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Foreword

Waste management in Lebanon is a significant issue anticipating cascading and spill-over effect on livelihood, environment and agriculture. North Lebanon has been experiencing population growth spurts due to humanitarian crises in neighbouring countries that contributes to the urgency of finding sustainable solutions. Adequate delivery of response measures is beyond the capacities of local authorities. Consequently, waste crisis has reached its historical peaks. It is unlikely that upcoming years can bring radical shifts related to the trends in rapidly increasing waste generation. However, the seemingly uncontrollable mechanisms should not lead to inaction, but concentrated efforts should be stepped up to eliminate harmful consequences.

Water resources are particularly vulnerable to the on-going dynamics, as waste mismanagement leads to faster spreading pollution. Waste disposed in irrigation canals is involuntarily carried towards adjacent parts of the water network, including lower level canals and ultimately the sea. Due to the increasing waste volume worldwide, the phenomenon can be observed across the globe. North Lebanon is no exception. Irrigation canals are extensively used as easy-to-reach dumpsites. The course of accumulating waste crosses through multiple villages and reach the sea, while leaving disruptive and uncontained damages in the status of natural resources.

The project “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, has been formulated to ensure minimal discharges of waste from El-Bared System to the Mediterranean Sea, thus improving the livelihoods of the people depending on the system through irrigation canal system rehabilitation, solid waste disposal, and improved agricultural output and job creation. Applying a pilot approach, the project mainly focuses on Akkar irrigation scheme to introduce both hard investment and soft measures in response to the waste crisis. Following a multi-criteria assessment approach, the current report maps waste removal technologies and provides recommendations on their functions and suitability in the context of the target area. Based on broader understanding of the feasibility, it helps come to a decision on technology selection.

Acknowledgements

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Abbreviations and acronyms

CAS	Central Administration for Statistics of Lebanon Council of Ministry
CDR	Council of Development and Reconstruction
EU	European Union
FAO	Food and Agriculture Organization
GEF	Green Environment Facility
GoL	Government of Lebanon
HDPE	High-density polyethylene
LCRP	Lebanon Crisis Response Plan
MCA	multi-criteria analysis
MoA	Ministry of Agriculture
MoE	Ministry of Environment
MoEW	Ministry of Energy and Water
MoIM	Ministry of Interior and Municipalities
MSW	Municipal solid waste
NGO	Non-governmental organization
NLWE	North Lebanon Water Establishment
O&M	Operation and maintenance
ODA	Overseas Development Unit
UN	United Nations
UNDP	United Nation Development Programme
UNEP	United Nation Environment Programme
UNFCCC	United Nation Framework Convention on Climate Change
UNHCR	United Nations High Commissioner for Refugees
UoM	Union of Municipalities of the North Lebanon

Symbols and chemical formulae

B	canal width
Ca	calcium
Cl	chlorine
Cu	copper
EC	electrical conductivity
D	hydraulic depth
d_{50}	mean sediment diameter
f	friction factor
Fe	iron
g	universal gravitational constant
HCO_3	bicarbonate
θ	shear resistance
K	potassium
ks	and-grain roughness
Mg	magnesium
Mn	manganese
Na	sodium
Ni	nickel
NO_3	nitrate ion
Pb	lead
Q_s	sediment discharge in days
q_s	sediment discharge in sec
S_0	bottom slope
S_s	specific gravity
SO_4	sulfate ion
V	mean velocity
y_s	solid specific weight
y_w	water specific weight
Zn	zinc

Units

cm	centimetre
ha	hectare
m	meter
m^3	cubic meters
mm	millimetre
kg	kilogram
kg/m^3	kilogram per cubic metre
kg/s	kilogram per second
km	kilometre
km^2	square kilometres
tonnes	tonnes
USD	US dollar
°C	Celsius degree
°	degree

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Introduction

Waste management in Lebanon is a significant issue that keeps fuel environmental and socio-economic crisis, exacerbated by rapid urbanization and limited environmental awareness. The competition over available resources and finances is at an all-time peak in Lebanon, counting 6 855 713 inhabitants in 2019 (World Bank, 2019). Demographic priorities have been restructured, thus entailing significant change in land and water use. Based on national research, between 1994 and 2017, the urban cover in North Lebanon replaced 10.2 percent of its agricultural cover and 5.3 percent of its natural cover (Husseini, 2020). As a result, this area has witnessed an increase in population, aggravated by being the second largest host of Syrian refugee population in Lebanon since the onset of the conflict. This urbanization trend and the rapid increase in population size contribute to the change in livelihood patterns – a factor that has pushed communities to adopt a more consumerist culture, requiring continuous renewable and non-renewable resources and generating larger volume of solid waste. Municipal solid waste (MSW) trends have attained new heights in Lebanon with the total daily amount reaching 6 500 tonnes (MoE, 2018).

Under the first pillar of Lebanon Crisis Response Plan (2017-2020), integrated MSW management is identified as critical investment need to reduce social tensions. Throughout the last 20 years, MSW in Lebanon has witnessed significant technical, legal and institutional changes (MoE *et al*., 2011). The private sector executed a number of small and medium size sorting and composting facilities at a municipal level, but the projects have known limited success due to the lack of financing of the operation and maintenance services and the lack of technical capabilities of the municipalities to ensure efficient MSW management. (MoE *et al*., 2011). According to the Updated Master Plan for the Closure and Rehabilitation of Uncontrolled Dumpsites throughout the Country of Lebanon by the UNDP and the Ministry of Environment (MoE), Akkar and North Lebanon had experienced significant drop in the number of operational dumpsites between 2011 and 2016. On the contrary, the volume of dumpsites had increased from 606 007 m^3 to 2 2246 797 m^3 in the same period. This is due, in particular, to structural changes, as open dumping activities were centrally controlled in the area (MoE and UNDP, 2017). However, only five solid waste management facilities are operational in Akkar and North Lebanon, which are not likely to be enough to support the sudden increase in MSW generation.

The cascading effects of MSW crisis are currently uncontained and have adverse impacts on several aspects including public health, environment and agriculture. Only 55 percent of MSW in Lebanon is disposed in managed landfills (MoE *et al*., 2019), while the remaining half is collected in open dumpsites or abandoned in the environment, along streets and rivers. Moreover, several major open dumpsites are not properly closed or rehabilitated, thus involving long-standing risk (World Bank, 2011). Several of them are situated in sensitive areas, in proximity of rivers, streams, irrigation canals and sea as well as urban centres and communities, contributing to groundwater contamination, pollution of soil and water, coastal degradation, public health damage and agricultural issues. In addition, illegal dumping and open burning of MSW are common throughout Lebanon, causing serious direct and indirect impacts on human health because of the dangerous emissions of pollutants into the air. Equally worrying, most of wastewater produced in Lebanon is discharged without prior treatment (World Bank, 2011) and rivers are adversely impacted by sewage and MSW together. Therefore, the water resources – of which 64 percent is used for agriculture and 26 percent is for domestic demand (World Bank, 2011) – are being contaminated by bacteria, heavy metals and hydrocarbons and, due to fertilizers and pesticides infiltration in the agricultural areas, they are exposed to further environmental degradation (MoE *et al*., 2011). The pre-existing pressures on Lebanon's natural resources are therefore extremely increased by incorrect disposal of MSW and water pollution – which affects freshwater, irrigation and coastal water.

Significant efforts are required towards the elimination of MSW pollution through translating national policy recommendations into on-ground actions. Proposed approaches must be built on solid evidence base that can be confidently transferred to further stakeholders.

About the report

This report introduces multi-criteria assessment of engineering solutions for MSW removal from irrigation canal, in order to minimize the pollution discharge into the sea. The report builds on twofold aspect, incorporating technologies for MSW and sediment removal to maximize the positive spillovers and dilute the negative ones. The report is produced in the framework of FAO's project "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" implemented in Akkar, El-Bared watershed under the authority of North Lebanon Water Establishment (NLWE), with the overall objective to:

- Contribute to the existing literature about impact assessment of MSW crisis in Lebanon in the context of water management;
- Obtain comprehensive overview of the interactions between MSW and water resources in the context of irrigation water;
- Identify available engineering solutions for MSW and sediment control in waterways that can be taken into account in the command area;
- Construct a high-rigor methodology for multi-criteria analysis of engineering solutions; and
- Provide expert-crafted recommendations on combined technologies for MSW and sediment control in the command area.

The report is structured as the following:

- The first section provides an outlook for the multiple impacts of MSW on agriculture, environment and water resources. Starting with the overview of the command area, the section narrows the scope to the complex interaction between MSW and water management.
- Following the stocktaking of available engineering solutions, the report presents multi-criteria assessment for technology prioritization in Akkar command. It finally provides recommendations of combined technologies and proposes future actions for effective implementation.

Overview of Akkar irrigation scheme

The command area

Akkar Governorate is located in the far North of Lebanon and has a total surface area of 79 800 ha with the Mediterranean Sea on its western border, Hermel to the East, Syria to the North and the El-Bared River and the district of Minieh-Dinnieh to the South. It is composed mainly of six areas: Al-Sahel, Middle and Higher Dreib, Joume, Shaffat, and Qaytaa (Mouchref, 2008). Akkar topography is extremely diverse, with three principal zones: the plain, the mid-elevation plateau and the mountains, with an altitude ranging from 0 to 2 100 m. This results in significant heterogeneity of climate, hydrology, soil and vegetation.

The population size in Lebanon has gradually increased over the years, from 1 804 941 inhabitants in 1960 to 6 855 713 residents in 2019 (World Bank, 2019). One of the most impacted and deprived regions in the country is North Lebanon, with high poverty levels, which remains to register the second largest host of Syrian refugees in Lebanon due to its geographical location bordering Syria (UNHCR, 2020). North Lebanon, composed of the North and Akkar governorates, cumulatively hosts a population size of 1 163 912 people of which 532 000 live under the poverty line: 341 000 deprived Lebanese, over 140 000 Syrian refugees, 51 000 Palestine refugees and almost 15 000 Lebanese returnees (OCHA, 2018).

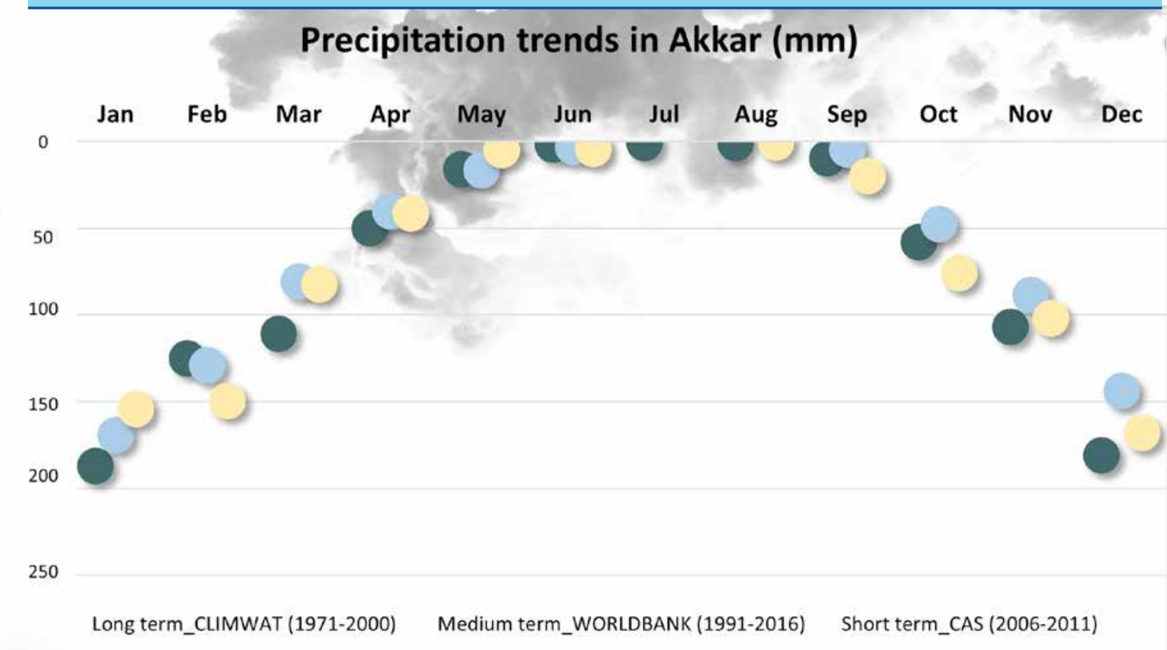
Climatic conditions

In Lebanon, climate is characterized by a Mediterranean-type weather, with hot and dry summers, and cool and rainy winters. The average annual temperature is 15 °C, having January the coldest month by average temperature of 5 to 10 °C (MoE *et al*., 2011). The mean annual rainfall of North Lebanon has been changing over the last decades. The annual values range between 500 and 1 000 mm, with an average around 800 mm. However, the rainfall pattern shows uneven distribution over the year, as around 85 percent of the annual rainfall is expected between November and March. Figure 1 displays monthly average rainfalls in long-term (1971-2000), medium-term (1991-2016) and short-term (2006-2011) trends. The monthly precipitation rate of North Lebanon has been extrapolated from Central Administration for Statistics of Lebanon Council of Ministry (CAS), CLIMWAT and Climate Knowledge portal of World Bank, incorporating the data from Tripoli Station and three other weather stations in North Lebanon. It can be already observed that there is a decrease in annual rainfall, from 848 mm per year in long term data to 803 mm per year in short term data. The major decrease is recorded from January to May – except February –with a mean decrease of 11 mm.

Water and land resources

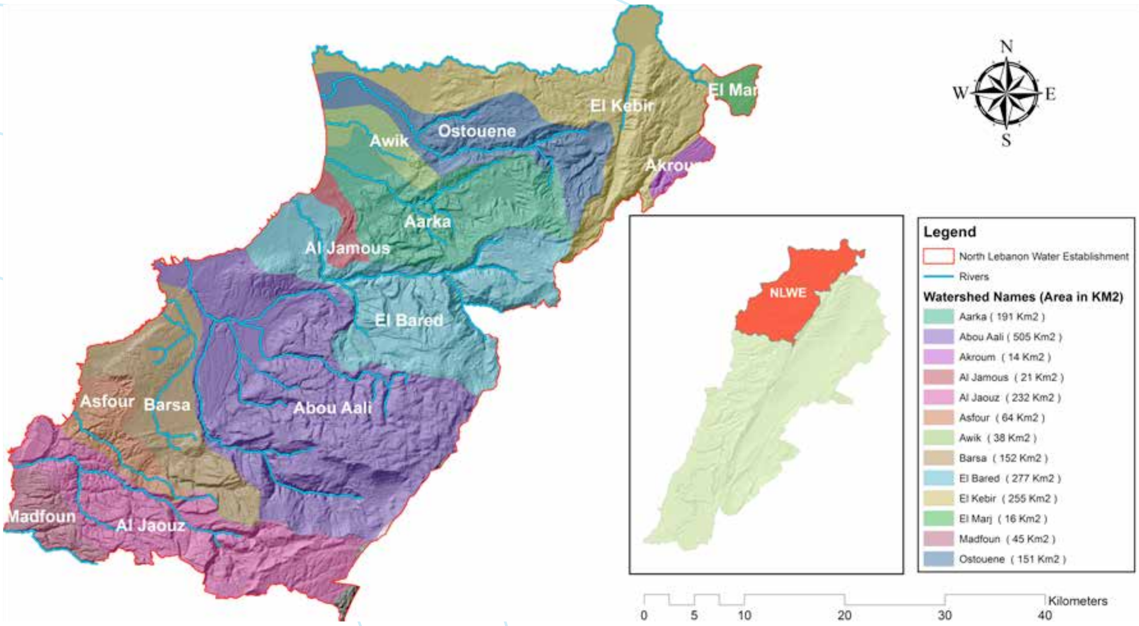
North Lebanon consists of 13 watersheds, of which El-Bared is the second largest with its 277 km^2 area. El-Bared watershed belongs to Akkar together with three other major perennial rivers (El Kabir, Ostouene and Arka) and the seasonal stream of Wadi Awik (ELARD and NLWE, 2016). El-Bared River is one of the most impacted with an estimated area of 1 477 ha and length of 24 km. Sourced by multiple springs, it supplies major agricultural areas such as the Union of Al-Qaytaa (including Mhamara and Bebnie) and Minieh. Based on the land use maps generated for Akkar Governorate, approximately 133 ha out of 1 477 ha total command area is covered by water bodies and rivers (ELARD and NLWE, 2016).

Figure 1: Average monthly precipitation rate in long, medium and short-term in North Lebanon



Source: CAS, CLIMWAT and World Bank, 2020

Figure 2: Watersheds in North Lebanon

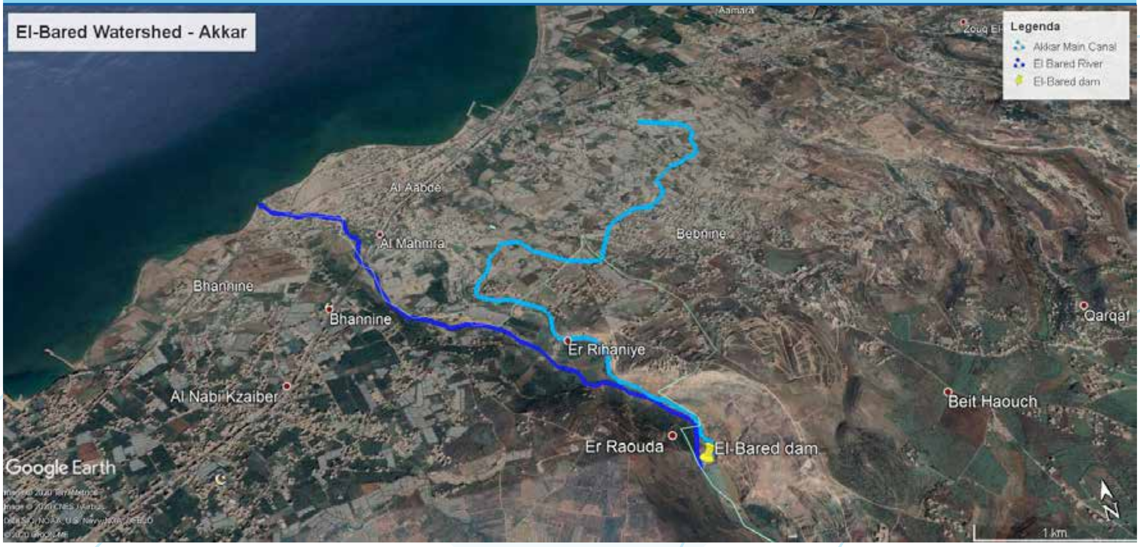


Source: FAO, 2018.

Due to its topography, the available water resources per capita is higher than of the neighbouring countries. Groundwater is an essential source of domestic water use, especially in Akkar where not all villages are linked to NLWE networks. NLWE network coverage reaches 60 percent in the North with Akkar still not fully covered, making some municipalities to have their independent water systems. The remaining 40 percent either utilize water from communal wells, private wells, water trucking or springs. Furthermore, it covers 50 percent of irrigation water which comes from wells and boreholes (MoE *et al.*, 2011). However, about 65 percent of the aquifers in Lebanon are of karstic limestone – that are affected by high level of fissures and fractures controlling groundwater flows and determining the infiltration and the transport of pollutants, also including fertilizers and pesticides. This together already poses significant health risk. Still worse, urban expansion and increasingly growing demand of irrigation water further contributes to the uncontrolled well drilling. More than 42 000 private wells are currently in use (MoE et.al, 2011). This might have contiguous effects on water quality, as depleted aquifers can experience high salinity level. Coastal groundwater is also threatened by the sea water intrusion and rising sea level. Current trends show increased intensity of sea water intrusion that must be taken into account in future water management strategies (MoEW and UNDP, 2014). Sea levels have been continuously rising at an average rate of roughly 20 mm per year in the Levantine basin of Mediterranean Sea, and it can reach up to a total of 30–60 cm in 30 years (MoE *et al.*, 2011).

Irrigated areas in North Lebanon are supplied by four major irrigation canals with varying lengths. Although Akkar primary canal is the shortest amongst them with 14 km, it supplies the largest portion of agricultural lands in the region. The canal sources water from El-Bared dam, which stores the natural river flow.

Figure 3: El-Bared River map view

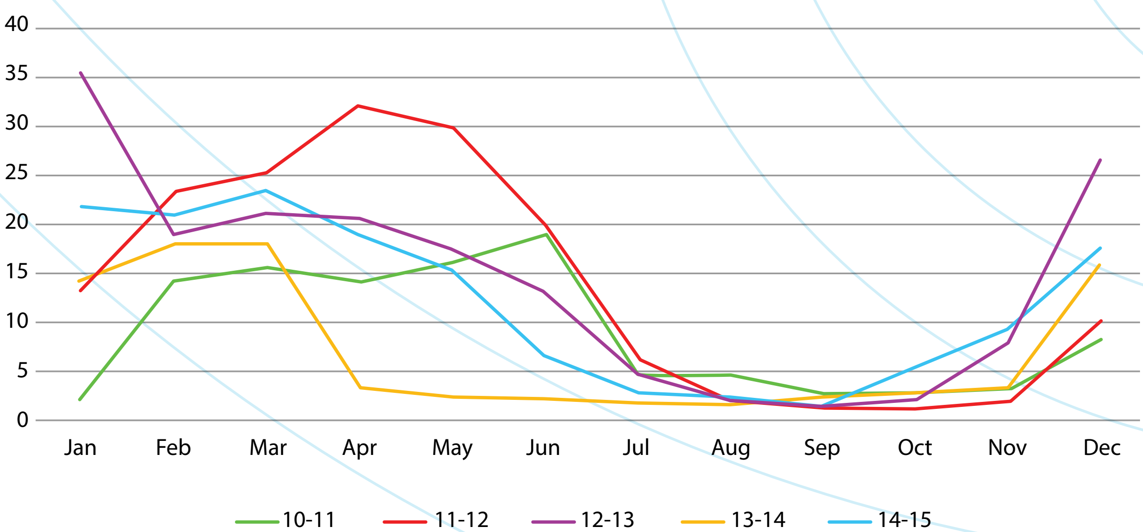


Source: Google Earth, 2020, elaborated by the authors.

Water volume of El-Bared River can be considered largely fluctuating in terms of both inter-annual and intra-annual variation. For example, water volume reached as low as 1.037 million m^3 in October, but 32.054 million m^3 in April in 2011.

