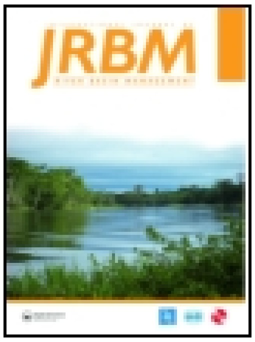

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Sustaining the ecological functions of the Litani River Basin, Lebanon

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ABSTRACT

Although Lebanon has the highest mean annual rainfall of all Middle Eastern countries, it is affected by water stress, negatively impacting agricultural food production, energy generation, and undermine ecosystem functions. The Bekaa area, where the upper Litani River Basin (LRB) is located, suffers serious water quality and quantity problems, which threaten agricultural productivity and public health. Most of the domestic and industrial water in the basin is left untreated. This study investigates prevailing water management issues in the basin. The analysis provides a critical reflection on the water quality and quantity indicators using Sustainable Development Goal 6 (SDG 6), to 'ensure availability and sustainable management of water and sanitation for all'. Results based on the author's observations and evidence from published reports and papers, since the early nineties, showed the existing management approaches fall short to mitigate the negative impact of the environmental problems in the LRB, particularly low water quality (indicator 6.3) and inefficient water use (indicator 6.4). Progress on achieving integrated water management (indicator 6.5) in the LRB is limited. Persistent environmental challenges remain due to weak governance, insufficient capacity, and law enforcement, which must be targeted by a public-private partnership.

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Sustainable water management; safe water; sanitation; contamination; ecosystem services

Introduction

Lebanon, with the highest amount of renewable water resources per unit area in the Middle East and with 30% agricultural lands, is increasingly suffering from climate change and water scarcity that has impacted water availability for irrigation and agricultural production (Shaban, 2008). With more than 7 million inhabitants and less than 2 billion m^3 of available water, Lebanon is a country under water stress and food insecurity. The Litani River, with the Qaraoun Reservoir, is a very important basin in Lebanon with a catchment area of about 2150 km^2 (Shaban, 2011). Since the last few decades, the Bekaa Plain, where the largest part of the Litani River Basin (LRB) is located, has been suffering serious water quality and quantity problems, which undermine the right and access to clean water, impact food security and food safety, threaten sustainable agricultural practices and affect ecosystem functions.

Since the early 1960s, hydrological measurements have been carried out by the Litani River Authority (LRA) on the river; hence, comprehensive feedback on flow regime through variable climatic conditions and community development has been obtained. Recently, the river water has been subjected to a decline in its flow and deterioration of water quality threatening public health and sustainable agriculture (Shaban & Hamzé, 2018). Hence, sustainable water management is a major challenge in the basin. Thus, the Litani River Basin is a representative hydrologic system for the contextualization of water-related SDGs (in particular SDG 6) to the aspects of sustainable water management.

The Litani River has essential significance in the national economy. It contributes to the water needs of more than one million people living within the basin, secures social, industrial, and energy needs and watershed ecosystem functions, including the soil and forest covers (IDRC et al., 2007). This significance has motivated several studies, policy briefs, working papers, and projects on this hydrologic system (Jaafar et al., 2016; Jaafar & Ahmad, 2020; Jaafar et al., 2020; Table 1 among others).

Despite many of these and older projects and studies aimed at addressing the environmental management of the basin, no remarkable improvement has been observed both in water quantity and quality. The Litani River is witnessing the worst situation ever, and thus it was described as a *dead river* (Shaban & Hamzé, 2018). The severe situation in the river basin has been exacerbated as a result of the increasing population, discharge of untreated wastewater, a variable climate, low water productivity, and many unsustainable practices (Jomaa & Shaban, 2018). Solid waste bulk disposal sites on riverbanks, direct discharge of non-treated sewage and industrial waters, and irrigation with contaminated waters are some causative factors affecting the basin health. Therefore, chemical and bacteriological contamination of water and sediments becomes widespread and exceeded the international standards (Mcheik et al., 2018; Nehme & Haidar, 2018). The described deterioration of water quality has been resulting in diseases and soil, crops, and air contamination that threaten public health, environment, food security, and safety as well as ecosystem functions.

However, the use of generated knowledge and information remains limited for the elaboration and implementation of sustainable policy for the management and monitoring of water quality in the basin leading to its protection and sustainable use (Darwich et al., 2018). Project outputs and the local administration failed to compile long term policy based on

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Table 1. Overview of environmental projects on the Litani River from 1994 to 2020 (Adapted from Shaban & Hamzé, 2018).

