lining area
10,772 m²

Concrete for rehabilitation
1,617 m³

Optimum flight altitude
30 m

© FAO/Jihad Saade
The impact of this methodology envisages its uptake and scaling up by implementing partners with the support of donor agencies for the rehabilitation of other irrigation networks. The uptake is planned according to the following execution matrix.

<table>
<thead>
<tr>
<th>Piloting</th>
<th>Learning</th>
<th>Scaling up</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Pilot areas are selected according to a multicriteria selection process</td>
<td>• Training of key technical staff for traditional and new methodology</td>
<td>• Demonstration of strengths and replicability potential</td>
</tr>
<tr>
<td>• Design, test and validate the methodology</td>
<td>• Methodology transfer and extended training of professionals on different forums</td>
<td>• Large scale implementation</td>
</tr>
<tr>
<td>• Finetuning during pilot implementation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Contact information

FAO Lebanon
Email: FAO-LB@fao.org

Land and Water Division - Natural Resources and Sustainable Production
Email: Land-Water@fao.org

Rome, Italy

Food and Agriculture Organization of the United Nations

With the financial support of

Norwegian Embassy

With the technical support of

The boundaries and names shown and the designations used on these maps do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers and boundaries. Dashed lines on maps represent approximate border lines for which there may not yet be full agreement.