El-Bared dam is a central core rock dam currently relying on gravity water. The dam operation is affected by a hydropower dam upstream. The catchment area is estimated at around 270 km^2 with 72 million m^3 annual runoff. With large storage capacity, the dam supplies irrigation water and drinking water to the poorest cazas in Lebanon, Akkar, Minieh and Dannieh (World Bank, 2003).

Figure 4: Water volume of El-Bared River in million m^3 between 2010-2015



Source: FAO, 2020.

Figure 5: El-Bared dam, 2019

Akkar sources water from El-Bared Dam through gated intakes. The open-canal system distributes water from one main canal into lower level network. Irrigation canals in the command area cover a length of about 97 km, of which about 14 km belong to the main canal and 86 km to the lower-level canals and drains. Throughout the last decades, the irrigation network remained unsecured from the adverse impacts of urbanization. Today, the previously separated municipal and agricultural water networks are involuntarily interconnected. Irrigation and storm-water drains are conjunct before reaching the sea. However, this multiple use of system is unintentional and lacks any kind of engineering considerations. The long-term trend of multiple use led to severely deprived infrastructure along the total lengths of the irrigation network. According to the original network profile, the canal network has around three formal outlets along the estimated 7 km of coastline. Further informal outlets are identified though. However, they are heavily deteriorated, and some of them are non-functional anymore due to human interference. The outlets are devoid to have any function to convey or control flow, and to trap trash. This overload on the system poses risk not only on the infrastructure but on environment, agriculture and human health.

Figure 6. Canal outlet to the sea, 2019

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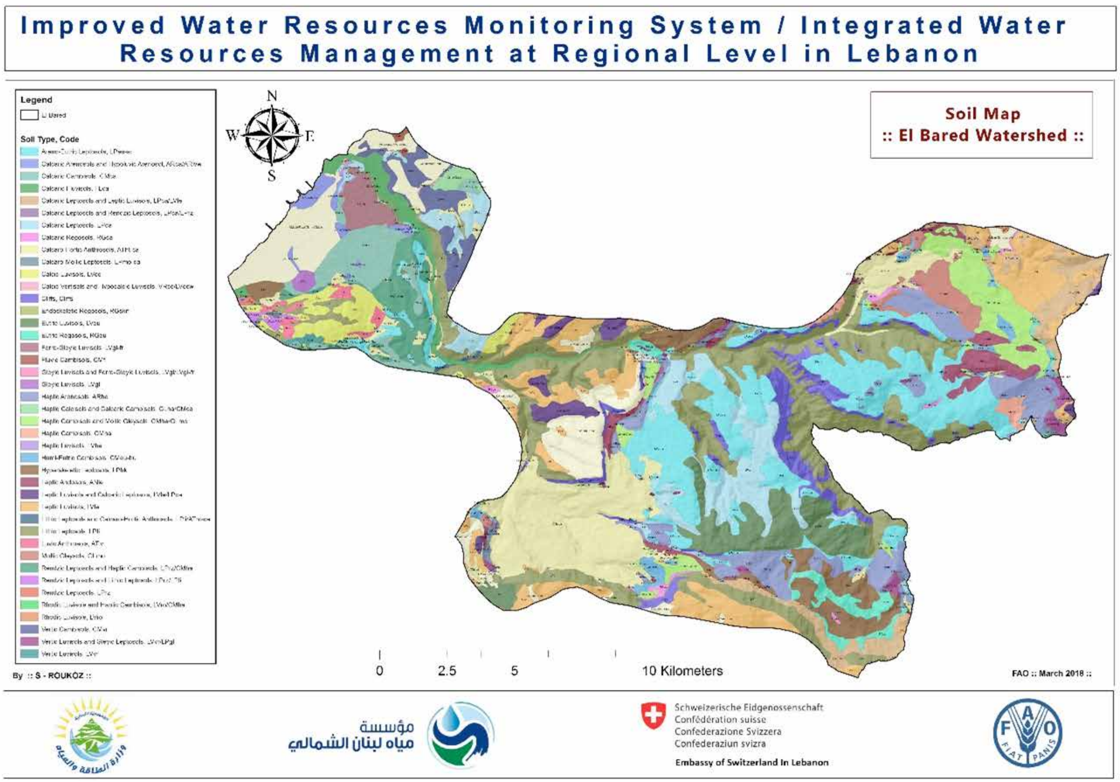
Marine ecosystem in Lebanon is considered Mediterranean with some sub-tropical elements (MoE *et al.*, 2011) characterized by various ecosystems, like coralligenous habitats, seagrass meadows, vermetid reefs, and deep-sea ecosystems such as underwater canyons (Bigagli *et al.*, 2018). On the base of an IUCN analysis on underwater canyons, six main habitat types exist over a broad depth ranging between 36 -1050 m: coralligenous habitats and rhodolithper maërl beds, rocky bottom areas, muddy and sandy-muddy bottoms, sandy bottoms, canyon heads, and bathyal muds (IUCN, 2018). However, Lebanese marine ecosystems are threatened by multiple sources. Sand and gravel extraction, sewage discharge, marine letter, unsustainable and illegal fisheries, habitat degradation, recreational uses and coastal urbanisation are the major risk factors in the command area (IUCN, 2018).

Generally, soils in Lebanon are young and typically Mediterranean, characterized by fragility, poor consistency and shallowness (especially on sloping terrains) that prone them to erosion and environmental degradation. El-Bared watershed has extremely divesre soil types, consisting mostly of cambisols, fluvisols, luvisols, leptosols, arenosols, anthrosol, hyperskeletic and cliffs.

Figure 7: Soil type classification in El-Bared watershed



Source: FAO, 2018.

In Akkar region, there are two areas mainly used for agriculture: the plain and the mid-elevation plateau. The first is characterized by shallow slopes, and it is composed of sandy soils formed suitable for agriculture (FAO, 2008). The middle area covers about 50 percent of Akkar region and is used for agriculture pastures and forest (MoA, 2003). This fertile land has enormous agriculture potential, making Akkar and northern areas the second largest agricultural region in terms of total cultivated area after Baalbeck-Hermel and Bekaa (FAO and MoA, 2010).

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Solid Waste Management Outlook in North Lebanon

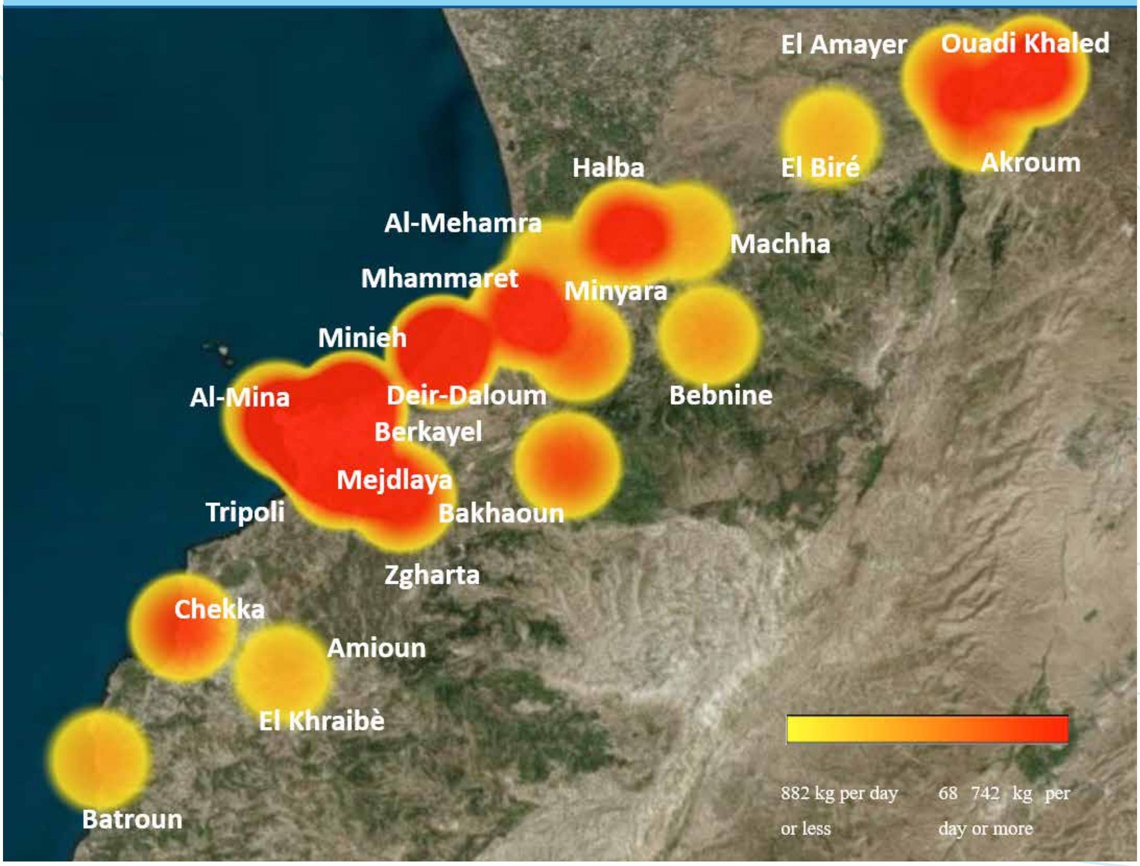
Poverty, high numbers of refugees and high unemployment rate make Northern Lebanon one of the most deprived regions of the country. North Governorate accounts 1 163 912 inhabitants, of which 328 408 are registered refugees from Syria and Palestine (OCHA, 2018). The public service capacities related to MSW management are not yet prepared to accommodate the intense population growth. Due to enormously increasing consumption and relatively weak policy regulations on sustainable production, the volume of waste generation has approximately doubled in the country and has contributed to public outrage over 5-year period between 2005 and 2010 (MoE *et al.*, 2011). MSW makes up most of the waste amount in Lebanon. Estimation shows that around 6 500 tonnes per day MSW is generated in Lebanon, of which the governorates of the North and Akkar shares 17 percent (MoE, 2018). The volume of waste generation is imbalanced, as rural areas account around 0.8 kg per capita compared to 0.95-1.2 kg per capita in urban areas. Together, the rural and urban areas, average 1.05 kg per capita waste (SWEEP-NET, 2014). Table 1 presents theoretical analysis of MSW production in main cities and villages of North and Akkar governorates. The calculated volume of waste production considers the population and the average waste generation per capita. Centralized efforts should be taken to extend the public services in order to create safe environment particularly in this region, where vulnerable communities are exposed to poor public facilities.

Table 1: Generated daily waste volume per cities in North and Akkar governorates

City	kg per day	City	kg per day
Akroum	11 331	Machha	5 434
Al-Mehamra	36 099	Machta Hammoud	12 266
Al-Mina Jardins	21 978	Mejdlaya	10 596
Al-Mina	12 399	Miniyeh	39 683
Amioune	5 018	Ouadi Khaled	20 699
Batroune	5 667	Tripoli Al Haddadin	56 601
Bakhaoun	11 465	Tripoli Al-Kobbé	68 742
Bebnine	18 612	Tripoli Al-Nouri	2 720
Berkayel	10 690	Tripoli Al-Souéka	10 315
Chekka	12 648	Tripoli Al-Tabbaneh	27 659
Deir-Daloum	5 415	Tripoli Al-Tal	64 721
El Beddaoui	44 387	Tripoli Al-Zehrieh	7 032
El Khraibé	6 314	Tripoli Jardins	5 174
El-Biré	5 057	Tripoli Zeitoun	23 613
Halba	17 567	Zghorta	16 363

However, the estimated daily 596 tonne waste generated in the indicated cities is distributed unevenly in the region. As the heat map shows, the largest cities such as Tripoli, Minieh, Mhammaret, are the hotspots of waste load. The concentration of waste is even more critical in the sense that all these cities are located in the coastal areas that have no significant infrastructure to prevent MSW disposal.

Figure 8: Distribution of MSW generation in North and Akkar governorates



Source: Google Earth, 2020, elaborated by the authors.

Policy background and responsibility share

Governmental bodies and private entities are at the heart of MSW management. Accordingly, the Ministry of Environment, Ministry of Interior and Municipalities (MoIM), Municipalities, and the Council of Development and Reconstruction (CDR) are mandated by law to govern the sector. As shown in Table 2, municipalities governed by MoIM are mainly tasked with the responsibility of waste collection, disposal and overall management at the sub-national level. This is not the case however, for municipalities in Beirut, Tripoli and the majority of Mount Lebanon that take on a less extensive role and assist CDR with overseeing the work of private contractors selected by CDR. Municipalities tend to play a more central role in waste management in the North of Lebanon especially in Akkar and Minieh. In 1974, Decree 8735 was put into force on the topic of public hygiene and included 39 articles with the purpose of controlling the discharge of domestic, agricultural, and industrial waste. It should be highlighted that this decree places the main responsibility of waste collection and disposal on municipalities. Also, it prevents waste dumping in public and private areas including adjacent roads and waterways, and it states that official disposal sites require approval from the province authorities. Adding to the above, Municipal law No 118, that dates back to 30 June 1977, also assigns municipalities the responsibility of MSW.

Table 2: Responsibility share of different stakeholders

Stakeholder	Main Responsibilities
Waste Management Board	Developing waste strategy and authorizing waste management plans
Ministry of Environment	Initiating waste management standards and guidelines and implementing waste management programs
Ministry of Interior and Municipalities	▪ Participation in the National Strategy and plan and implementation of local waste management plans ▪ Establishing/ implementing waste management programs
Municipalities	▪ Participation in the National strategy and plan through the Waste Management Board ▪ Proposing and implementing local waste management plans for non-hazardous municipal waste ▪ Establishing / implementing waste Management programs ▪ Management of waste collection

Stakeholder	Main Responsibilities
Council of Development and Reconstruction	▪ Assistance in procurement of WM projects upon request ▪ Assistance in the development of WM plans upon request
Private Sector / the Public	▪ Abiding by laws, regulations and guidelines on waste management ▪ Prohibition of littering, illegal bumping and burning ▪ Participation in the National strategy and plan through the Waste Management Board ▪ Participation in the development and implementation of local waste management plans ▪ Participation of facility and generator managementplans

Source: MoE *et al.*, 2011; Massoud, 2016; Abbas *et al.*, 2017.

The recent waste crisis was instantly followed by early response from decision-makers to adopt more efficient integrated solid waste management. Law 80 was issued by the council of Ministers in 2018 as a means to ensure an integrated framework for MSW management and to safeguard the environment. Though no action plan was put in place to make its implementation more efficient, it highlighted the importance of the principles of integrated household MSW management (reduction, reuse and recycle) and the concepts of sustainability, awareness and transparency (MoE, 2018). In the last few years, more and more organizations and institutions have tended to focus primarily on preventing MSW accumulation and its spread on land or water. Common practices include the provision or restoration of sanitary landfills/waste disposal facilities, the supply of compactors trucks or bins to collect household waste and prevent it from seeping in waterways or spreading, and the promotion of recycling and reusing and reducing polluted water quality. In the North, for example, most organizations (local or international), specialized in MSW, tend to focus mostly on sorting or waste collection at source level, in addition to awareness and capacity building at the local and municipal level.

Stakeholder analysis of solid waste management in Akkar

In order to conduct exploratory analysis of the current situation of solid waste in Akkar, semi-structured face-to-face interviews were conducted with main stakeholders over the period May 2020 to July 2020. The overall objective of this qualitative analysis is to establish causal relationships based on identified synergies (Green *et al.*, 2003). The structured questionnaire consists of three main modules:

- General overview:
  - stakeholders and their role in waste management
- Mechanisms of MSW management
  - Sources of waste
  - Collection of waste
  - Sorting of waste
  - Disposal of waste
- Capacity bottlenecks

In Lebanon, MSW management is divided into zones under the responsibilities of different Municipalities and Union of Municipalities. Therefore, stakeholders' involvement included two main Union of Municipalities of the North Lebanon (UoM) and the belonging municipalities along El-Bared River: (1) UoM of Minieh, including 5 main municipalities; (2) UoM of Al Qaytaa, including 15 municipalities; and (3) Municipality of Mhamara, along El-Bared river.

1. General overview

The survey results show that MSW activities undertaken by municipalities outside of Beirut and Mount Lebanon are not streamlined nor equivalent; they are rather autonomous (affected by available support and in accordance to their share from the municipal fund), where each municipality relies on its own waste collection protocols. This is the case of the municipality of Mhamara, Union of Jurd Al Qaytaa and Union of Minieh, which all benefit from El-Bared watershed. The stakeholders take similar responsibilities regarding day-to-day to activities such as municipal cleaning, waste collection, etc. However, prioritization of activities might be different from one to another. For example, the focus of the municipality of Mhamara is on enhancing water services through the implementation of various activities, while the rest might prioritize MSW management. In addition, collection and disposal services might differ between municipalities. The frequency of provided services also differs amongst stakeholders. While some collects waste on a daily basis (sometimes twice a day), others only collect waste once a week.

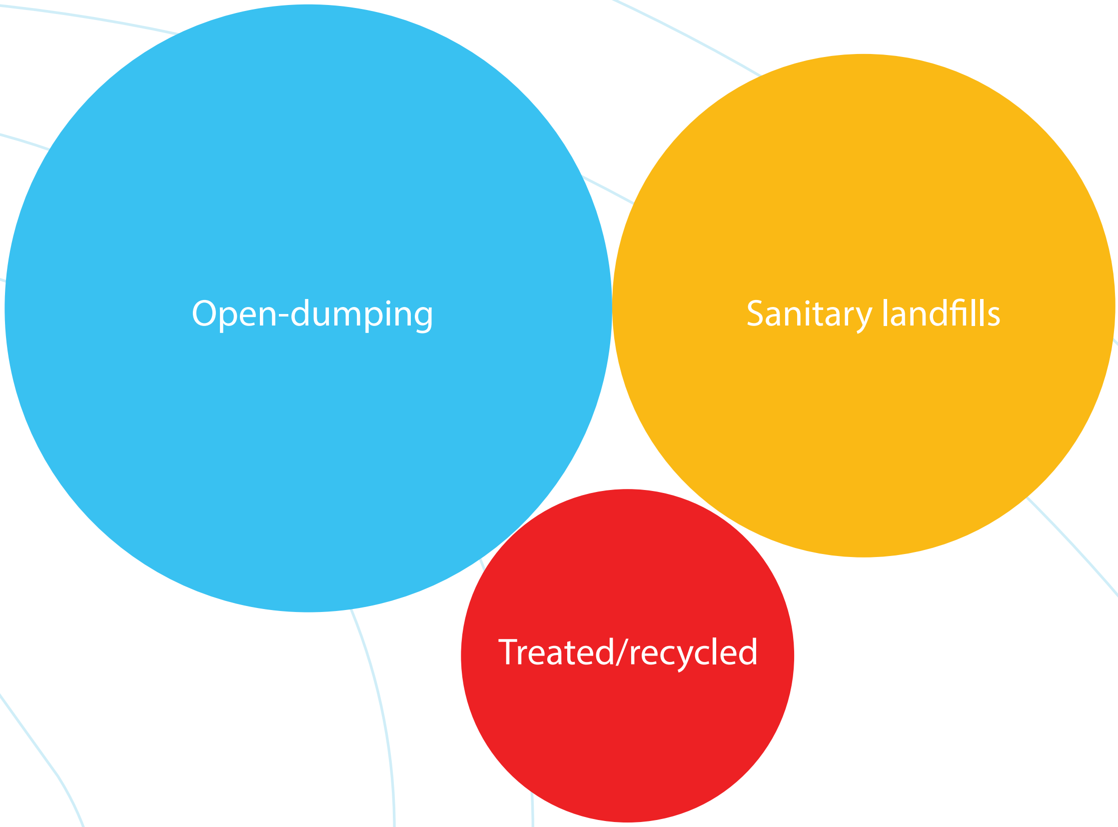
Figure 9: Removed MSW from irrigation canals, 2019

This fact gives clear explanation why some villages are put behind the others. Infrequent waste collection leads to waste accumulation, thus forcing inhabitants to dispose their waste randomly and use irrigation canals as means of waste transport. Until regulations for all are not effectively monitored and enforced, and universally applicable protocols are not introduced, the current practices further aggravate the tension. Still worse, the cascade effect of MSW pollution continues to induce adverse impact on the surrounding environment. However, mainstreaming MSW management into policy and enforce its implementation might not be easily forthcoming. It is important not only to impose new intervention strategy for MSW management in theory, but to showcase real-term implementation that matches social reality and delivers immediate remedial measures.

2. Mechanisms of waste management and capacity gaps

In terms of waste generation, the Union of Minieh and Al-Qaytaa alone can generate around 130 tonnes per day. According to the Union of Minieh, the quantities of waste generated has increased by 33 percent in the last five years – from 60 tonnes per day to 80 tonnes per day. Similarly, for Mhamara, a village that falls under the Union of Al-Qaytaa, quantities of MSW have doubled for the same period. Regarding waste disposal, half of the volume of MSW was mostly openly dumped, while 35 percent was disposed in sanitary landfills, and negligible rate of 15 percent was treated or recycled (MoE, 2018). Increasing social awareness together with recycling capacities would certainly provide effective intervention strategy to champion the cause of healthy environment.

Figure 10: Final destination of disposed waste in Lebanon



Source: MoE, 2018.

In Akkar, the Union of Minieh relies primarily on a treatment facility for sorting and composting (SWEEP-NET, 2014). This facility has been operational since 2016 and receives around 90 tonnes of waste per day, whereas its capacity is 100 tonnes per day. Sorting activities occur manually after waste is transferred to the facility not at source level. After treatment, recyclables can be sold while the rest used to be disposed of in Adweh dumpsite, which is currently not operational (MoE and UNDP, 2017). Adweh was an unregulated large dumpsite at an estimated volume of 255 372 m³ (MoE and UNDP, 2017). Not only did Adweh receive waste from the North and the rejects from Minieh's sorting facility, it used to take on waste from municipalities outside of the Caza, which contributed to a lot of tension between municipalities (MoE and UNDP, 2017). Moreover, medical waste from the three major hospitals of the Union was disposed by a local non-governmental organization (NGO), in a separate manner, to Adwen landfill. In 2019, the dumpsite was shut down and was substituted with a new proposed sanitary landfill, which is still pending approval and it is causing major public outrage. Without an alternative, the result would be a larger number of open landfills scattered throughout the region, making any land reform plans a technical and financial issue (OMSAR, 2018). The Union of Al-Qaytaa, on the other hand, directly disposes waste in Srar landfill, which can absorb around daily 300 tonnes of waste. Finally, in the municipality of Mhamara, MSW is collected through pick-ups or compactor and then transported to Srar Landfill. A sorting facility project was started in the area, although, it has been suspended.