Title	Date	Category	Executing Agencies/ Partners/Authors	Major Focus
Pollution of the Litani River and Qaraoun Lake	1994	Technical Report	Jaafar et al.	Pollution
Protection and sustainable management of the soil and groundwater	1997–2003	Project	BGR, CNRS, ACSAD	Pollution and management
Water management plan for the Litani River and Qaraoun reservoir	1998	Research	S. Srour	Management of pollution
Nature and extent of pollution of land resources in Central Bekaa, Lebanon.	1999	Article ICS-UNIDO Workshop	Darwish et al.	Pollution
Environmental Master plan for Litani River and Qaraoun Lake catchment area	2000	Project	Swedish MVM konsult AB, MoE	Management and pollution
Evaluation of water quality of the Qaraoun reservoir, Lebanon: suitability for multi-purposes usage	2002	Article (Envi. Monit. Ass)	Jurdi et al.	Pollution
Water Quality Assessment of the Upper Litani River Basin and Lake Qaraoun	2003–2004	Project	Dia,Wess	Pollution
Water quality in the Litani River and the Qaraoun Lake. Forwarded programme: Integrated water and coastal resources	2003–2005	Project	USAID-Bureau for Asia and Near East	Pollution
Towards an ecosystem approach to the sustainable management of the Litani watershed	2004–2007	Project	IDRC, CNRS, LRA, DSA, Cadham Hayes	Pollution & ecosystem management
Pollutants transport in the soil of Central Bekaa	2006–2008	Project	CEDRE Project	Dynamics of soil infiltration and pollutants transfer to groundwater
Environmental and health risks of nitrates dynamics in the soil-groundwater-food chain	2007–2009	Project	CNRS	Applied research on health and environmental transfer of nitrates
Assessing water quality in the Upper Litani Basin, Lebanon, using an integrated GIS-based DSS	2008	Paper	Assaf and Saadeh	Pollution and management
Preliminary contamination hazard assessment of land resources in Central Bekaa Plain of Lebanon.	2008	paper	Darwish et al.	Pollution
Litani water quality management	2009–2013	Project	USAID/AUB/NGO	Pollution
Regional Coordination for Improved Water Resources Management and Capacity Building-CAPWATER	2012–2015	Project	WB Grant/NASA/ CNRS	Crop Mapping, ET, Biomass production, drought, flood in Litani basin. Talal Darwish
Balancing water stress and human crises under a changing climate: Integrating international policy agendas in the Bekaa Valley, Lebanon.	2016	Project	DFID IIED-AUB, BWE	Water Resources analysis, water balance, and refugees water use.
Water Intelligence for NEAR East (WIN)	2016–2020	Project	IHE-Delft; CNRS. LRA, LARI	Water accounting and water productivity
'Promotion of Good Agricultural Practices, Including Integrated Pest Management, to reduce agrochemical pollution in upper Litani basin' - UTF/LEB/028/LEB'	2017–2021	Project	WB Loan CDR, MoA, LARI, LRA, Farmers	To reduce pesticides and fertilizers in the upper Litani basin and Qaraoun Lake area
The Litani River Lebanon an assessment and current challenges	2018	Book	Shaban and Hamze	General assessment
'Integrating time series ET mapping into an operational irrigation management framework (ITSET)' - UTF/LEB/028/ LEB'	2019–2020	Project	Ministry of Foreign Affairs, Netherlands DUPC2-IHE Delft AUB, Farmers	To develop a smart application for irrigation scheduling using remote sensing and data fusion

Abbreviations: BGR = Federal Institute for Geosciences and Natural Resources, CNRS = Conseil National de la Recherche Scientifique, ACSAD = Arab Center for the Studies of Arid Zones and Dry Lands, ICS = International Centre for Science and High Technology, UNIDO = The United Nations Industrial Development Organization, MVM-AB = The Swedish Association of Waste Management Companies, MoE = Ministry of Environment, USAID = The United States Agency for International Development, LRA = Litani River Authority, DSA = Development Studies Association, CEDRE = French-Lebanese research funding programme, AUB = American University of Beirut, WB = World Bank, NASA = The National Aeronautics and Space Administration, DFID = the UK's Department for International Development, IIED = International Institute for Environment and Development, BWE = Bekaa Water Establishment, IHE = Institute for Water Education, LARI = Lebanese Agricultural Research Institute, CDR = Council for Development and Reconstruction, MoA = Ministry of Agricultue, DUPC2 = IHE Delft Partnership Programme for Water and Development.

continuous capacity building and upgraded infrastructure. For instance, the measurement of water flow, monitoring of climatic conditions, and groundwater depth are intermittent and data is not readily available. The lack of resources and weak governance leads to a shortage in measurement and monitoring equipment beside the large mobility of trained staff. Such a situation threatens the expected outputs from the invested resources and efforts and it constrains the implementation of sustainable development goals (SDGs) and SDG 6 targets, specifically targets: 6.1, 6.2, 6.3, 6.4, and 6.5 (Table 2). These targets are applicable in integrated river basin management, considering the major elements of river basins, including water, ecosystems, socioeconomic development, capacity, and data (Ge et al., 2018). Therefore, future tasks and programmes dealing with Litani River environmental management need to focus on bridging the gap between research and policy and improving water governance, legislation, and institutional capacity. This paper aims at the contextualization of SGD 6 to the Litani River Basin, through the analysis of the current situation and challenges in the basin. It will review the sustainable actions using SDG 6 indicators addressing the protection and restoration of water-related ecosystems, assurance of strong participation of the local population in the elaboration and implementation of mitigation and prevention measures to ensure water and sanitation for all, equitable access to good quality water and sustainable socio-economic development.