In conclusion, the MSW-induced problems are stemming from the following major factors:

- Rapid population growth that exceeds the capacities of the current public services;
- Institutional gaps that leads to unequal access to MSW-related services;
- Deteriorated infrastructure of facilities that does not allow the proper disposal of MSW; and
- Lacking awareness of communities that results in environmental degradation.

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Assessing water resources vulnerability to solid waste

Growing need for irrigation water

Agriculture is considered to be one of the main mainstays in Akkar. Agriculture and fishery absorb around 29.6 percent of active population in the region (Mouchref, 2008). The sector also has long depended on Syrian workers in various forms of agricultural activities, and more than 20 percent of Syrian refugee families rely on employment in the agricultural sector (IRC *et al.*, 2013). Thus, agriculture as a sector is a source of income to some of the most vulnerable community. However, agriculture faces multiple challenges including climatic changes, water availability and downward market trends. The country's cereal production meets only 20 percent of domestic demand, thus making the country import-dependent. The profitability of agriculture is severely constrained by the high input costs, as most of the agricultural inputs, including seeds, fertilizers, plant protection materials are imported (FAO, 2020). The currency floating poses further risks, as the rapidly devaluating exchange rate has caused trade disruptions. The field risks together with market risks require productivity increase to enable farmers to cope with mounting uncertainties. It can be readily accepted that improving access to reliable irrigation services is a cornerstone to stabilize and increase yields.

Figure 11: Greenhouses in Akkar region, 2020

Akkar and the North of Lebanon have a total cultivated area of 26 percent with the majority of holdings having an average area size of less than 1 ha (FAO and MoA, 2010). The main crops grown in Akkar are cereals, vegetables (mainly potatoes, green beans, tomato and eggplants), citrus, pome fruits (mainly apples) and stone fruits (FAO and MoA, 2010). In parallel, the sources of water used for irrigation purposes are both surface and groundwater. Out of the total irrigated area in the Caza of Akkar, 54 percent is mainly originating from rivers and springs, while 41.5 percent is from wells (FAO and MoA, 2010). Around 850 ha out of 1 500 ha are currently used for agricultural purposes in Akkar command area, thus making up 58 percent of the total area size. Considering an average irrigation value of 4 500 m^3 per ha, the theoretical annual crop water requirement of the area is around 3.7 million m^3. Current trends show the increasing dominancy of greenhouses driven by farmers' efforts as an adaptation strategy to challenges related to water and the shrinking land availability. However, poor water management still significantly hampers the farmers' ability to establish well-organized greenhouse production. Beside the water quality issue, greenhouse production is further restricted by unreliable flowrates, low flexibility, and lack of flow control.

Though water resources from rivers and springs can be considered abundant, access to these resources is hindered due to the outdated or absent networks responsible for its delivery. As a result, rather than being used, water from rivers and springs ends-up being wasted in the sea. To compensate the loss, farmers are increasingly relying on groundwater to irrigate their lands. A large number of these wells are illegal in nature and cannot be properly monitored, thus putting groundwater resources at risk of depletion. Whether sources originate from rivers or wells, more than 70 percent of the total agricultural area is irrigated using surface irrigation techniques, which are considered less efficient compared to drip and sprinkler irrigation (FAO and MoA, 2010). Though available, water resources are not efficiently used in the Caza because of the lack of proper infrastructure and absence of proper management knowledge or guidance, with negative consequences on agricultural yields and quality. Amplifying the situation further is the projected change in climatic patterns. According to Lebanon's Second National Communication to the United Nation Framework Convention on Climate Change, temperatures are expected to increase by 1 percent while precipitation is expected to decrease by 10-20 percent by 2040 (UNFCCC, 2011). With every 1 percent increase in temperature, the total volume of water resources is expected to reduce by 6-8 percent contributing to water shortages and drier weather (MoE *et al.*, 2011). The projection assumes sharp increase in agricultural water demand. Hence, a mixture of excessive use, pollution and climatic change can be detrimental to the available resources and ultimately to the agricultural sector. In order to sustain agricultural production and farming livelihoods, effective measures should be introduced to preserve water resources both in terms of quantity and quality.

Irrigation network as alleged actor of spreading waste

The growing agricultural water demand is compounded by the urban water use. Irrigation infrastructure interconnected with sewage and storm-water infrastructure proves to be hazardous to the environment, agriculture, and human health. To make matters worse, irrigation canals running through urbanized areas are commonly used as means for MSW disposal. Consequently, waste is delivered through the adjacent irrigation network. Due to the smaller dimensions of lower level canals, the largest share of the waste volume remains in Akkar main canal, thus being carried towards the Mediterranean Sea. Smaller size waste can intrude into the secondary and tertiary canals and end up in the agricultural fields.

Figure 12: Solid waste reaching the fields through irrigation canals, 2019

In order to protect both water and land resources, gradual intervention should be planned, starting from the main reaches of irrigation system to lower level networks. However, such intervention must avoid the disruption of irrigation and allow for further system development to improve conveyance efficiency increase.

Impact of solid waste and sediment load on water resources

In 2014, alone population pressure has contributed to a 15 percent increase in MSW, 14 percent in wastewater and 12 percent in water demand (GoL and UN, 2019). According to Jaffar (2019), at the watershed level, watersheds in Lebanon show a crisis-induced increase in water stress of 2–10 percent. The vulnerability assessment can be approached from two perspectives: water availability and water quality. Water availability refers to the actual capacity of the system to deliver the required water amount; while water quality is defined as set of physical, chemical and biological parameters that support safe water use for both beneficial and non-beneficial purposes.

Impact of solid waste on water availability

MSW has direct impact on the system capacity, as accumulated MSW blocks the canals, gated offtakes and outlets. The current engineering design does not include any equipment to intentionally trap and/ remove MSW. The main canal has narrow sections, where parts of the MSW volume is retained. The water distribution into irrigation zones is equally impacted by the MSW as gated offtakes are often blocked and damaged.

Figure 13: MSW course in Akkar main irrigation canal, 2019

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However, larger flows can easily flush the accumulated MSW to downstream stretches and finally to the sea. However, this way of sea pollution is not an isolated incident. It has been estimated that around 80 percent of marine litter comes from river inflows (Jambeck *et al*., 2015). Consequently, it can be assumed that at this rate and in the absence of any mitigation strategies, waste will continuously be dispersed contaminating much larger areas (MoE *et al*., 2014). As their surface area is enlarged, oceans and marine life are to be considered at high risk level.

The issue of unregulated groundwater use is, here, reiterated in order to discuss the indirect impact of MSW on water availability. The impacts on surface water are no more significant than those on groundwater sources that are also at risk of diminishing as water abstraction trends increase. Due to the lack alternative water resources, poor management of surface water hit by MSW crisis and the absence of proper monitoring, people often bypass the procedure of well permit application and dig-up illegal wells which might not be environmentally acceptable (Farajalla *et al*., 2015). Hence, the current number of wells spread out in Akkar can be considered contributing to the decrease in water levels and the increase of sea water intrusion risk. In addition, farmers in Akkar are known for their extensive use of pesticides and fertilizers that infiltrates into groundwater and ultimately contaminates it. In addition, fertilizer bags and pesticide containers are often seen floating on the surfaces of irrigation canals.

Impact of sediment deposit on water availability

In addition to the MSW crisis, canal capacity is further decreased by the significant sediment deposit in the bottoms. Seasonal averaging is difficult as no meaningful measurement has been conducted on sediment transport in the irrigation system. However, it can be assumed that the main source of sediment is the dam, collecting water from El-Bared River and multiple springs. In order to increase the canal capacity, sediment concentration entering the canal must be reduced (ODA, 1993). Based on field experiences, general estimation shows that 1 m long trapezoidal prism with average 45 cm sediment depth, 150 cm bottom width and 250 cm top width, retains 0.9 m^3 sediment. Along the 14 km main canal, the total volume would reach 9 900 m^3 sediment. The dynamic building-up of sediment bed decreases the capacity, causes backwater effect, while large part is flushed away to the sea. Without effective filtering and sediment extraction, MSW is also stuck in the mud, thus further increasing the trash volume.

Box 1: Sediment transport in Akkar main canal

Up to date, no regular and consistent sediment removal was carried out in the canal. The accumulated sediment taking around 40 – 50 percent of the canal dimension does not enable proper measurement of sediment transport and deposit rate. Therefore, theoretical calculation is established on estimated values of sediment transport in Akkar main canal. In case of missing values, standard values or estimation replace the actual ones. Based on Engelund-Hansen equation, the bedload volume is calculated as the following (Engelund-Hansen, 1967):

$$S_s = y_s / y_w$$

$$\theta = DS_0 / \left[(S_s - 1)d_{50}\right]$$

$$f = (2gS_0D)/V^2$$

$$q_s = 0.1\left(\frac{1}{f}\right)\theta^{\frac{5}{2}}y_s[S_s - 1)gd_{50}^3]^{1/2}$$

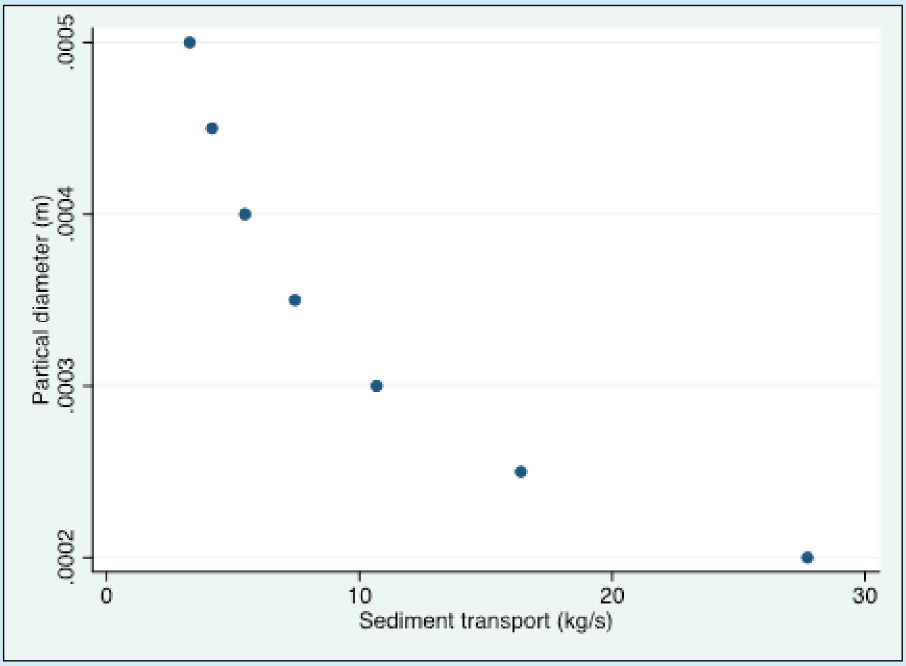
$$Q_s = Bq_s$$

Where, S_0 is the bottom slope, D is the hydraulic depth, V is the mean velocity, B is the canal width, d_{50} is the average particle fall diameter, S_s is the specific gravity, q_s is the total sediment volume and Q_s is the sediment weight in unit meter of the canal width.

The calculation is applied to the upstream stretch of Akkar main canal, directly at the dam. The lined subsection is of rectangular shape with flat slope. Based on the canal dimensions of 0.87 m average flow depth and 1.6 m canal width, the area of subsection is 1.392 m^2. The average velocity measured by surface structure image velocimetry method is 1.8 m/s in the subsection. As actual measurement of sediment density is not available, theoretical value of 2 600 kg/m^3 is applied. Average bed roughness of 0.0007 ks is derived from standard value for concrete canals. Also, actual sediment mean diameter is replaced with estimated values ranging from 0.0002 – 0.0005 m.

The theoretical volume of total bedload sediment weight varies from 3.29 to 27.7 kg/s.

Figure 14: Relationship of sediment size diameter and sand transport in Akkar main canal



By increased fallen particle diameter, the transport of bedload sediment significantly decreases, thus ending up in permanent accumulation in the canal bed. The deposited sediment reduces the canal conveyance capacity and requires regular removal. Sediment extracting equipment is required upstream to retain the larger size particles, thus decreasing allowing better sediment transport in the irrigation canal. Sufficient capacity of the sediment extracting equipment can be, however, defined only based on trend analysis. Since the canal has been deteriorated due to the lack of maintenance work, the first step of proper equipment sizing is the clean-up of sediment deposit accumulated throughout the years.

Figure 15: Sediment removal from canal bottom in Akkar, 2020

The first campaign of canal cleaning was carried out in July 2020. Based on expert observations, the canal capacity improved by 50 percent after the maintenance work, including cleaning of vegetation, removal of MSW and sediment remediation from canal banks and bottoms. However, occasional cleaning is not sufficient to maintain improved conditions. Further engineering solutions are required to ensure regular clean-up of MSW and sedimentation. Twofold intervention, whereas trash-and-remove mechanism is coupled with sediment extraction, will be introduced within the context of this report as remedial measure to achieve long-standing solution.

Impact of solid waste and sediment load on water quality

Soaring trend of improper MSW disposal has deleterious impact likewise on water quality. In fact, water quality is the proxy of any susceptible mechanism before effects become visible. An FAO-developed water quality monitoring system has established a protocol for regular data acquisition and analysis. The quality system consists of multiple monitoring sites in Akkar part covering the course of the main canal. The following parameters are defined to assess irrigation water quality:

- Bacterial Count: Total Coliform, Fecal Coliform, E-coli
- Turbidity
- Electrical Conductivity (EC)

- pH
- Soluble cations: Na, K, Ca, Mg
- Soluble anions: HCO_3, Cl, NO_3, SO_4
- Heavy metals: Pb, Fe, Zn, Cu, Mn, Ni

The physical and chemical analysis registered slightly fluctuating values of measured parameters, but the values are within the acceptable threshold over the main canal. The turbidity results show strong correlation with external factors such as industrial works that temporary increased the values. However, turbidity values also can be considered acceptable in general. Regarding the salinity values, the monitoring results consistently re-approved that surface water has good to excellent quality for irrigation. Therefore, reliable irrigation service is highly important to assist in shifting farmers' preferences from groundwater to surface water use.

Sediment transport has multiple and distinct effects on water quality. On one hand, it absorbs certain level of pollutions thus improving water quality. On the other hand, sediment load carries and spreads pollutants such as pesticides, fertilizer residues, organic compounds and other hazardous pollutants that adversely affects the water quality. Before-, post-analyses are required in order to determine the role of current sediment levels in the irrigation network.

Figure 16: Canal cleaning campaign in Akkar, 2020

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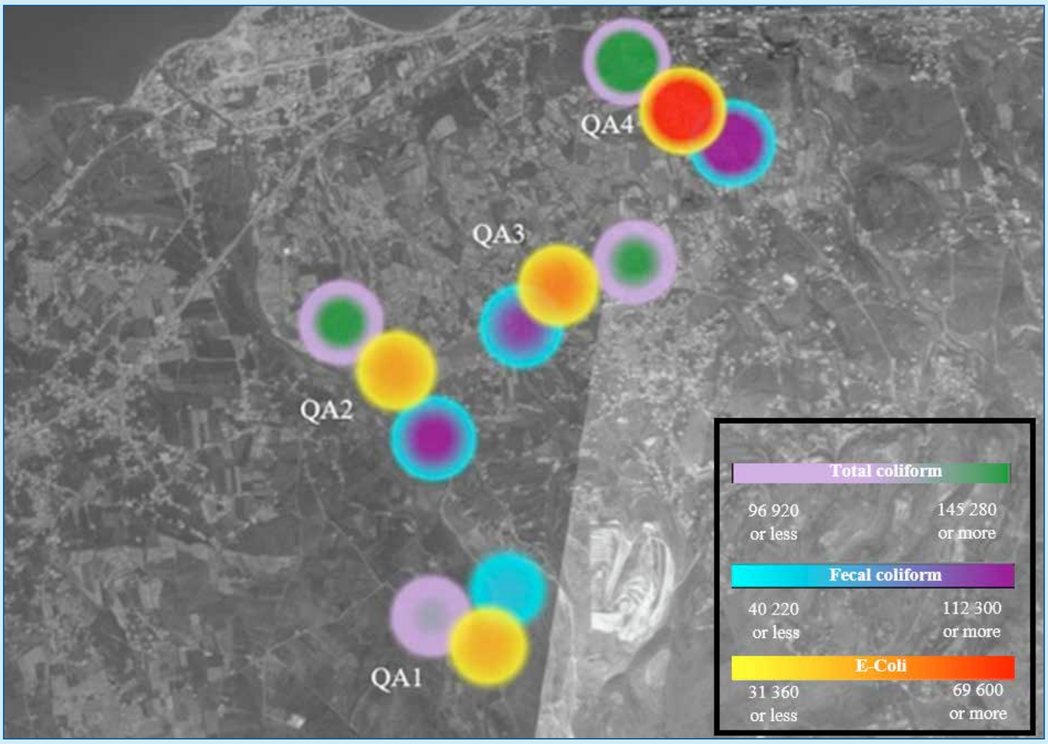
Box 2: Biological analysis - Alerting side story

The results of the biological analysis are discussed to shape further actions built on the MSW and sediment management. The proximity of urban areas entails another source of heavy contamination. In lack of solid urban planning processes, the surrounding houses are directly connected to the irrigation canals, and many of the plumbing systems discharge sewage into the canals. Consequently, as final receiver, the sea collects more than 60 percent of the total sewage load of Lebanon from at least 53 sewage outfalls (MoE *et al.*, 2011), and most of the MSW and pollutants transported along the rivers and artificial waterways. Biological analysis, applying measurements of total coliform, fecal coliform and E-coli resulted in utterly critical impacts of this common phenomenon. Corresponding to the population density around Akkar main canal, the bacterial count, already high at the head works, is enormously growing. The heat map of bacteria trend displays the count values along the main canal.

Figure 17: Bacteria trend in Akkar main canal produced by the authors, 10.09.2020)



Such level of contamination has eventually multiple impacts on health and environment. Although the bacterial contamination is attributed to sewage disposal, actions cannot be taken until the overall condition of the irrigation network is recovered. Build on it, successive measures can be introduced to mitigate the impacts and eliminate pollution sources.

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Engineering solutions to protect water resources

There are ample numbers of available engineering solutions to manage MSW and sediment. Despite of the marvellous technology advances, adoption is often slow due to the possible deployment limits though. The concept of "no-one-size-fits-all" is neither new nor philosophical in the context of engineering solutions. Compiling a comprehensive set of engineering solution was done systematically reviewing existing technologies. Beyond the literature review of MSW and sediment management in irrigation systems, the search involves the available sources demonstrating the implementation of the technologies. However, the compiled toolbox of engineering solutions is not merely a repository of readily available technologies. It proposes re-engineering process to align the technologies to local context.

Efficient technology uptake must consider several limiting factors related to scalability, functionality, economies of scale, social acceptance, and degree of usefulness. For example, overly complex systems can put unnecessary burden on users and operators, while too simple structures might narrow the scope of functionality. However, trialability of large-size and fixed equipment is often troublesome since they are less flexible to any modification. Although some of the relevant technologies are scale-neutral, most of the trash removal equipment falls under the aforementioned category and requires significant resource mobilization. Consequently, they require rigorous assessment prior to implementation. In order to identify the most fitting technology, a multi-criteria analysis (MCA) method was developed to prioritize technologies in the context of Akkar irrigation scheme. It is worth mentioning that the current analysis is conducted in well-defined frames: what works in the targeted area, might not work in other area. The current approach does not aim to establish universally acceptable priority order of available technologies, but rather presents stepwise logics for contextualized decision-making.

A twofold intervention assessment

A twofold intervention was set focusing mainly on techniques that minimize MSW and sediment deposit, and a number of engineering solutions are selected to intercept and remove MSW in irrigation canals and control sediment. To support the selection of adequate technologies, procedure of rapid site identification was, first, presented. A synthesis of an extensive literature review was, subsequently, provided to introduce existing waste and sediment removal technologies. The applied MCA to evaluate the suitability of technologies involved four selection criteria: engineering design, operation and maintenance (O&M), investment, and socio-economic impacts.

1. **The engineering dimension** focuses on analysing the default engineering design, its suitability and the flexibility of construction. Regarding the engineering design, assessing the potential impacts of the proposed structure is inevitable since the deployment of new constructions can significantly modify the hydraulic performance of the system. For example, the suggested design might affect the speed and the flow of water in the irrigation canals which might, in turn, change the required water delivery to farmlands. In other cases, the implementation of a new technological design might require structural modifications of the irrigation canals (e.g. foundation, mounting structure etc.), imposing an additional level of examination to its feasibility on-ground.
2. **In O&M dimension**, multiple factors have to be taken into account to ensure the smooth operation and ease of maintenance of systems in place. According to the Reference Guide for Asset Management Tools (EPA, 2020), O&M should equally take into account rudimentary operational activities and upkeep drills to ensure that assets are in viable conditions. O&M factors that are looked at include the system's susceptibility to erosion, impacts of debris on engineering solutions, necessity and frequency of cleaning, and degree of required maintenance.
3. **Investment dimension** considers both the capital and operating expenses of the technology, upon which decision-makers should be alerted before implementation. Accordingly, when conducting the analysis, factors such as cost of construction, cost of O&M, and system lifespan are deeply evaluated.
4. **Regarding socio-economic dimension**, the potential effect and consequence of technology deployment on the community is at focus. Experiences show that induced flooding is common phenomenon while installing equipment in the canals. In the case of Akkar, specifically, the primary consequences of flooding risks can lead to yield loss, damage in public places, deterioration of irrigation infrastructure, and soil erosion.

Strengths and limitations were defined to understand the potential challenges that could be encountered during implementation, and a qualitative assessment was followed by scoring in 5-point Likert scale, whereas aggregated score is assigned to each selection criterion. The scoring is based on an all-encompassing discussion of an expert pool that took into account the context of the command area and the community's response to such interventions. It is worth mentioning that technologies with relatively simple design were not scored per dimension due to their limited assessment perspective. Finally, the findings were summarized, and the techniques were ranked accordingly.

Rapid identification of implementation sites

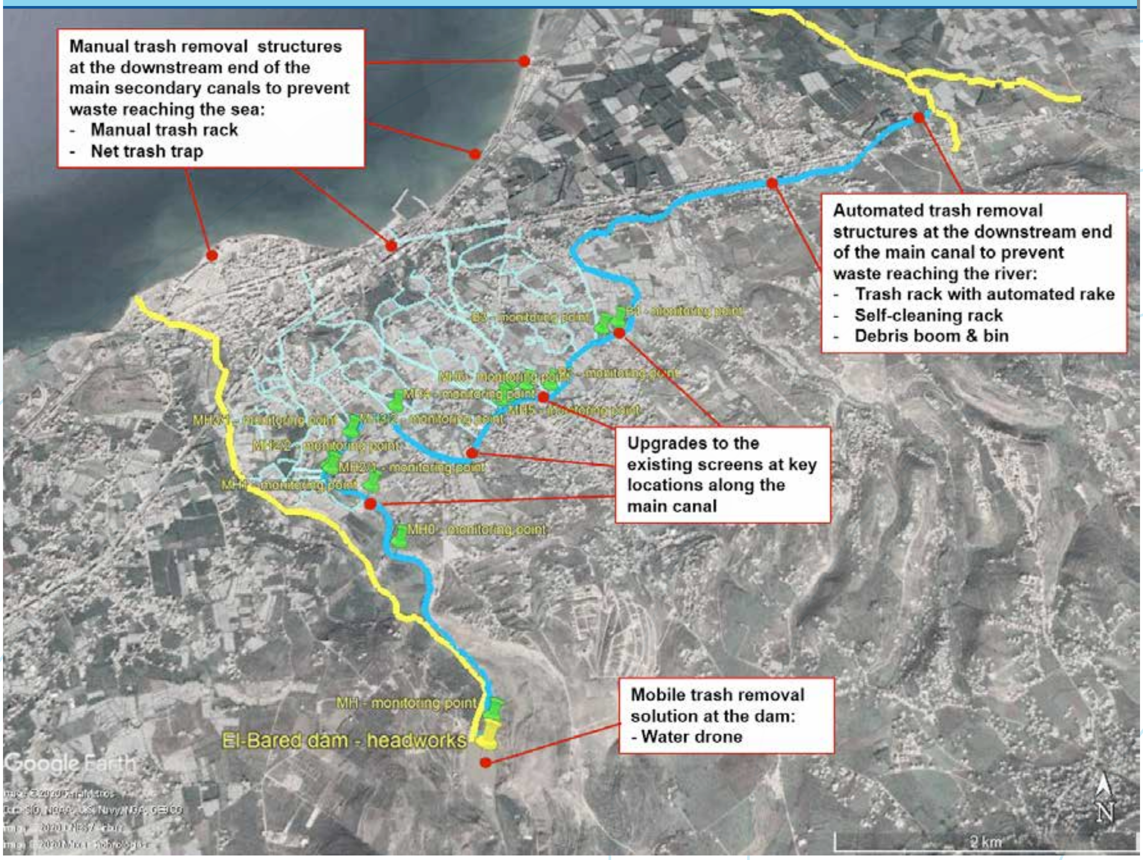
The irrigation system in Akkar is currently accumulating large amounts of debris, organic waste, plastics and sediments. The site identification considered a set of criteria based on prevailing conditions:

1. Accumulation dynamics observed in field visits were imbalanced between upstream and downstream reaches. As the upstream parts are out of urbanized areas, MSW disposal in the canal is negligible. Reaching the first village and beyond, the MSW volume greatly increases. Therefore, the first criterion of site selection was the degree of urbanization in the surrounding environment.
2. Depending on the type of MSW, whether it is floating or submerged, the site selection must consider the trapping mechanism. Based on trapping mechanism, the second criterion was the suitability of canal section to be equipped by full-dimension or fractional trash traps.
3. The applicability of technology largely depends on the MSW load. While small volume can be manually removed within defined frequency, large MSW volume requires automated system. Accordingly, the third criterion built on the site suitability to construct large structure.
4. Surface area size is severely constraining factor of technology selection. For example, extended water surface such as El-Bared dam requires scale-neutral trash removal techniques that are flexible and mobile enough to cover the area. The fourth criterion of site selection was, therefore, the size of water surface.
5. Finally, the fifth criterion was based on the existing facilities in Akkar command area. Some canal sections are already equipped with bar screens acting as trash trap, thus upgrading might provide inexpensive solution to maximize their impact.

Based on the defined set of criteria, rapid identification of implementation sites was carried out. The map in Figure 15 depicts suggested sediment and waste control solutions along with their adequate intervention sites. It provides an overview of the identified MSW removal solutions and illustrates their role as an integrated MSW control system within Akkar command area. These solutions are grouped in four categories:

1. Automated solid waste removal structures;
2. Manual solid waste removal structures;
3. Upgrades to the existing bar screens; and
4. Other solid waste control solutions.

Figure 18. Overview of solid waste control solutions within Akkar command area



Source: Google Earth, 2020, elaborated by the authors.

These solutions are not limited to the main and secondary canals; they also include adequate interventions for El-Bared dam. In order to ensure the minimum discharge of MSW into the sea, the outlets of the main and lower level canals were identified as final safeguards of preventing sea pollution.

Sediment build-ups have multiple direct and indirect impacts on the water network, drastically reducing the conveyance capacity of the irrigation scheme, and ultimately affecting water delivery and availability at the level of end-users. Thus, removing the sediments already contained in Akkar main canal and preventing the future formation of large sediment deposits are crucial measures to enhance the performance of the irrigation scheme and to improve its sustainability. El-Bared River conveys debris and sediments from the upstream watershed to the dam, where sediments settle in the bottom of the reservoir. From there, the finest sediments (fine sand and silt) enter the head reach of the main canal through the water intake. Removal of sediments from the dam is currently undertaken by the North Lebanon Water Establishment (NLWE) at a frequency that is lower than needed. Hence, sedimentation upkeep is generally unaccounted-for. Sediment management for dams and irrigation schemes comprises a wide range of strategies that can be broadly grouped in five categories:

1. Methods to reduce sediment inflow from the upstream catchment;
2. Methods to trap sediments upstream of the dam;
3. Methods to pass sediment through the dam;

4. Methods to remove sediment deposits from the dam and water intakes; and
5. Methods to remove sediments from the irrigation canals.

Assessment of engineering solutions for solid waste removal

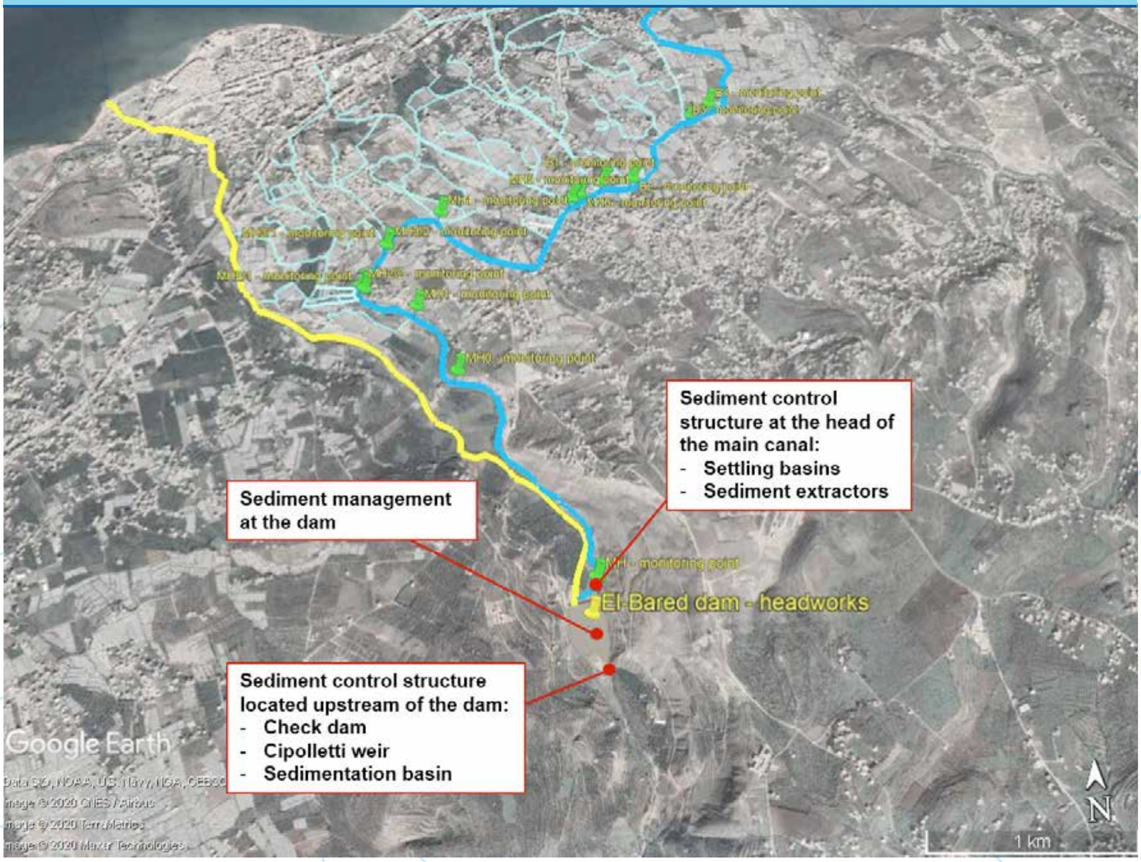
The engineering solutions toolbox corresponds to the four categorized groups discussed earlier. Each solution is illustrated with a brief description of its main objectives, design, and function. Furthermore, the location of the technology deployment is proposed in order to assign it to the most fitting site. Arbitrary evaluation of technology efficiency is presented with respect to the proposed site condition. Finally, a technical sheet of the MCA is enclosed to present main strengths and limitations of the proposed solution.

Automated solid waste removal structures

Option 1. Fixed trash rack with automated rake

The trash rack is a fixed steel structure used to trap debris and prevent its migration further downstream. The trash rack can be cleaned manually, or it can be equipped with an automated mechanical/hydraulic rake. The automated rake scrapes the rack and conveys the collected debris into the disposal unit.

Figure 19. Overview of sediment control solutions within Akkar command area



Source: Google Earth, 2020, elaborated by the authors.

Design and Function

Typical trash rack design consists of rows of parallel rectangular steel bars with a clear spacing between the bars varying in the range of 5-30 cm, depending on the size of the debris present on site. The steel bars are welded on a steel frame, which is bolted into the concrete banks and bed of the canal. The trash rack is usually placed in the canal at a 45°-60° angle to the flow to reduce the head loss through the structure. Automated systems can be powered with renewable energy and conveyor belts that transport collected trash directly into trash bin. This advanced technology helps retaining the collected trash and easing the trash collection by public service.

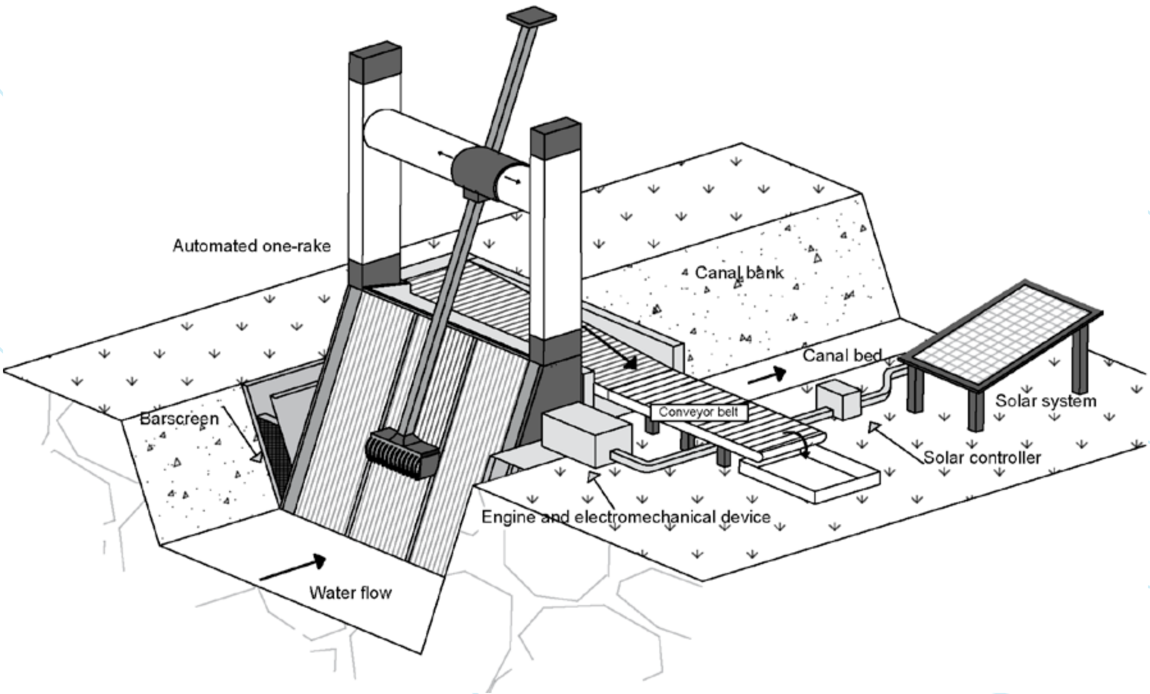
Proposed application

This solution is recommended to be installed at the downstream end of Akkar main canal to intercept and remove large and continuous debris load before the discharge into the river. As downstream parts are the hotspots of waste accumulation, collecting the waste from four upstream villages, the automated systems are required to provide sufficient capacity and frequency of waste removal.

Efficiency

Very High - this solution is effective for both floating and submerged debris and it is flexible to a wide range of debris size.

Figure 20: Grab rake on high-mounted rails, 2020



Source: Reproduced from ENERQUIP, 2020.

Advantages and disadvantages

Table 3: Advantages and disadvantages of fixed trash rack with automated rake

Strengths	Limitations
Engineering	
Large removal capacity, in terms of both debris load and size Design is moderately flexible to different canal shapes and dimensions Robust solution Allows maximum flow to avoid flooding Stand-alone solution for waste removal (interception, collection and disposal)	Fixed structure, cannot be easily replaced or removed Complex design May require private-public land acquisition Require source of electricity
1. Operation and Maintenance	
Fully automated operation (little human labour force required) The rack can be still cleaned manually, in case of automation's failure	Mechanical and electrical components – Specialized maintenance is required (know-how of the system is essential) Larger repair works are expected compared to less automated systems Vulnerable to vandalism
2. Investment	
Low operation costs Co-benefiting sectors	Large investment need (design, fabrication and installation) High maintenance costs Short lifespan
3. Socio-economic	
Minimum health and safety risks during operation and maintenance	

Option 2. Self-cleaning trash rack

The self-cleaning trash rack consists of a fixed steel, concrete frame and a travelling steel component that collects the debris and discharge it at the top of the structure. A conveyor belt then conveys the debris to the disposal unit.

Design and Function

Two main design solutions are available for the travelling component of the structure:

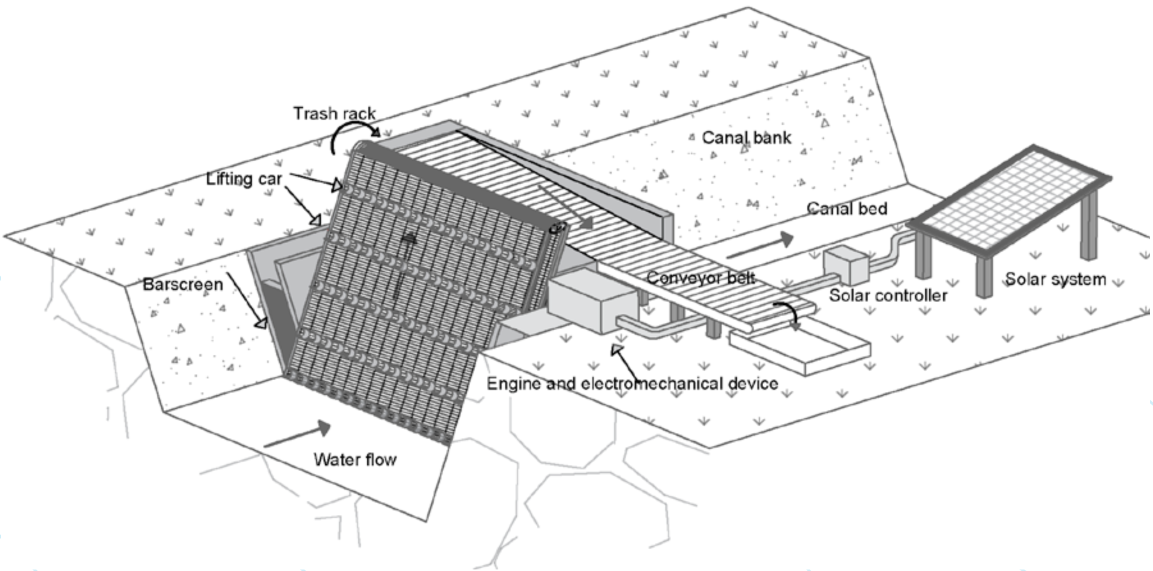
- Automated and continuous chain of raking beams that travel up the rack face and return along a guided path at the back of the rack. The raking beams contain a plate with teeth cut to match the trash rack bars. When raking, the teeth are perpendicular to the trash rack. At the top of the rake travel, debris is dropped into a conveyor belt.

- Automated and continuous travelling screen. The screen is usually placed in the canal at an angle lower than 45° to the flow to reduce the water head loss through the structure and to allow effective collection of debris. The screen elevates the debris from the water and drops it into a conveyor belt

Proposed application

This solution is recommended to be installed at the downstream end of Akkar main canal to intercept and remove large and continuous debris load before the discharge into the river. Similar to the trash rack, the high capacity and frequency cleaning can be guaranteed by self-cleaning racks to eliminate accumulation hotspots.

Figure 21: Schematic design of an automated trash rack structure with continuous travelling screen, 2020



Source: Reproduced from Duperon Corporation, 2020; ENERQUIP, 2020.

Figure 22: Front view of automated trash rack structure with continuous travelling screen, 2020

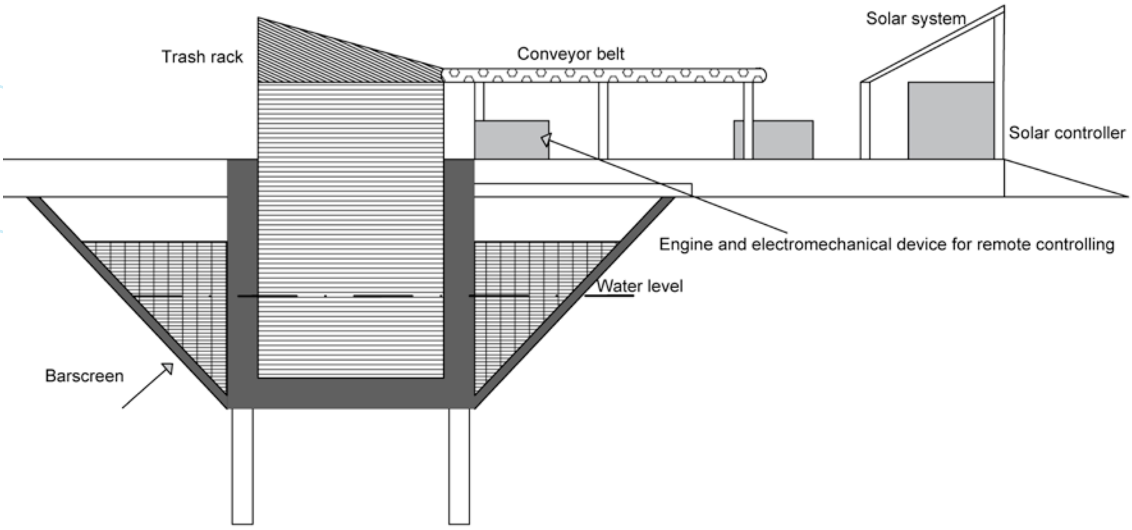
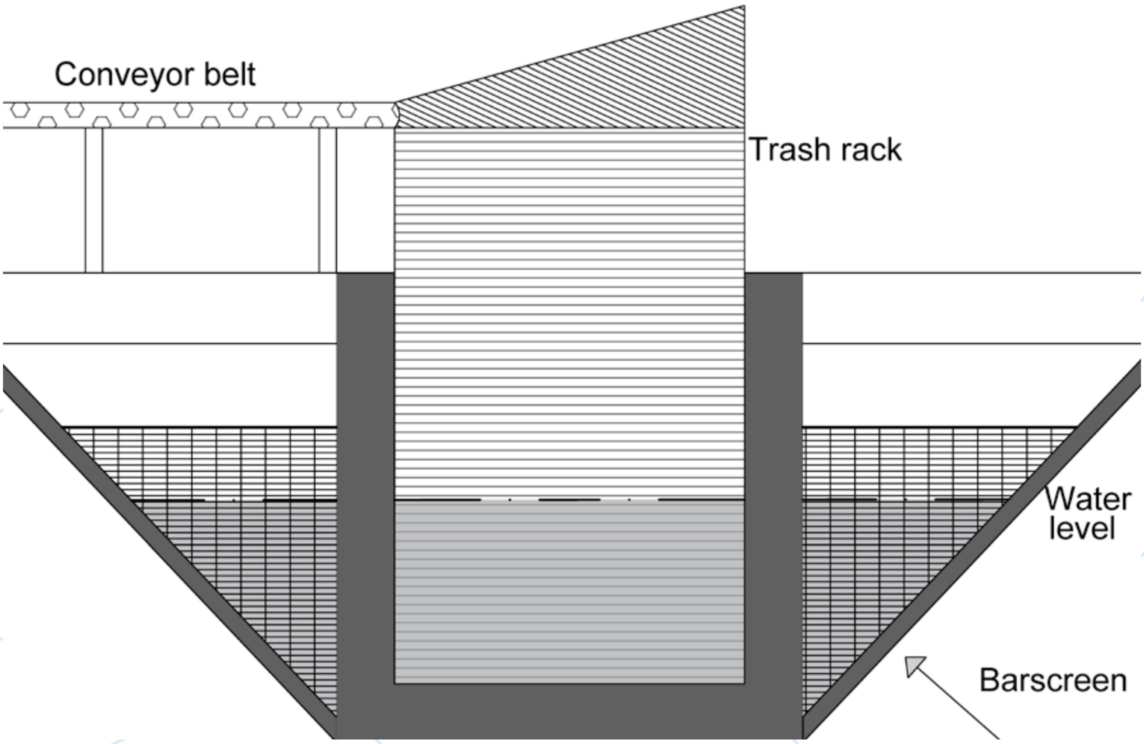


Figure 23: Back view of automated trash rack structure with continuous travelling screen, 2020



Efficiency

High - This solution is effective for both floating and submerged debris. However, it is generally recommended for small- to medium-sized debris and it is only moderately flexible to wide range of debris size.

Advantages and disadvantages

Table 4: Advantages and disadvantages of self-cleaning trash racks

Strengths	Limitations
1. Engineering	
Large removal capacity, mostly in terms of debris load	Fixed structure, cannot be easily replaced or removed
Stand-alone solution for waste removal (interception, collection and disposal)	Complex design, not flexible to different canal's shapes and dimensions
Allows maximum flow to avoid flooding	Moderate head-loss through the structure – increased water levels upstream
	May require private-public land acquisition
	Source of electricity is required
2. Operation and Maintenance	
Fully automated operation (little human labour force required)	Vulnerable to jamming
	Cannot be operated in case of automation's failure
	Mechanical and electrical components-specialised maintenance is required
	Larger repair works are expected compared to less automated systems
	Vulnerable to vandalism
3. Investment	
Low-moderate operation costs (human labour will be required occasionally)	Large investment need (design, fabrication and installation)
	High maintenance costs
	Short lifespan
3. Socio-economic	
Minimum health and safety risks during operation and maintenance	

Manual solid waste removal structures

Option 3: Debris Boom and Bin

Debris booms are floating structures used to trap debris and prevent downstream migration in rivers, waterways, canals and at sea. The boom on its own only traps and directs the debris into a collection area. A complementary technique is, therefore, required to collect the debris and convey it to the disposal unit. In addition to the "debris bin/basket", other complementary techniques include:

- Grab bucket mounted on lifting machinery per digger.
- Work boat debris boom applications at sea and in wide rivers.

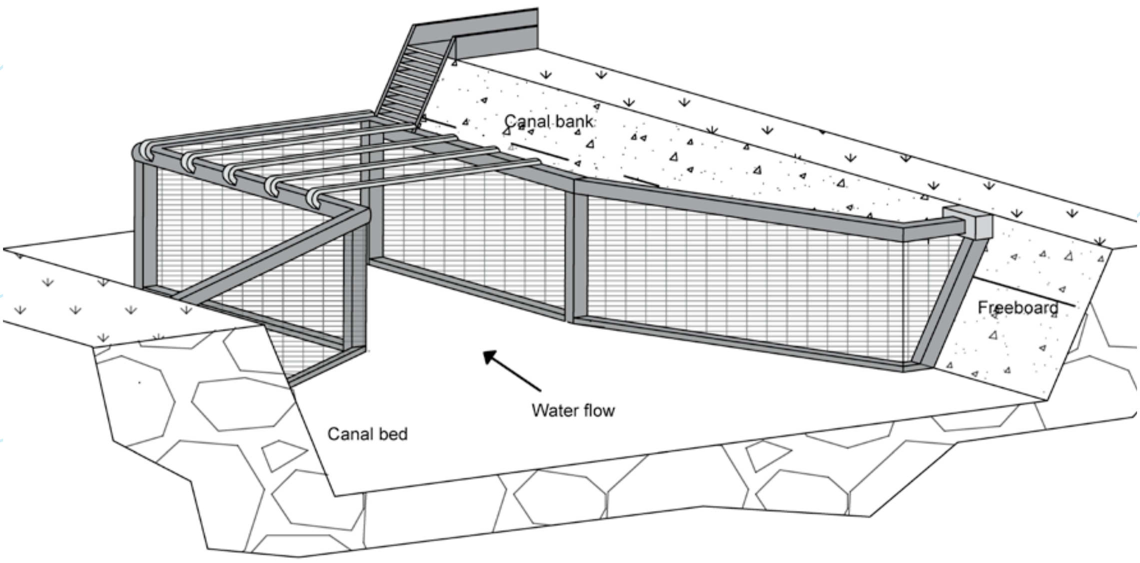
Design and Function

Heavy-duty polyethylene cylinders/pipes allow the debris boom to float on the water. The boom is installed perpendicular to the flow and it is anchored to the banks of the canal or to steel pilings. A polyethylene curtain can also be installed beneath the waterline to prevent debris escaping under the main float. The debris boom traps the debris and directs it towards the mouth of a floating basket/bin, where debris is temporarily collected and stored. Once full, the basket is lifted out of the trap by a lifting machine and the debris is disposed. Fixed, flexible and semi-flexible debris bins slightly differ in their design. While fixed structures have rigid screen walls, the flexible and semi-flexible technologies can be moderately extended to increase their capacity. Manhole for unloading can be created in the top of the structure in order to ensure continuous flow while cleaning.

Proposed application

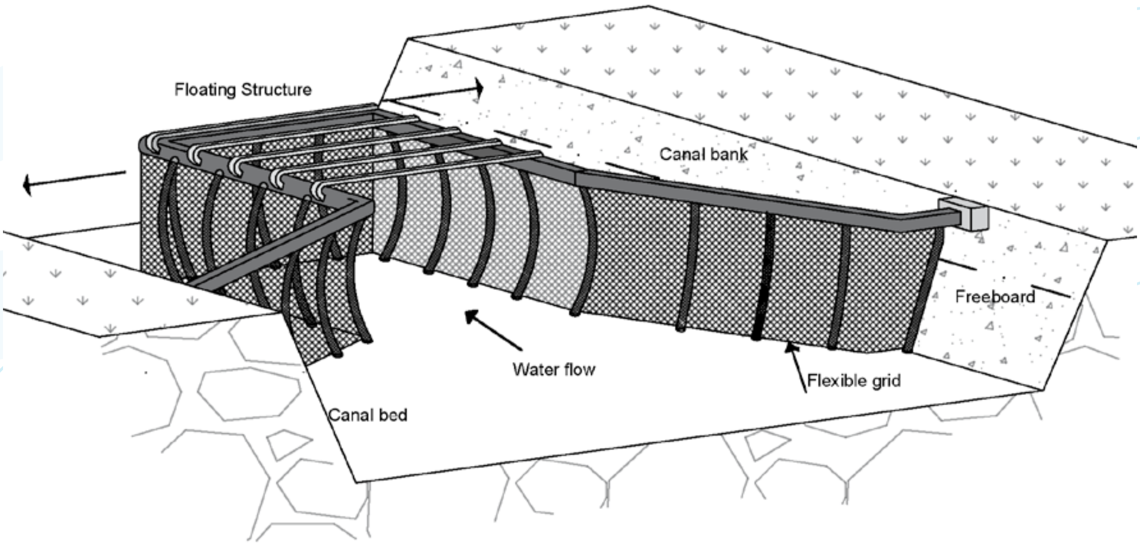
This solution is recommended to be installed at the downstream end of Akkar main canal to intercept and remove large and continuous debris load before the discharge into the river. Although the technology is not automated, the flexible design can compensate the limited capacity.

Figure 24: Debris bin - fixed structure, 2020



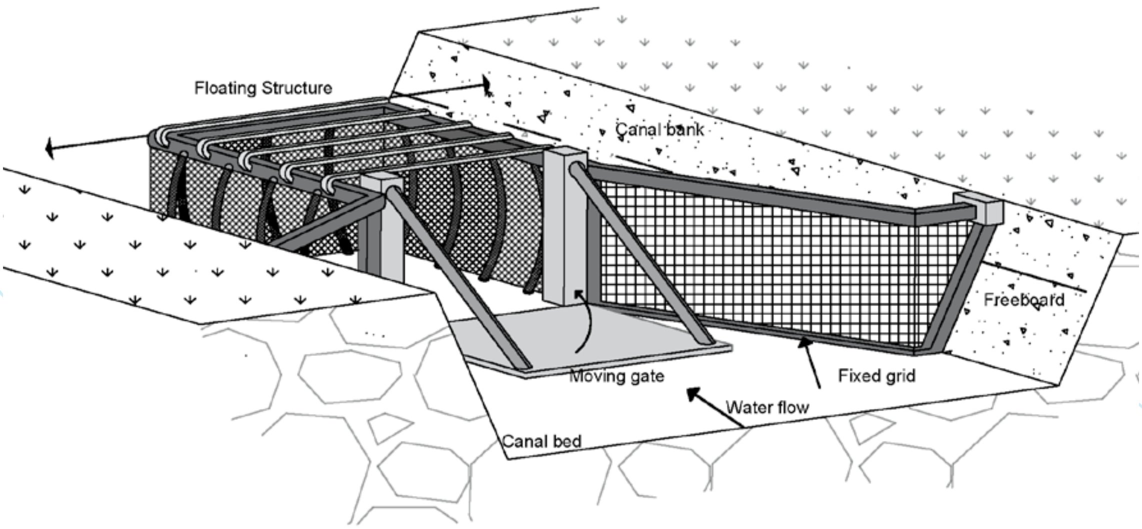
Source: Reproduced from Storm Water Systems, 2020.

Figure 25: Debris bin - flexible structure, 2020



Source: Reproduced from Storm Water Systems, 2020.

Figure 26: Debris bin – semi-flexible structure, 2020



Source: Reproduced from Storm Water Systems, 2020

Efficiency

Moderate - This solution is effective for capturing debris only, while removal requires further manual/automated work. Over spilling may occur if debris load is too large.

Advantages and disadvantages

Table 5: Advantages and disadvantages of debris bin

Strengths	Limitations
1. Engineering	
▪ Simple design and installation ▪ Can be manufactured locally ▪ Design is flexible to different canal's shapes and dimensions ▪ Does not require source of electricity	▪ Lower capacity removal ▪ Limited removal possibility of non-floating debris ▪ Vulnerable to lager debris load – system can jam and waste overspill ▪ Requires complementary technique for waste removal
2. Operation and Maintenance	
▪ Little human labour force required ▪ Lower maintenance requirements compared to more automated systems	▪ Vulnerable to jamming ▪ Requires constant monitoring of the capacity ▪ Requires lifting machine/device to remove the collected waste
3. Investment	
▪ Low investment need (design, fabrication and installation) ▪ Low maintenance costs	▪ Operation costs may be higher than more automated solutions
3. Socio-economic	
	▪ Moderate health and safety risks during operation and maintenance that can however be mitigated through the design

Option 4: Net trash trap

The net trash trap is a trash screen system used to intercept debris (vegetation, trash, etc.), and prevent migration further downstream. It is mostly used at the outlet of culverts and pipes, but it has also been installed in open channels. A complementary lifting machine is generally required to lift the net out and dispose the waste.

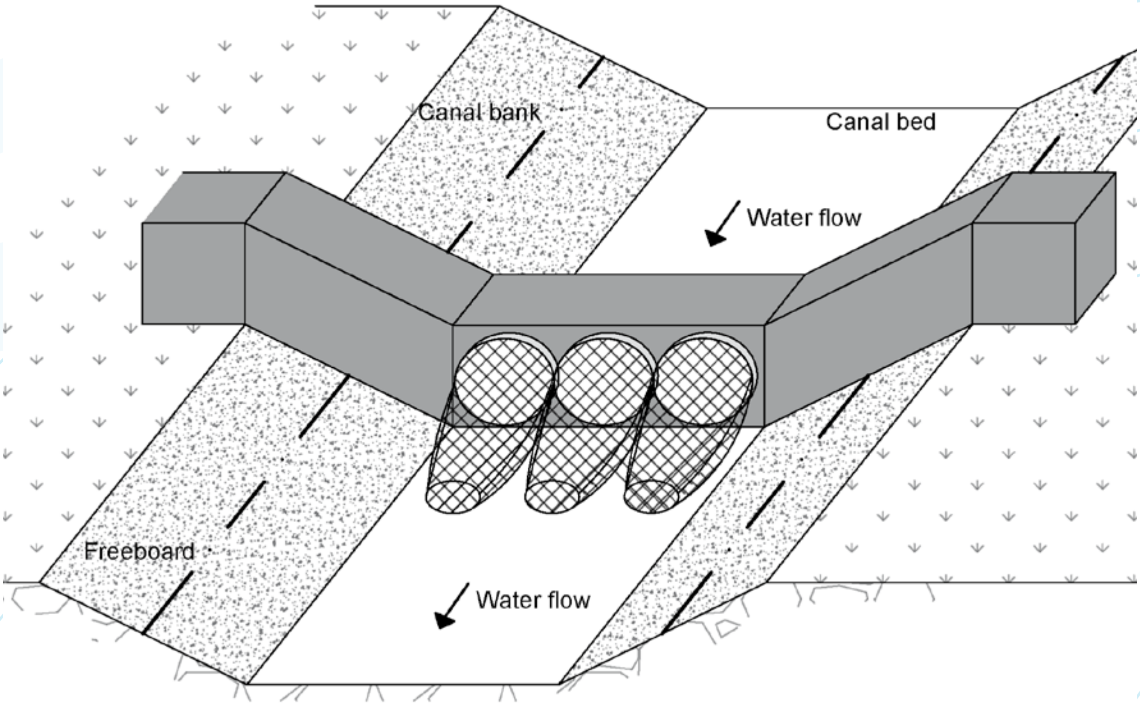
Design and Function

The net trash trap consists of a stainless-steel frame with support legs and a removable heavy-duty polyethylene filtration net that can be lifted out for cleaning and maintenance using a small crane per lifting machine.

Proposed application

This solution could be installed at the outlets from the drains, lower level network and outlet of the main canal.

Figure 27: Net trash trap, 2020



Source: Reproduced from Storm Water Systems, 2020.

Figure 28: Proposed location of net trash trap in canal outlet, 2020

Efficiency

Moderate to high – it is effective mostly for submerged debris but can be designed to eliminate floating trash if spillways are constructed. However, it is not suitable for large debris as these would easily clog the net and cause upstream flooding.

Advantages and disadvantages

Table 6: Advantages and disadvantages of net trash trap

Strengths	Limitations
Simple design and installation	Limited trapping capacity
Design is flexible to different canal's shapes and dimensions	Vulnerable to large-sized debris – the net may clog and cause upstream flooding
Low investment need	Regular monitoring/inspection is crucial to flag need for waste removal and disposal
	Regular emptying of the net is required to avoid upstream flooding
	Conditionally to the debris load, a lifting machine may be required to lift the net out and dispose the waste
	May require spillway for water to bypass the jammed net

Option 5: Fixed trash rack with manual rake

The trash rack is a fixed steel structure used to trap debris (vegetation, trash, etc.) and prevent downstream migration. In this solution, the trash rack is cleaned with a manual rake. Design features are included in the structure to facilitate the manual O&M.

Design and Function

In addition to the design features commonly used in fixed trash racks, additional design details are usually included to facilitate the manual operation and maintenance. Rack is inclined at a 45° angle to the flow and to not exceed 2 m in length. Bars have a return length at the top to facilitate scraping. Grid working platform span across the canal, and handrails to be provided at the back of the working platform.

Application

This solution could be installed:

- Along the upstream stretch of Akkar main canal in Bibnieh as a complementary technique to the automated structures, whereas hotspots of waste accumulation are not critical.

Figure 29: Bar screens functioning as manual trash rack, 2020

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- At the outlets of the main secondary canals in Akkar command area as an alternative solution to the net trash trap, if high-capacity traps are installed upstream from the outlets.

Efficiency

Moderate - This solution is effective for both floating and submerged debris. However, the removal capacity (load and size of debris) is significantly limited by the manual operation, especially if installed along the main canal in Akkar.

Advantages and disadvantages

Table 7: Advantages and disadvantages of manual trash rack

Strengths	Limitations
Simple design and installation	Removal capacity (debris load and size) is limited by the manual operation
Design is flexible to different canal's shapes and dimensions	Requires significant human labour force – high operation costs
Low to moderate investment need	Regular monitoring and operation is crucial to avoid clogging and risk of upstream flooding
Lower maintenance costs compared to more automated systems	

Option 6: Upgrades to existing bar screens

Horizontal bar screens are installed in the upstream and middle stretch of Akkar main canal to act as water flow tranquilizer. As the water flows through the screen, poor velocity profiles are broken up and a laminar flow is restored. Nevertheless, the bar screens also effectively act as trash racks since they trap floating debris and prevent downstream migration.

Field observation shows that the design of the screens could be complemented to overcome some of challenges encountered during operation and maintenance, amongst which is:

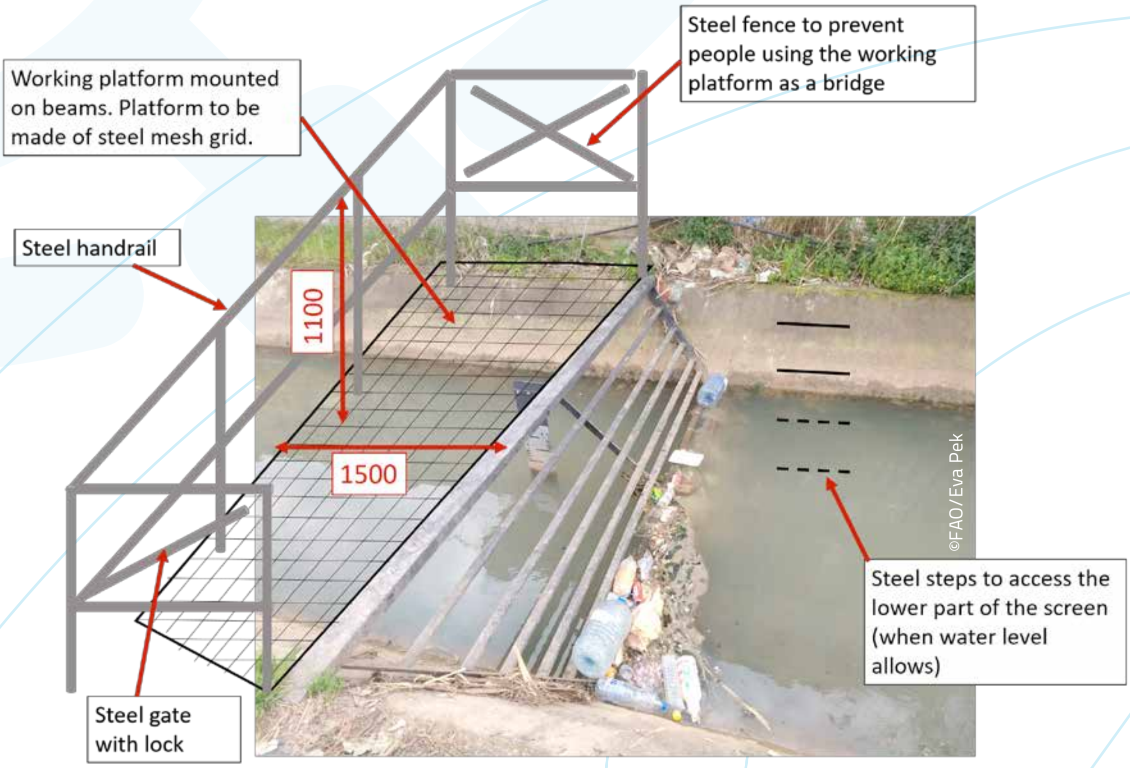
- the cleaning of the lower part of the screen is not easily achieved;
- the significant safety risks for the operators; and
- the screen's bars being damaged during the cleaning process.

Working platform and manual rake tool

As upgrade strategy, platforms at all bar screens can be installed along the main canal. The working platform spans across the canal immediately downstream of the bar screen as per the draft design shown in. The platform would facilitate cleaning of the screen by providing an easy access to both banks of the canal. The current horizontal bars can be either replaced by vertical bars or additional vertical bars can be installed at the front to facilitate the waste removal by human force.

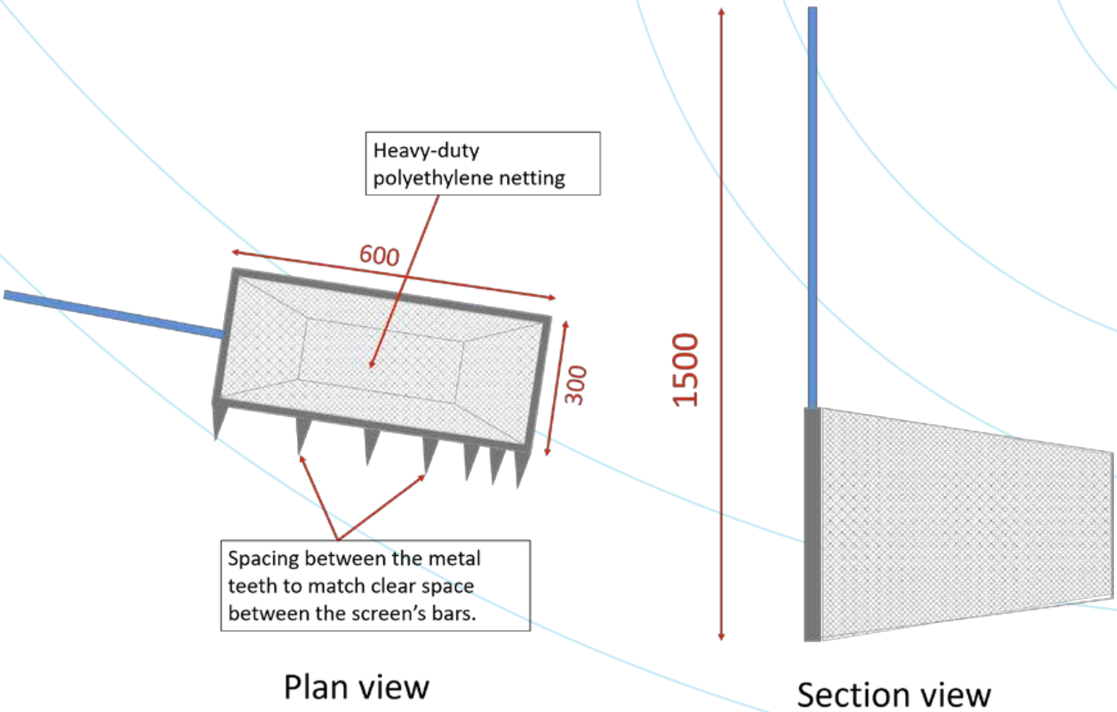
Figure 30: Proposed bar screens for manual trash rack, 2020

Figure 31: Proposed inspection space for existing bar screens, 2020



Custom-designed raking tool is proposed to scrape the horizontal bar screen and allow the operator to reach the lower part of the screen.

Figure 32: Design of the manual rake tool, 2020



When used in combination, the working platform and the manual rake help address the challenges currently experienced during the operation of the bar screen. However, a significant labour force input is still required. With the aim of providing a complementary solution that reduces human labour force input and that enables a quicker and more efficient cleaning of the bar screen, additional design features have been developed.

High-density polyethylene net

High-density polyethylene (HDPE) net can be installed on the upstream face of the existing screen, extending to the concrete channel. By working from the platform, the operator is able to pick up the corners of the net and pull it towards the road-side bank. A system of pulleys and levers included in the design facilitates the manual operation. Once emptied, the net will be put back into the canal.

Figure 33: Design of an HDPE netting system installed on the existing screen, 2020

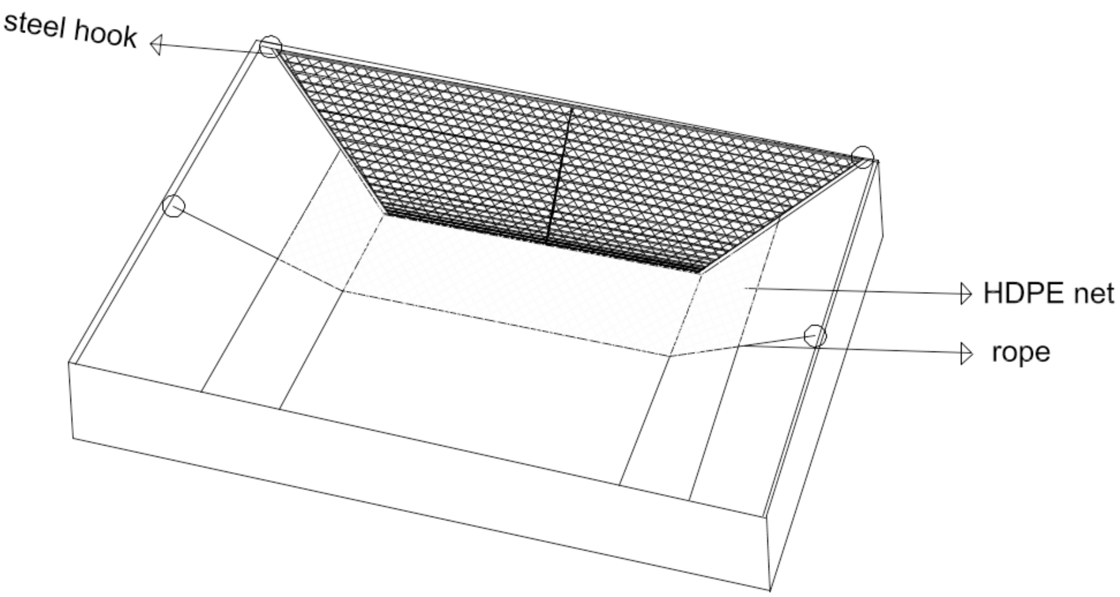


Table 8: Advantages and disadvantages of the steel basket system

Strengths	Limitations
Flexible solution that can be easily modified to fit conditions Enables quick removal of debris	Heavy-weight solution – a system of pulley and levers will be required to enable operation by a single person Increased maintenance requirements The flow tranquilising function of the original bar screen may be compromised - increased turbulence Flow's cross-sectional area is reduced - might cause excessive head loss through the structure and upstream flooding

Other solid waste control solutions

Option 7: Mobile devices

Mobile devices such as innovative aqua drones can be introduced. Drones are autonomous surface vessel used to clear floating plastics and other debris from calm water environments. It can be operated manually via an onshore operator (radio controlled) or autonomously with online control and access (Ranmarine, 2020). Likewise, mobile drones are suitable to cover large surface area such as the dam.

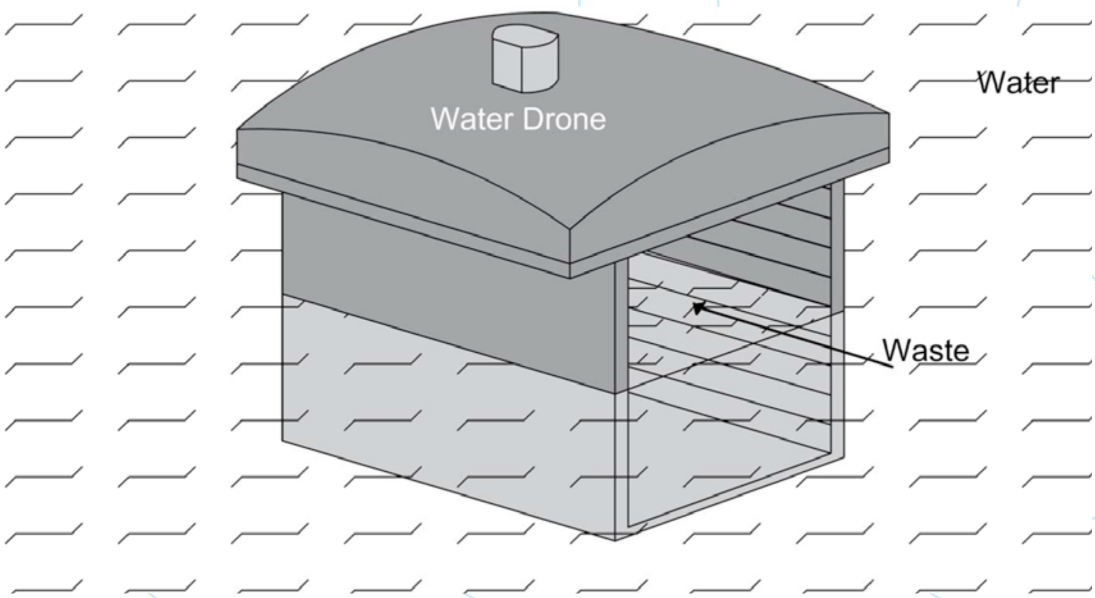
Design and function

Floating trash trapping devices are remotely operated, on-the-spot solutions to carry out occasional cleaning. The drones are mobile; therefore the technology transfer from one site to another is easy. The drones are manoeuvred around the water surface and directly capture the floating waste.

Proposed application

This solution is to be used in larger water surface, such as at the dam to collect floating debris before entering the river and the irrigation canals and along the shoreline.

Figure 34: Floating drone for waste collection, 2020



Source: Reproduced from Wasteshark, 2020.

Efficiency

High - this solution is effective for small- to medium-sized floating plastic debris

Advantages and disadvantages

Table 9: Advantages and disadvantages of the water drone technology

Strengths	Limitations
Mobile system – it can be used at different locations (e.g. dam, shoreline)	Not suitable for large debris
It covers large and extended surface area	It requires a source of energy to recharge the battery pack
Low investment need	Only suitable for relatively calm water environment (reservoir, ports, marinas, calm sea)
Fully automated - little human labour force required	It requires complementary technique for waste removal
Water quality monitoring functionality	

Assessment of engineering solutions for sediment control

Removing the sediments already contained in the Akkar main canal and preventing the future formation of large sediment deposits is crucial to enhance the operational performance of the irrigation scheme and to improve its sustainability. Sediment control must be introduced right at the source. As El-Bared dam is the main container and distributor of sediment, cleaning the canals occasionally is not efficient enough to provide long-standing and sustainable solution. Therefore, sediment techniques are proposed at the dam, more specifically upstream the dam and right in the dam. As complementary solution, methods to control sediment in the canals are presented to maximize the effects.

Figure 35: Sedimentation depth in main canal, 2020

Upstream sediment control structures

Option 1. Open check dam

Open check dams are overflow structures installed perpendicular to the channel flow to reduce flow velocities, prevent erosion, and moderately trap sediment.

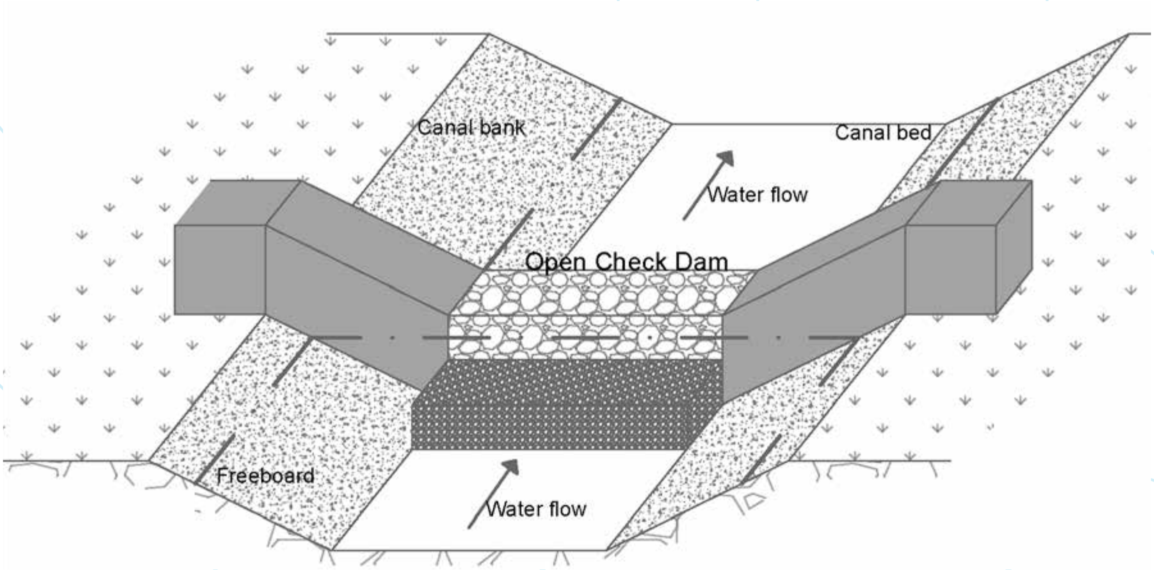
Design and Function

Check dam types vary by composition and installation approach. Check dam materials may include rock, fibre logs (e.g. wattles), triangular sediment dikes, wood, sandbags, and other materials or prefabricated systems (Minnesota Control Pollution Agency, 2019). Depending on the materials, minimum infiltration is allowed in the case of rocks, fibre logs or wood. Check dams are often installed in sequences, with the spacing between them varying in accordance with slope and soil type. Design including sediment settling captures the sediment spilling over thus providing double fences. The sediment is trapped in the upstream part of the dam and right at the downstream part. Dams equipped with topping prevents the overspill of floating trash.

Proposed application

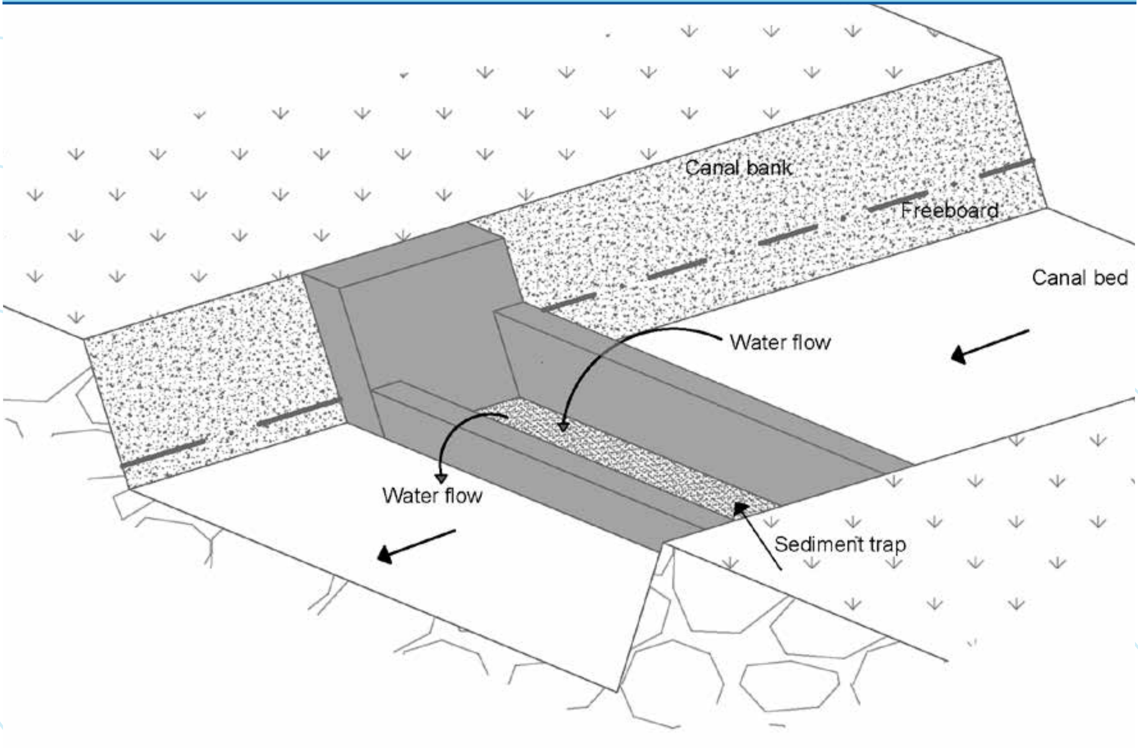
This solution is recommended in El-Bared River immediately upstream of the dam to trap the sediments before they enter the reservoir. It can be installed as a stand-alone structure or in a series of dispersed structures along the most downstream end of the river.

Figure 36: Open check dam, 2020



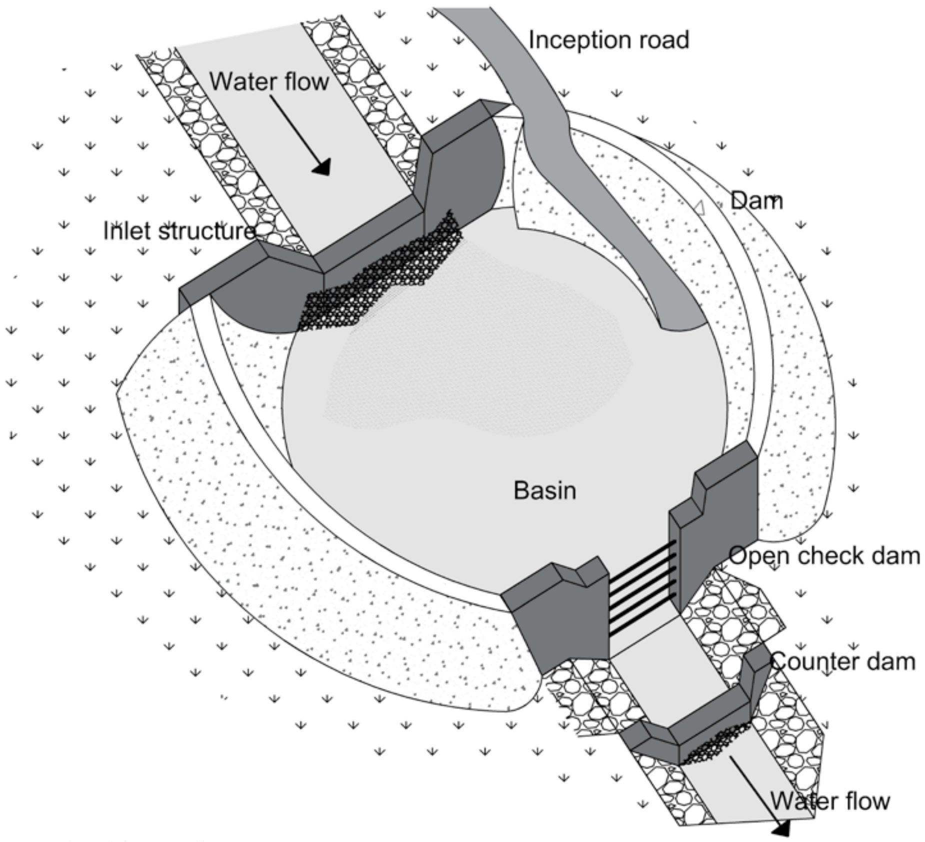
Source: Reproduced from Malesu *et al.*, 2008.

Figure 37: Sediment settling basin of open check dam, 2020



Source: Reproduced from Government of Andhra Pradesh, Department of Rural Development, 2014.

Figure 38: Sediment trap with an open check dam, 2020



Source: Reproduced from Zollinger, 1983.

Efficiency

Moderate - The primary objective of the check dam is to reduce velocity and temporary reserve water by elevating water level flow control, it reduces sediment intake as secondary objective

Advantages and disadvantages

Table 10: Advantages and disadvantages of the open check dam

Strengths	Limitations
1. Engineering	
Flexible design Large variety of construction materials Velocity control co-benefit Relatively simple construction	Possible backwater effect / flooding upstream Decreased water velocity into the dam / water supply threat Not suitable in extreme events
2. Operation and Maintenance	
No moving items – low maintenance requirements No erodible parts Rocks can be replaced	Regular sediment removal is required Access road for excavator is required for sediment removal Need of harmonization of reservoir operation (upstream hydro power plant)
3. Investment	
Low-to-Moderate investment need Long lifespan Fast return Could be productive asset – if upstream irrigation facilities are improved	Long-term planning process Required investment in discharge monitoring (for design and operation phase)
4. Socio-economic	
Potential for creation of new irrigation facilities upstream of the dam More reliable water flows upstream	Necessary flood prevention measures upstream

Option 2: Cipolletti weir

Cipolletti weirs are overflow structures installed perpendicular to the channel flow to control flow, reduce velocity and moderately trap sediment (Raudkivi, 1993). Cipolletti weirs are recommended for high velocity flows, whereas check dams could more likely cause flooding and water level control is required. Weirs can be installed in cascade in order to maximize the impact.

Design and function

Cipolletti weir is generally trapezoidal in shape and constructed from reinforced concrete. Additional design adjustments may include wave-breakers to be installed downstream from the weir in order to avoid erosion at the intake. Automated weirs with opening gates are more efficient to control both the velocity and sediment.

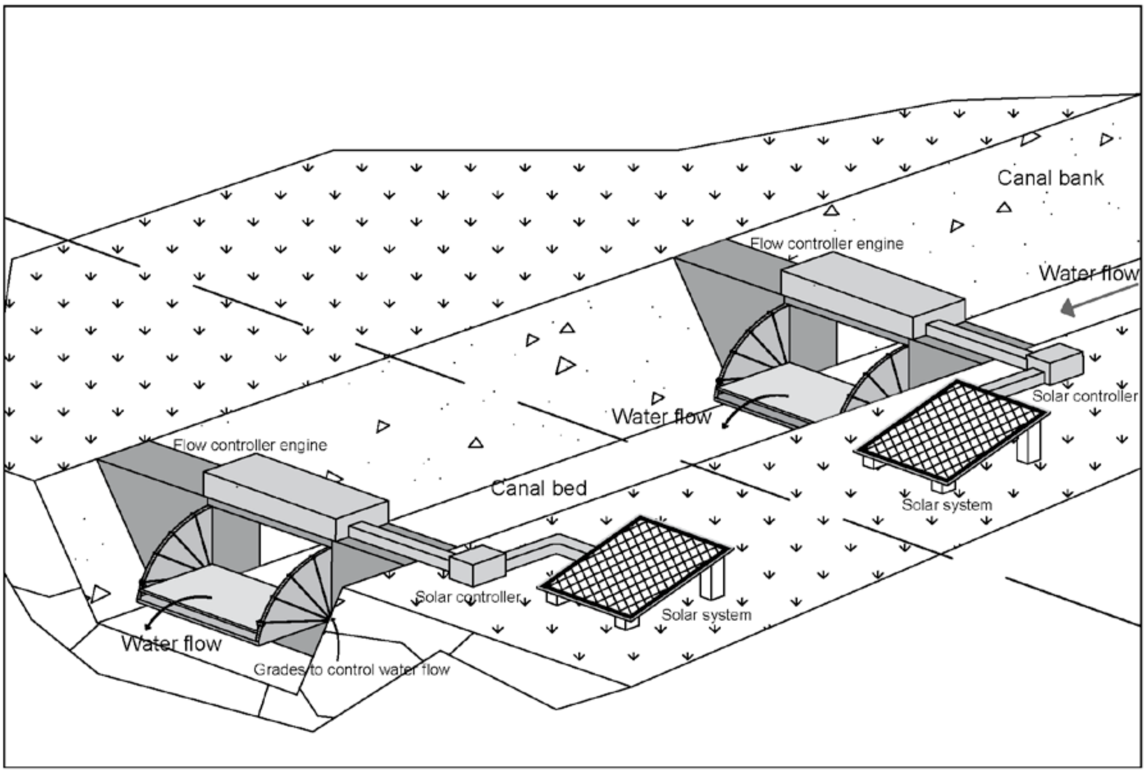
Proposed application

This solution represents an alternative to the open check dam presented above. Installation immediately upstream of the dam allows to trap the sediments before they enter the reservoir.

Efficiency

Moderate - The primary objective of the Cipolletti weir is flow control, it reduces sediment intake as secondary objective. Moreover, sediment can overflow if the crest is too deep and can be deposited in the gates.

Figure 39.Sequential Cipolletti weirs, 2020



Source: Reproduced from Bongers, 2013.

Advantages and disadvantages

Table 11: Advantages and disadvantages of the Cipolletti weir

Strengths	Limitations
1. Engineering	
Robust design (capable of withstanding extreme events) Water level control benefit It can include discharge measurement function	Possible backwater effect / flooding upstream Decreased water flows into the dam / water supply threat in case of available upstream storage facility Rigid solution made of reinforced concrete
2. Operation and Maintenance	
Low human force requirement for operation and can be automated	Regular sediment removal is required Access road for excavator is required for sediment removal Need of harmonization of reservoir operation (upstream hydro power plant)
3. Investment	
Moderate investment need Long lifespan Could be productive asset – if upstream irrigation facilities are improved	Long-term planning process Required investment in discharge monitoring (for design and operation phase)
4. Socio-economic	
Potential for creation of new irrigation facilities upstream of the dam More reliable water flows upstream in case of available storage capacity upstream	Necessary flood prevention measures upstream

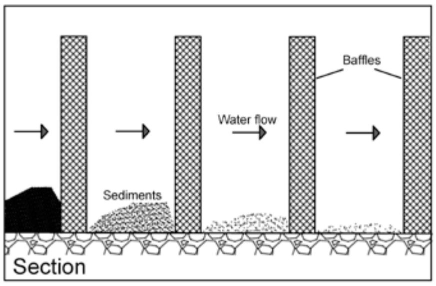
Option 3: Sedimentation basin

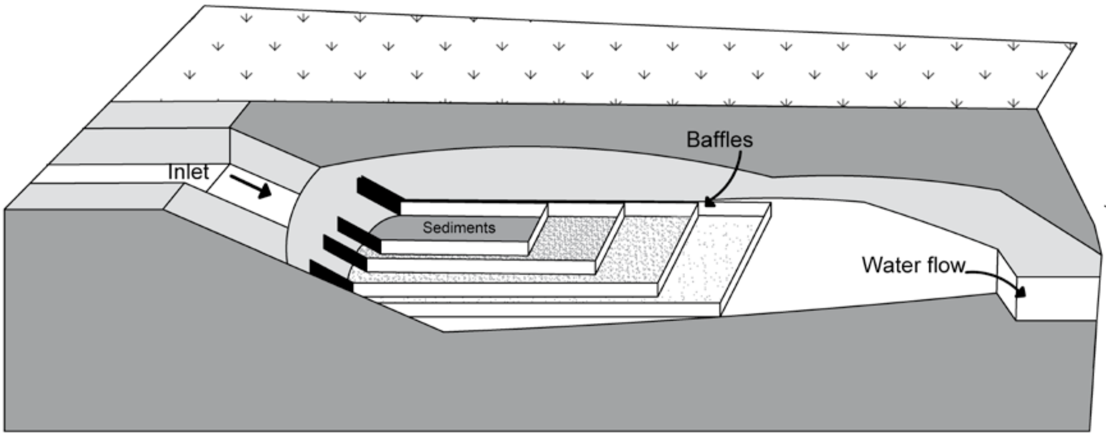
Sedimentation basins are settling ponds excavated in depression points to retain sediment-laden runoff through concentrating sediment in smaller bottom surface, while the principle is the same as dam operation and cleaning.

Design and function

Sedimentation basins function by intercepting and retaining surface runoff, allowing particles to settle prior to discharge downstream. They may feature earthen/rock embankments that retain runoff and stream flows for longer periods of time and allows fine sediments to settle. Their overall function is similar to the one exercised by the dam, however, they aim to concentrate the sediments over a smaller area. Baffles can be installed within the sedimentation basin to have controlled and fragmented concentration of deposit thus saving time and cost of cleaning.

Figure 40: Sedimentation basin with baffles, 2020





Source: Reproduced from Department of Environment and Science, Queensland, 2018 and Sides Seeding and Erosion Control, 2018.

Proposed application

The solution is proposed to be installed right in the check dam or at the entry of El-Bared River to trap the sediments before they enter the reservoir.

Efficiency

High - sediment trapping is the primary objective (scaled to small and medium-sized sediment).

Advantages and disadvantages

Table 12: Advantages and disadvantages of the sediment basin

Strengths	Limitations
1. Engineering	
Flexible design	Not suitable in high-velocity conditions
No backwater effect	Requires land acquisition
No considerable change in flow regime	

Strengths	Limitations
2. Operation and Maintenance	
No moving items – low maintenance requirements No erodible parts Easy flagging of necessary sediment removal (no need for measurement) Facilitated dredging work by collecting a large amount of sediment	Regular vegetation removal is essential Access road for excavator is required for regular sediment removal Requires soil compacting Gully erosion threat
3. Investment	
Low-to-Moderate investment need Long lifespan – in case of regular maintenance Hydraulic structures not required – except for a dam at the downstream end to hold the water back Stand-alone solution	Non-productive asset Single objective of sediment trapping No significant additional value/function compared to the existing dam

Sediment management at the dam

The North Lebanon Water Establishment (NLWE) leads the sediment removal activities at El-Bared dam. Sediment removal is carried out only occasionally through a combination of dry excavation and empty flushing. Water level in the reservoir is lowered to a riverine flow causing scour and release of the previously deposited sediments. Simultaneously, dry excavation is used to increase the extent of the scour. Nonetheless, most of the sediment removal is limited to the flushing channel, leaving behind large sediment deposits across the rest of the reservoir.

Based on the outline of sediment management alternatives provided by Annandale *et al*. (2016), a list of methods to manage sediments applicable to El-Bared dam is presented in Table 13.

Table 13: Potential sediment management practices at El-Bared dam

Name	Description	Comments
Reservoir drawdown and sluicing	It involves drawing down the water level during periods of high discharge and sediment load to increase flow velocity in the reservoir. The increase in flow velocity leads to reduced sediment trapping and scour of previously deposited sediments.	Hydrological data and modelling is required to accurately guide this method and to ensure the discharge from the dam does not cause downstream flooding. Sedimentation transport to the downstream irrigation system and water treatment facilities must be solved.

Name	Description	Comments
Dry excavation	The reservoir level is lowered to allow access to deposits by earth-moving equipment. Dry excavation can be undertaken on a seasonal basis at sites with predictable seasonal water level variation (dry summer and wet winter).	Dry excavation is generally costly and requires availability of land for sediment disposal, unless sediments are reused in agriculture or other applications.
Dredging	A range of techniques used to remove sediment from beneath the water, including: hydraulic dredging by suction dredger and siphon dredging (gravity driven).	Usually not cost-effective for small reservoirs.
Flushing	▪ Pressure flushing occurs when a submerged low-level outlet is opened to release sediment while the reservoir level is high, producing a localised scour cone around the intake. ▪ Empty flushing consists in opening a low-level outlet to completely empty the reservoir, thereby scouring sediment deposits.	▪ Pressure flushing is applicable to dams that have a low-level in the immediate vicinity of the intake. ▪ Empty flushing is currently being used at El-Bared dam in combination with excavation. ▪ Sedimentation transport to the downstream irrigation system and water treatment facilities must be solved.
Modify intake	Raising or otherwise modifying intakes (e.g. provision of sluices and low-level outlets to handle the sediment).	

Source: Annandale, 2016

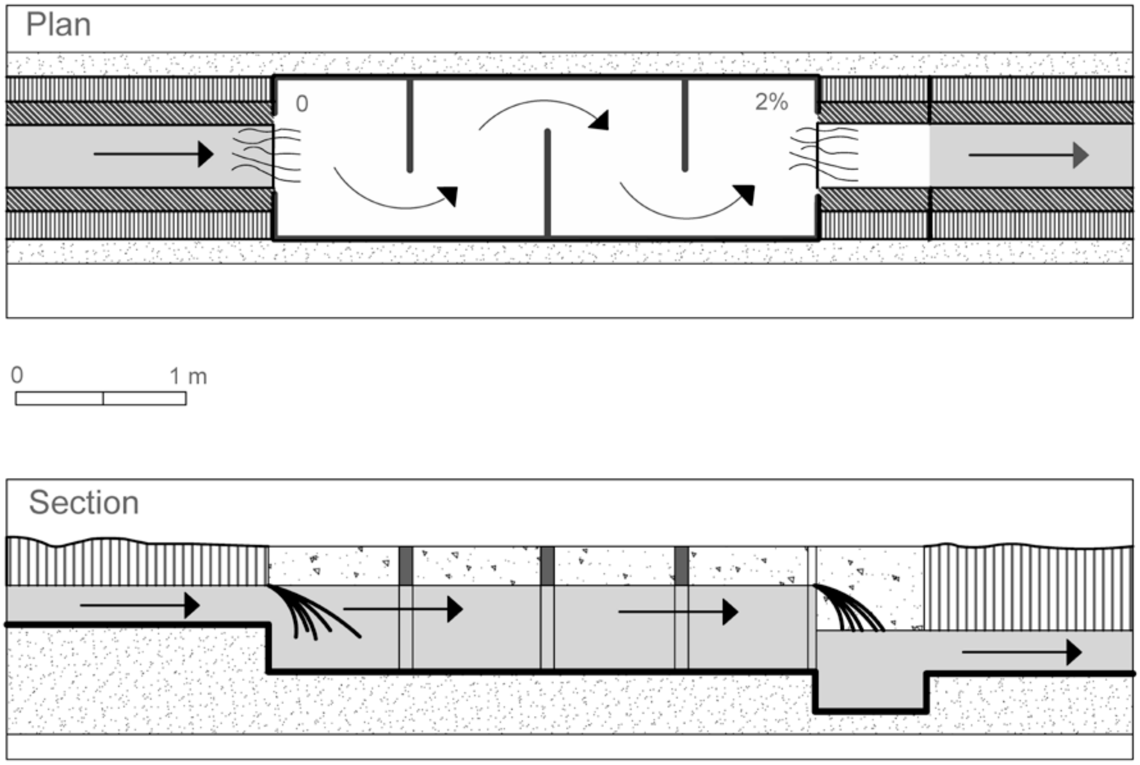
Sediment control structures on the main canal

A number of engineering solutions have been developed to facilitate the extraction of sediments from the head reach of irrigation canals. These include settling basins and sediment extractors.

Settling basins are concrete structures used to remove solid particles from water flows. When water enters the basins, the velocity is sufficiently reduced to allow solid particles to settle. The reduction in the velocity is achieved by a change in the bottom slope and in the cross-sectional area of the canal.

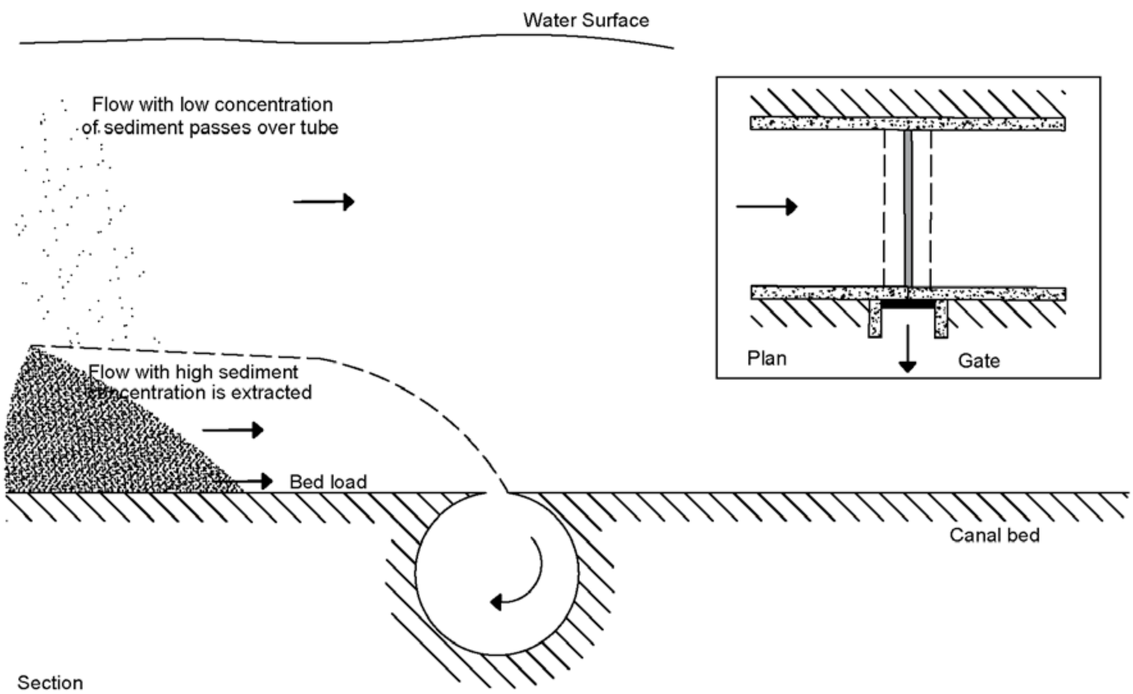
Sediment extractors function by separating, and then ejecting, the sediment-laden bottom layer of flow in a canal. They are usually located in the head reach of canals where head is available so that the extracted water and sediment can be conveyed back to the river (Wallingford, 1993).

Figure 41: Design of settling basin in irrigation canal, 2020



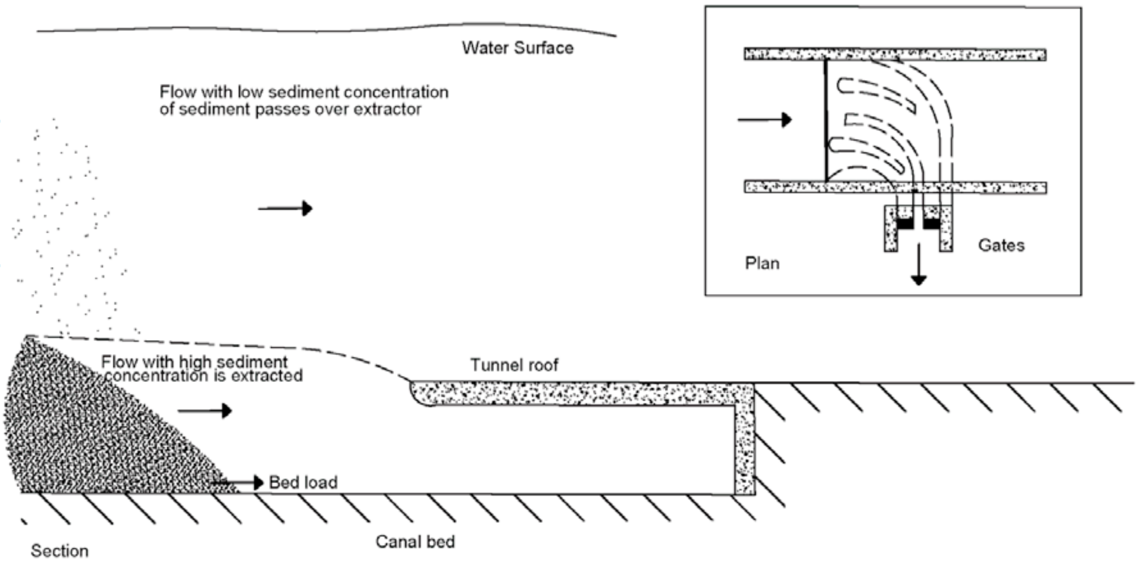
Source: Reproduced from FAO, 2003

Figure 42: Vortex tube-type sediment, 2020



Source: Reproduced from Wallingford, 1993.

Figure 43: Tunnel-type sediment extractors, 2020



Source: Reproduced from Wallingford, 1993.

Settling basins and sediment extractors can be efficient structural measures to control bed material sediments in irrigation systems, where water is directly diverted from the river into the canals, e.g. Wadi system. They are most effective in the accumulation and removal of the coarser sediments, fine gravel and sand. In the case of El-Bared dam, it is expected that coarse sediments accumulate on the upstream part of the reservoir and that most of the sediment load entering the water intakes is constituted by fine sand, silt and clay. In order to evaluate the applicability of settling basins and sediment extractors in the upstream reach of Akkar main canal, the efficiency of these systems in the removal of fine sediments should be further explored and assessed.

Other sediment control structures

Option 4: Dewatering bags

Dewatering bags are a filtration system used to contain silt and sediment during dewatering operations. They are commonly used during temporary works on construction sites.

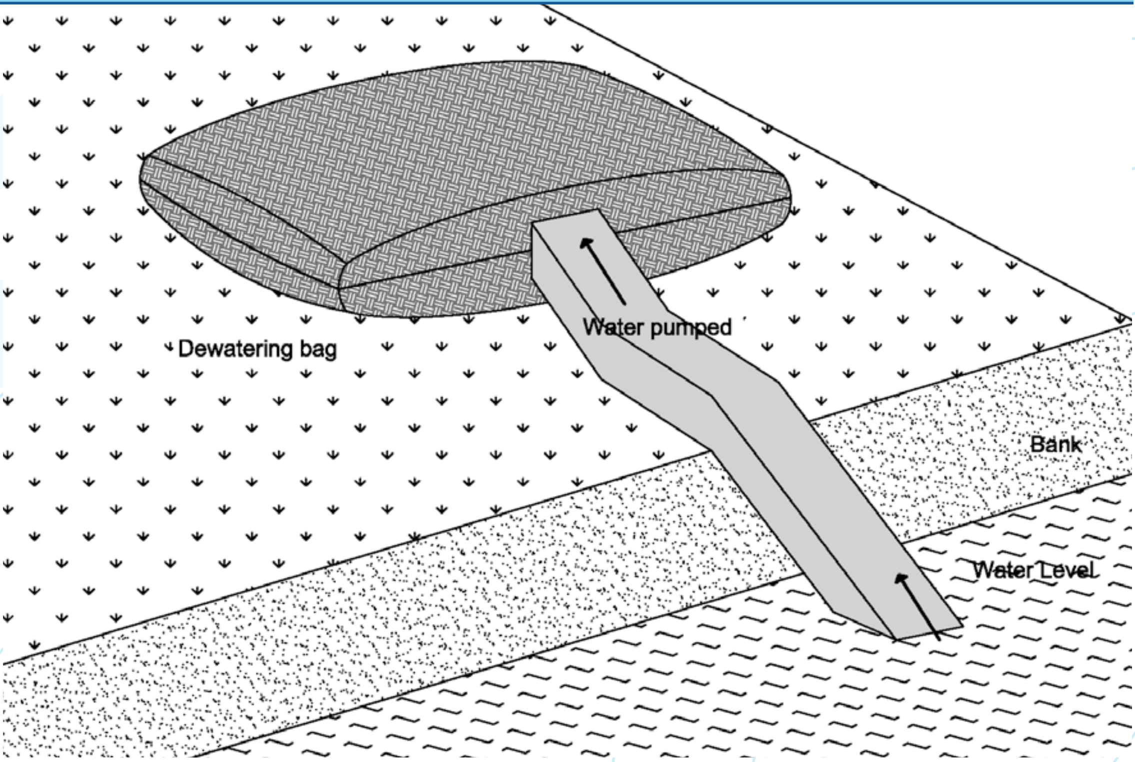
Design and function

The dewatering bags are constructed of high strength woven geotextile. Water/sludge is pumped through the bag and as the liquid escapes from the bag, solid particles are trapped inside. Once the load capacity of the bag is reached, the entire bag and its contents it is disposed of to a sanitary landfill. However, reusable models of dewatering bags are also available.

Proposed application

It could be used during the dam's dewatering operations in order to prevent discharge of large sediment load into the river.

Figure 44: Dewatering bag for sediment removal, 2020



Source: Reproduced from ULTRATECH International Inc., 2020.

Efficiency

Moderate - This solution is effective for fine sediments (sand, silt)

Advantages and disadvantages

Table 14: Advantages and disadvantages of dewatering bags

Strengths	Limitations
Side-process of cleaning/dewatering	Requires pumping and transportation
Low investment need	Short-term solution
Removed pollution	Low capacity
No civil works required	Requires disposal to dumping site
	High operation costs

Optimal strategy for a twofold intervention of MSW

Although the stocktaking resulted in robust technologies, default design requires re-configuration to understand how it fits best the local conditions. Furthermore, stand-alone technologies are often constrained by having single objective, while multifunctional technologies imply necessary trade-off amongst multiple objectives. In order to ensure a more cohesive waste removal system, implementing a combination of technologies is recommended. For example, installing an automated waste removal structure at the downstream end of the main canal would ensure that the large load of debris is seized and removed prior to reaching the river or the sea. However, having large-capacity systems in accumulation hotspots should not lead to neglecting other parts of the system. Otherwise, smaller accumulation spots might have multiplier effect and cause ultimately similar magnitude of negative impact. The major challenge in technology selection is the right understanding how the different components of the irrigation system are interrelated. In order to reach optimal combination of the equipment, the complex technology categories are evaluated per dimension in 5-point Likert-scale and drawn on radar chart to allow comparison. The scoring is carried out by an expert pool and given scores are aggregated in final score. According to the scoring guide, 0 indicates the lowest score and 4 the highest. Based on the evaluation results, complementary equipment and strategies are proposed.

Recommended solid waste management technologies

Considering the solid waste removal structures with large-capacity, the fixed trash rack with automated rake, and the debris boom and bin are deemed the most suitable solutions for the removal of MSW at the downstream end of Akkar main canal. Drawing on the strengths and limitations of all three presented, the self-cleaning trash rack was assessed least favourable. Although the self-cleaning trash rack may represent an efficient stand-alone solution for the interception and removal of solid waste, it shows several limitations related to operation and investment: requirement for a continuous source of energy, vulnerability to jamming and large debris, requirement for specialised maintenance, large investment need and high maintenance costs. The fixed trash rack with automated rake also presents similar disadvantages which are intrinsic of the automation component, for example larger investment need, requirement for specialised maintenance, requirement for source of energy and larger maintenance cost. However, it shows the highest removal efficiency, as it is able to intercept and remove large loads of both floating and submerged debris. It can still be operated manually when the automated rack fail operating. On the contrary, the debris boom and bin solution has a reduced removal capacity, it is less efficient in the removal of submerged debris and it necessitates a complementary technique to lift the bin out of the canal and dispose the collected waste. However, it requires considerably smaller investment need, lower maintenance costs and the design is more flexible to different canal's shapes and dimensions. It should be noted that the debris boom and bin would require a complementary technique to lift and unload the bin. The following radar chart displays the scoring results of the technologies.

In order to minimize the seepage of debris further downstream, the technologies should be combined with lower-capacity, manual equipment. Intervention strategy can build on existing efforts through the upgrading of existing bar screens. In fact, the installation of a working platform on already constructed bar screens and installation of vertical bars will allow manual cleaning works to run smoothly, lowering any safety concerns. Further upgrades can multiply the effect to overcome some of the challenges encountered during the O&M of the bar screens already installed on Akkar main canal. Three technical solutions are also considered as complementary addition to the existing bar screen: HDPE net, tilting vertical bars and tilting steel tray. Although vertical bars and steel tray may represent robust systems for a time-efficient removal of the accumulated waste, they both show the disadvantages of increasing maintenance requirements and potentially compromising the function of the screen as flow tranquiliser. On the other hand, installing an HDPE net on the upstream face of the existing bar screen could represent a cost-effective and simple upgrade with the additional advantage of being flexible to different canal's dimensions. It is, therefore, suggested to develop the design of the HDPE net system further and to test it at a selected location along Akkar main canal.

Two manually operated structures are presented as complementary solid waste removal solutions for the outlet of main secondary canals in Akkar command area: net trash trap and fixed trash rack with manual rake. Although the first solution requires lower investment need and enables quick removal of the accumulated waste, it is more prone to clogging and to causing upstream flooding if regular monitoring and operation is not performed. The fixed trash rack with manual rake has the advantages of being a robust solution and of higher efficiency in the interception of waste, however it requires larger investment need and may lead to higher operation and maintenance costs. It should also be noted that the net trash trap is most suitable in small rectangular canals, whereas the trash rack is highly flexible to different canal's shapes and dimensions. The final selection between the net trash trap and the trash rack is based on site-specific characteristics, including shape, size and material of the canal, availability of vehicular access, and likely debris load. Field observation proved that while trash tracks are more suitable in canal sections, net trash traps perform better in outlets to the sea.

Finally, the provision of mobile devices such as drones is recommended as a cost-efficient and fully automated measure to collect and remove floating solid waste from El-Bared reservoir.

Figure 45: Comparison of solid waste removal structures, 2020

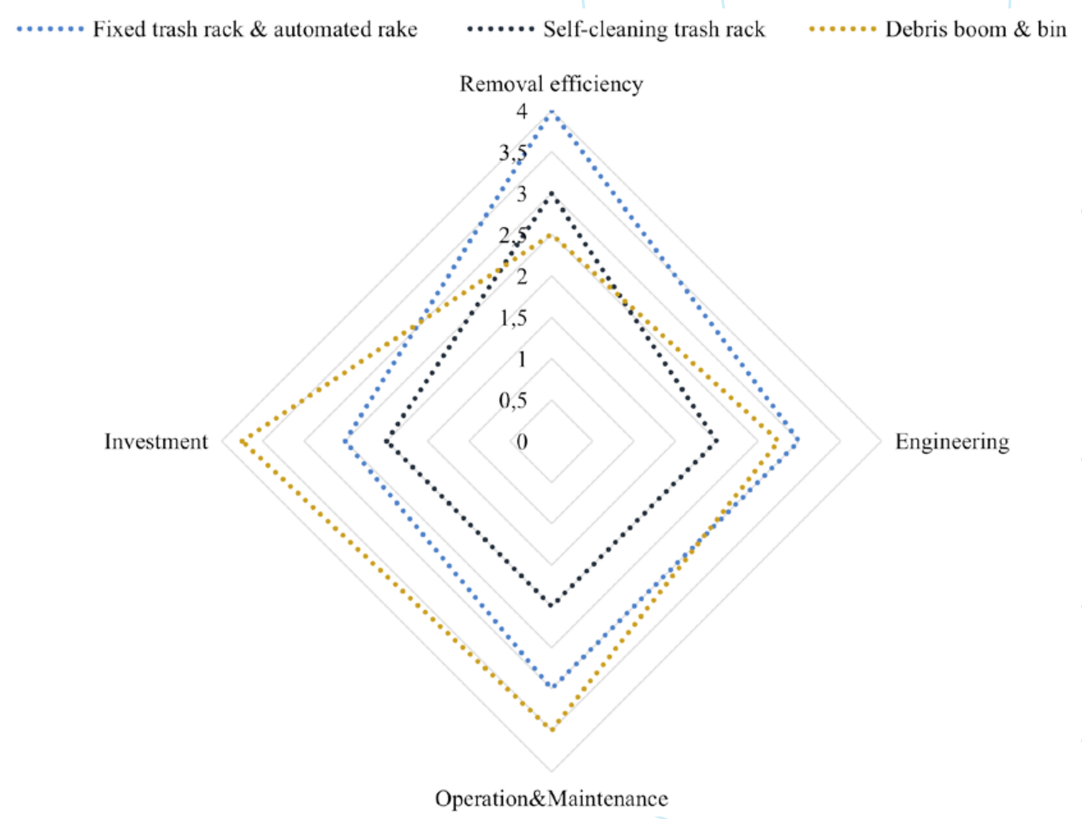
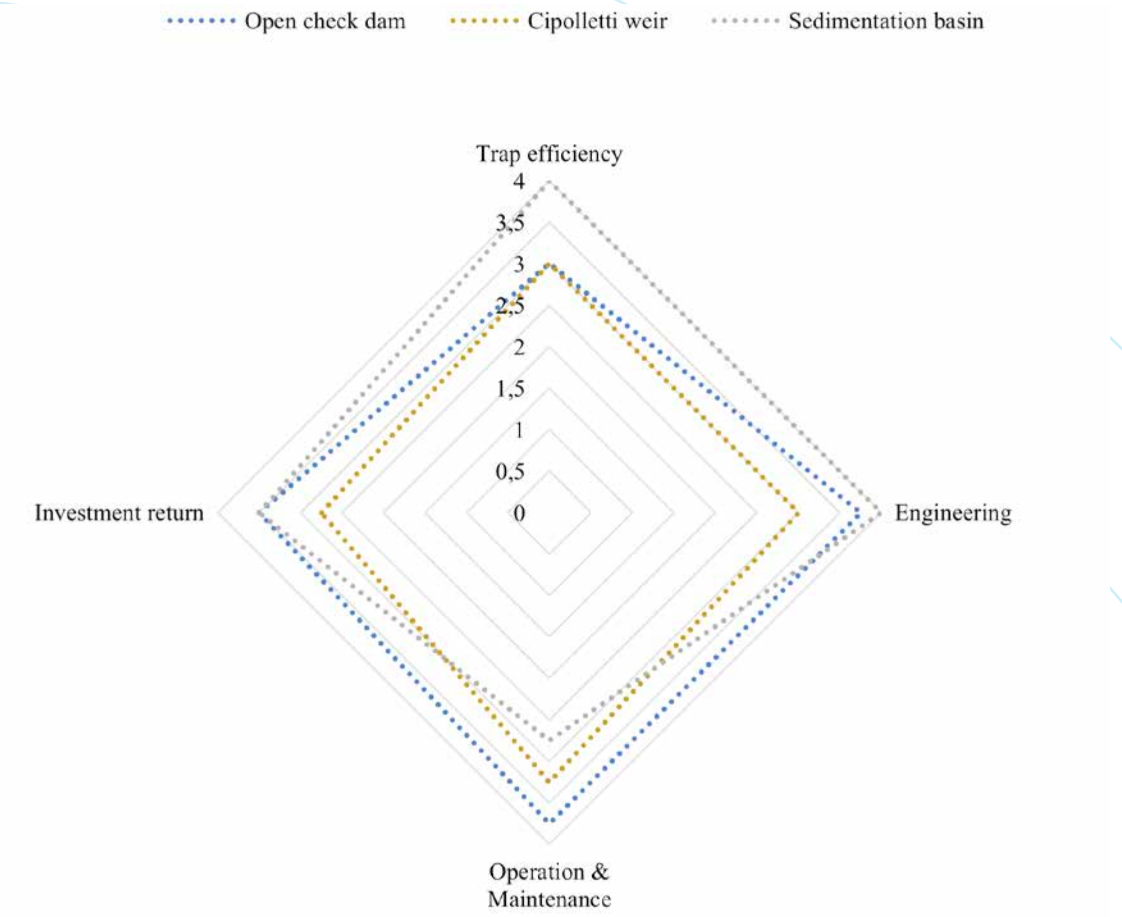


Figure 46: Comparison of upstream sediment control structures, 2020



Recommended sediment removal technologies

To efficiently and sustainably reduce the problem of sedimentation in Akkar irrigation scheme, different strategies should be considered with the aim of controlling source and fate of sediments. Three methods are considered to trap sediments before entering El-Bared dam: open check dam, Cipolletti weir, and sedimentation basin. The radar chart displays the results of technology scoring.

The sedimentation basin shows the highest trapping efficiency as water is retained for a longer period allowing fine sediments to settle. However, it performs poorly on O&M, as it requires regular removal of vegetation and accumulated sediment. This has a direct impact on the operation and maintenance costs. Indeed, the sedimentation basin would not show a significant added value to the current sediment removal activities in the dam, except from the fact that it helps accumulate part of the sediment load over a smaller area upstream of the dam. Although the primary function of open check dams and Cipolletti weirs is flow control, they show moderate efficiency in trapping coarse sediment, especially when deployed sequentially. Their installation upstream of El-Bared dam would help reduce sediment inflow and consequently, would redirect the need for sediment removal from the dam to smaller deposits accumulated upstream of the new structures. The open check dam should be preferred over the Cipolletti weir as it is a more flexible solution in terms of geometry and construction material, and it generally requires a lower investment need. It should be noted that open check dams and Cipolletti weirs might lead to a detrimental impact to the natural flow regime causing a rise in upstream water level and a discontinuous water supply to the dam and, consequently to the irrigation scheme. However, these advantages can be reduced and mitigated during the design of the structure, which needs to be preceded by a thorough hydrological and sediment transport study of El-Bared watershed. A hybrid solution consisting of a sequence of sediment traps and open check dams is deemed the most suitable method to trap sediments upstream of El-Bared dam. The construction of a sediment trap immediately upstream of the check dam can significantly decrease the surface area of cleaning and it allows additional sediment storage.

Potential management methods to control sediment in El-Bared dam are complementary strategies to increase the impact of any equipment. Some consists of regulating water and sediment flows within the impoundment to limit deposition and to scour previously deposited sediments. Others involve removing sediment deposits from beneath the water or in dry conditions through machinery. Although dredging and excavation may require large capital investment and operating costs, other management method such as empty flushing and reservoir drawdown should be further considered as low-cost complementary techniques to sediment trapping upstream of the dam. However, the impact of flushing reservoir strategy on agriculture production, potable water plants O&M and groundwater aquifer level and quality should be considered.

Settling basins and sediment extractors are examined as potential complementary solutions for trapping sediments along the upstream reach of Akkar main canal. Their trapping efficiency is highly dependent on the grain size distribution of the sediments present in the canal. Although both structures have proven to be efficient in the removal of coarse sediments at the head of many run of river irrigation schemes, their ability to trap fine sediments (fine sand, silt and clay) in reservoir fed irrigation canals may be limited. It is worth to note that sediment management strategies are built on data-intensive planning process. Data and information involving particle counting, measurement of sedimentation rate, particle and characterisation analysis and topographical surveying are all required parameters to established informed decision-making. It is important to mention that sediment removal upstream of the dam must be prioritized for principal development strategy and deployment of downstream facilities must be harmonized according to it.

Conclusions

A pathway to combat water pollution

Water resources are under immense pressure in Lebanon. In parallel, MSW keeps on pilling-up affecting both the water availability and quality. Adopted strategies of collection and waste disposal have changed massively over the years, with varying efficiency levels. At present, the role of waste collection and disposal falls mainly under the responsibility of municipalities, entities that are under-resourced and act independently. Despite of the numerous attempts to tackle this issue, the MSW situation reached its tipping point. Adequate delivery of effective measures is beyond the capacities of local authorities. As the cascading effect extend to both livelihood and environment, the counting back has begun. Adopting optimal combination of technologies are much desired in North Lebanon to eliminate the impacts until shift in consumption brings radical changes in waste generation.

Water resources are particularly vulnerable to MSW, as habitants, voluntarily or forcedly involved in pollution, consider waterways as vehicle for waste transport. The domino effect of improper disposal ends up in spreading waste pollution around the irrigation network and the sea. Hence, when different forms of litter reach waterways, it cannot be overlooked as its consequences are tremendous on the quality of water reaching ultimately marine life. The magnitude of the problem is aggravated by heavy sediment load that reduces the conveyance capacity, contributes to the MSW retaining in irrigation canals, and affects the overall conditions of irrigation system. In order to minimize the impacts, two-folds and multi-layered system design is required that collectively resolve the current crisis.

Based on a comprehensive review of possible engineering solutions, it can be concluded that there is a need to explore and invest in new technologies. As the implementation of such techniques in Lebanon is almost non-existing, pathways of technology adoption must be critically pre-evaluated. Assessment built on multi-criteria can highlight both strengths and limitations that must be exploited and tackled during implementation. Any configuration of explored technologies can be context-tailored in order to achieve maximum functionality. Combined systems involving automated technologies in high-density spots with complementary techniques constitute a robust and complex solution to address MSW crisis together with sediment control. However, the role of complementary techniques should not be undermined, as easy-to-implement design can act as “wild-card” to recover any error of large equipment. Sediment control is approached from different perspective than MSW management. While MSW is sourced from multiple locations along the irrigation system, sediment originates from some typical and well-defined sources. The system layout follows site selection process based on multiple criteria such as number of emission sources, suitability of canal section, volume of removable waste and sediment, territorial coverage and degree of recent system equipment.

Large equipment such as trash-racks or debris booms are selected as high-capacity, labour-independent technologies to eliminate large MSW volume. Complementary, manual equipment such as trash racks, upgraded bar screens and trash nets are recommended to minimize the remaining waste volumes and break the trend of improper disposal almost right at the source. Sedimentation must be controlled by properly sized check dams with sediment basins. Targeting its source, sediment removal structures are the most effective when deployed in sequence.

Future perspectives

Just as the problem of solid waste and sediment is complex, so too the definition of strategies that address the entire cycle from source of generation to transportation and storage. The steps of waste and sediment life cycle require integrated management, involving a large number of actors. The removed waste from irrigation canals without collection, transportation and processing can be considered only halfway measure. Strengthening the collaboration amongst actors, such as NWLE, municipalities, unions, local communities and other stakeholders is a key step forward to provide sustainable solutions. In order to create a win-win position for all stakeholders, beneficial strategies must be identified. For example, treated sediment can be used for agricultural, construction, habitat restoration or structural application (Regional Water Authority of Schieland and Krimpenerwaard, 2016). Depending on its composition, removed solid waste can be recycled or composted. The learning process of turning waste into benefit is still in its infancy in Lebanon, where yet only 8 percent of the MSW is recycled (SWEEP-NET, 2014). Future perspectives, therefore, must embrace the entire life cycle of solid waste and sediment management to improve sustainability of proposed solutions.

Though hard measures are key in these types of situations, soft measures are required to create better management plans. In the case of Akkar, one can perceive that individual liability in relation to waste management is lacking. The vicious cycle of being both the source and victim of the MSW crisis has not been broken yet. Strengthening the sense of ownership is certainly just as important as investing in technology. If only too little attention is paid by local communities, any effort put into hard measure development might decay. Hence, pilot technology interventions must be twinned with sufficient awareness-raising and capacity-building of locals. As a first step to ensure the message gets through, educational awareness campaigns should be organized for communities. These should be developed taking into account various socio-economic and educational levels. Campaigns should also be built on the lessons learnt from past experiences, what has not worked previously should be the basis of a more inclusive and better targeted soft intervention. This can be accomplished through the establishment of collaborations with local, national and international actors who interact and approach communities differently. The current report sets the scope on MSW and sediment induced water pollution. However, further efforts are required to address the water quality deterioration by sewage discharge. Holistic awareness-raising campaigns can achieve more pro-environmental attitude.

Implementation is just a first step towards long-standing MSW management. Due to its interdisciplinary nature, responsibility allocation of O&M should be agreed amongst key stakeholders. Mainstreaming the system management into day-to-day activities of relevant entities and local communities must be properly planned since a single weak link in the chain might cause complete failure. As a means to ensure better response from the community, bottom-up participatory approach is recommended; it should engage various stakeholders including municipalities and end-users. Finally, achieved results should be institutionalized and mainstreamed into national policies that encompass monitoring and enforcement mechanism. Upscale and out-scale of the implemented technologies is of paramount importance in order to transfer evidence-based practices and technologies to areas facing similar challenges.

References

Abbas II, Chaaban JK, Al-Rabaa AR, Shaar AA. 2017 Solid waste management in Lebanon: challenges and recommendations. *Journal of Environment and Waste Management 4(3)*: 235-243.

Annandale, G.W., Morris, G.L., Pravin, K. 2016. *Extending the life of reservoirs, sustainable sediment management for dams and run-of-river Hydropower.* International Bank for Reconstruction and Development. World Bank. Washington, USA.

Bigagli, E; Samaha, Z; Sévin-Allouet. 2018. *Deep sea Lebanon-results of the 2016 expedition exploring submarine canyons.* IUCN Centre for Mediterranean Cooperation and IUCN Regional Office for West Asia - Lebanon.

Bourgers, P. 2013. *Ontwerp document stuwen.* Report Versie 5. Waterschap Aa en Maas, Netherlands.

Central Administration for Statistics of Lebanon Council of Ministry. 2020. Rainfall statistics. [Online] Available at: http://www.cas.gov.lb/index.php/statistical-yearbook#2006

Department of Environment and Science, Queensland. 2018. Sediment basins – key considerations, WetlandInfo. [Online] Available at: https://wetlandinfo.des.qld.gov.au/wetlands/management/treatment-systems/for-agriculture/treatment-sys-nav-page/sediment

Duperon. 2020. Duperon Adaptive Technology. [Online] Available at: https://www.duperon.com/Downloads/articleType/CategoryView/categoryId/67/Open-Channel-Bar-Screen

ELARD, NLWE. 2016. Hydrogeological study of Akkar Caza and assessment of well siting – phase 1.

ENERQUIP. 2020. [Online] Available at: https://enerquip.no/

Engelund, F.; Hansen, E. 1967. *A monograph on sediment transport in alluvial streams.* Taknisk Forlag. Copenhagne, Denmark.

EPA. 2020. *Reference guide for asset management tools: asset management plan components and implementation tools for small and medium sized drinking water and wastewater systems.* Office of Water. Washington, USA.

FAO. 2003. *FAO training series: Simple methods for aquaculture*. [Online] Available at: http://www.fao.org/tempref/FI/CDrom/FAO_Training/FAO_Training/General/f1_e.htm

FAO. 2008. *Irrigation in the Middle East region in figures* – AQUASTAT survey 2008. Rome, Italy.

FAO. 2020. *Global Information and Early Warning System.* Country Brief. Lebanon. Rome, Italy

FAO. CLIMWAT database. 2020. [Online] Available at: http://www.fao.org/land-water/databases-and-software/climwat-for-cropwat/en/

FAO, MoA. 2010. The core module of the census of agriculture 2010 - Main Results.

Farajalla, N., Kerkezian, S., Zeinab Farhat. 2015. *The way forward to safeguard water in Lebanon national water integrity risk assessment.* American University of Beirut, Lebanon.

GoL, UN. 2019. Lebanon crisis response plan (2017-2020).

Government of Andhra Pradesh, Department of Rural Development. 2014. Integrated Watershed Management Programme (IWMP). [Online] Available at: http://iwmp.ap.gov.in/WebReports/Content/ImageTestWithPaging.aspx

Green, J. M., Draper, A. K., Dowler, E. A. 2003. Shortcuts to safety: risk and 'rules of thumb' in accounts of food choice. *Health, Risk and Society,* 5, 33–5.

Husseini, M. 2020. The rural urban continuum: towards a new spatial policy the case of North Tripoli. Unpublished thesis from American University of Beirut. Beirut, Lebanon.

IRC, Save the Children, DRC, Oxfam, UKAID. 2013. E*mergency Market Mapping and Analysis (EMMA) of the agricultural labor market system in the North and Bekaa, Lebanon.*

IUCN. 2018. *On the path of resilience to climate change in the upper Akkar watershed Lebanon. Gland, Switzerland.*

Jaafar H, Ahmad F, Holtmeier L, King-Okumu C. 2020. Refugees, water balance, and water stress: lessons learned from Lebanon. *Ambio*.49(6):1179-1193.

Jambeck, J. R., Geyer R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Ramani Narayan, R., Law, K. L. 2015. Plastic waste inputs from land into ocean. *Science 347*, 768–771.

Malesu, M., Oduor, A. R., Odhiambo, O. J. 2008. *Green water management handbook: rainwater harvesting for agricultural production and ecological sustainability.* Nairobi, Kenya: World Agroforestry Centre ICRAF.

Massoud, M., Merhebi, F. 2016. *Guide to municipal solid waste management.* American University of Beirut - Nature Conservation Center. Beirut, Lebanon.

Minnesota Control Pollution Agency. 2019. *Sediment control practices - check dams Minnesota Stormwater Manual.* Minnesota Control Pollution Agency.

MoA. 2003. *National action programme to combat desertification.* Beirut: Ministry of Agriculture.

MoE. 2018. *Policy Summary on integrated solid waste management PPT.* Beirut: Ministry of Environment

MoE, EU, UNDP. 2014. *Lebanon environmental assessment of the Syrian conflict and priority interventions.* Beirut: Ministry of Environment.

MoE, UNDP. 2017. *Updated master plan for the closure and rehabilitation of uncontrolled dumpsites throughout the country of Lebanon (Volume A).* Beirut: Ministry of Environment.

MoE, UNDP, ECODIT. 2011. *State and trends of the Lebanese environment.* Beirut: Ministry of Environment.

MoE, UNDP, GEF. 2011. *Lebanon's second national communication to the UNFCCC.* Beirut: Ministry of Environment.

MoE, UNDP, GEF. 2019. *Lebanon's third Biennial Update Report (BUR) to the UNFCCC.* Beirut, Lebanon.

MoEW, UNDP. 2014. *Assessment of groundwater resources of Lebanon.* Beirut: Ministry of Environment.

Mouchref, A. 2008. Fo*rgotten Akkar - socio-economic reality of the Akkar region.* MADA Association. Beirut, Lebanon.

OCHA. 2018. *North & Akkar governorates profile.* New York, USA.

OCHA. 2019. *Akkar governorate profile.* New York, USA.

ODA. 1993. *Design manual for canal sediment extractors. Volume 1.* HR Wallingford Ltd, Oxon, UK.

OMSAR. 2018. Waste treatment and disposal facility in Srar, Akkar, s.l.: s.n.

Ranmarine. 2020. WasteShark. [Online] Available at: https://www.wasteshark.com/

Raudkivi, A. J. 1993. *Sedimentation: exclusion and removal of sediment from diverted water.* IAHR Hydraulic Structures Design Manual No.6 Balkema, Rotterdam.

Regional Water Authority of Schieland and Krimpenerwaard, De Vlaamse Waterweg, Westcountry Rivers Trust, Brightlingsea Harbour Commissioners, IMT Lille Douai. 2019. *Using sediment as a resource.* Prepared in Interreg 2 Seas Mers Zeeen. Lille, France.

Sides Seeding and Erosion Control. 2020. *Pond Baffles.* [Online] Available at: http://sidesseeding.com/pond-baffles/

SWEEP-NET. 2014. Country report on the solid waste management in Lebanon, s.l.: s.n.

Storm Water System. 2020. [Online] Available at: http://stormwatersystems.com/stormx-netting-trash-trap/

ULTRATECH International, INC. 2020. *Ultra-Dewatering Bags.* [Online] Available at: https://www.spillcontainment.com/products/dewatering-bags/

UNHCR. 2020. *Total Registered Refugees.* [Online] Available at: https://data2.unhcr.org/en/situations/syria/location/71

World Bank. 2003. *Policy note on irrigation sector sustainability.* Republic of Lebanon. Report No. 28766. Washington, USA.

World Bank. 2011. *Country environmental analysis. Republic of Lebanon.* Report No. 62266-LB. Washington, USA.

World Bank. 2018. Total population size in Lebanon. Washington, USA

World Bank. 2019. Population, Total – Lebanon. Washington, USA

World Bank Climate Knowledge portal. 2020. [Online] Available at: https://climateknowledgeportal.worldbank.org/watershed/161/climate-data-historical

Zollinger, F. 1983. *The processes in sediment traps: their morphology and their possibilities of control.* No 7419, Zurich, Switzerland

Assessment of engineering solutions for solid waste removal from irrigation canals in North Lebanon

Waste management in Lebanon is a significant issue anticipating cascading and spill-over effect on livelihood, environment and agriculture. Water resources are particularly vulnerable to the on-going dynamics, as waste mismanagement leads to faster spreading pollution. Applying a pilot approach, the project mainly focuses on Akkar irrigation scheme to introduce both hard investment and soft measures in response to the waste crisis. Following a multi-criteria assessment approach, the current report maps waste removal technologies and provides recommendations on their functions and suitability in the context of the target area. Based on broader understanding of the feasibility, it helps come to a decision on technology selection.

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