Methodology

The source of the Litani River is in the Bekaa Plain, south of Baalbek where it is fed by several springs from the adjacent

Table 2. Main targets and indicators of SDG6.

Target	Indicator (Custodian Agencies)
6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all	6.1.1 Proportion of population using safely managed drinking water services (World Health Organization (WHO)/United Nations Children's Fund (UNICEF))
6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	6.2. la Proportion of population using safely managed sanitation services (WHO/ UNICCF) 6.2.1b Proportion of population using a handwashing facility with soap and water available (WHO/IJNICEF)
6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	6.3.l Proportion of wastewater safely treated WHO/united Nations Human Settlements Programme (UN-Habita/United Nations Statistics Division (LINSD)) 6.3.2 Proportion of bodies of water with good ambient water quality (united Nations Environment Programme/LNSD)
6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water and substantially reduce the number of people suffering from water scarcity	6.4.1 Change in water-use efficiency Dar time (Food and Agriculture Organization of the united Nations (FAO)) 6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources (FAO)
6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate	6.5.1 Degree of integrated water resources management implementation (D—1 00) (united Nations Environment programme) Proportion of transboundary basin area with an operational arrangement for water cooperation (united Nations Educational, Scientific and Cultural Organization (UNESCO)/United Nations Economic Commission for Europe (UNECE))
6.6 By 2020, protect and restore water-related ecosystems, including mountains forests, wetlands, rivers, aquifers and lakes	6.6.1 Change in the extent of water-related ecosystems over time (united Nations Environment Programme/Ramsar Convention)
6.a By 2030, expand international cooperation and capacity building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies	6.a.1 Amount of water- and sanitation-related official development assistance that is part of a government-coordinated spending plan (WHO/United Nations Environment Programme/Organization for Economic Co-operation and Development (OECD))
6.b Support and strengthen the participation of local communities in improving water and sanitation management	6.b.l Proportion of local administrative units with established and operational policies and procedures for participation of Baal communities in water and sanitation management (WHO/United Nations Environment programme/ OECO)

Source: Adapted from United Nations, Department of Economic and Social Affairs (2017).

mountain chains and eventually enters the Mediterranean Sea, North of Tyr (Figure 1). The basin represents diverse topographic and geologic features with mountains, plains, and hills, where it hosts agricultural and human activities. The upper and lower sub-basins are separated by the 220 Mm^3 Qaraoun Lake. While the Lower Litani benefits from multiple springs with good water quality, the Upper Litani witnesses the impact of several sources of contamination including industry, human settlements, and solid and liquid waste disposal affecting water quality and ecosystem services (Shaban, 2014).

This work is based on the results of several projects run in the LRB with the participation of institutions and individuals participating in the contextualization exercise. The early projects in the LRB focused on water management and water allocation for agriculture as well as water quality protection (Shaban & Hamzé, 2018). Several national and international projects have been tackling water pollution and ecosystem management in the LRB since the early 1990s (Table 1). The elaborated studies, researches, and projects are based on scientific concepts where different tools and methods were applied. These scientific outputs were utilized in several implementing processes towards the enhancement of water management in the Litani River Basin. Therefore, several applied development projects (e.g. treatment plants, water conveyance systems, etc.) used these studies, notably in the pollution prevention actions which were recently taken at the national level, and they are largely based on the results of these studies and researches.

These projects characterized the basin and lake, analyzed major problems of water quality, and proposed recommendations for sustainable water use and basin management. The project on protection and sustainable management of soil and groundwater (1997-2003) showed large exploitation at the Bekaa Valley where soils are being intensively cultivated. Intensive agriculture was identified as one of the main sources of pollution affecting soils through the heavy accumulation of nutrients and pesticide residues. Soils of the Bekaa could be considered as a buffer zone regarding trace elements mobility because of its high alkalinity status. However, nitrates and other mobile elements are leached and pollute the soil-groundwater system. Until now, the extension service could not successfully disseminate sustainable use of chemicals and fertilizers despite the pilot introduction of integrated and organic agricultural business. More efforts from the Ministry of Agriculture (MoA), LRA, and farmer's associations are needed to promote good agricultural practices in the basin.

The environmental Master plan for the Litani River and Qaraoun Lake catchment area project (2000) demonstrated at least seven-sewer networks discharge raw untreated wastewater directly to the Litani River or its tributaries, in the northern portion of the basin. Moreover, industrial wastewater is also discharging directly into the river, such as the sugar-beet factory, paper factories, lead recovery plants, limestone crushers, agro-industries, and poultry farms, tanneries, and slaughterhouses. However, until 2019 no measures were practically taken to impose the treatment of industrial and agricultural wastes. The new Administration of LRA is paying more attention to addressing water and environmental issues in the basin, for example, LRA has taken legal actions against the polluters and following these actions directly and through appointed environmental experts.

The USDA water quality in the Litani River and the Qaraoun Lake Forwarded programme: Integrated water and coastal resources project (2003-2005) showed that the Litani River Basin could be better managed to serve the interests of the people of Lebanon. The course of action could be chosen after further investigation and studies. The water of the river is used for irrigation, hydropower, household, and industrial

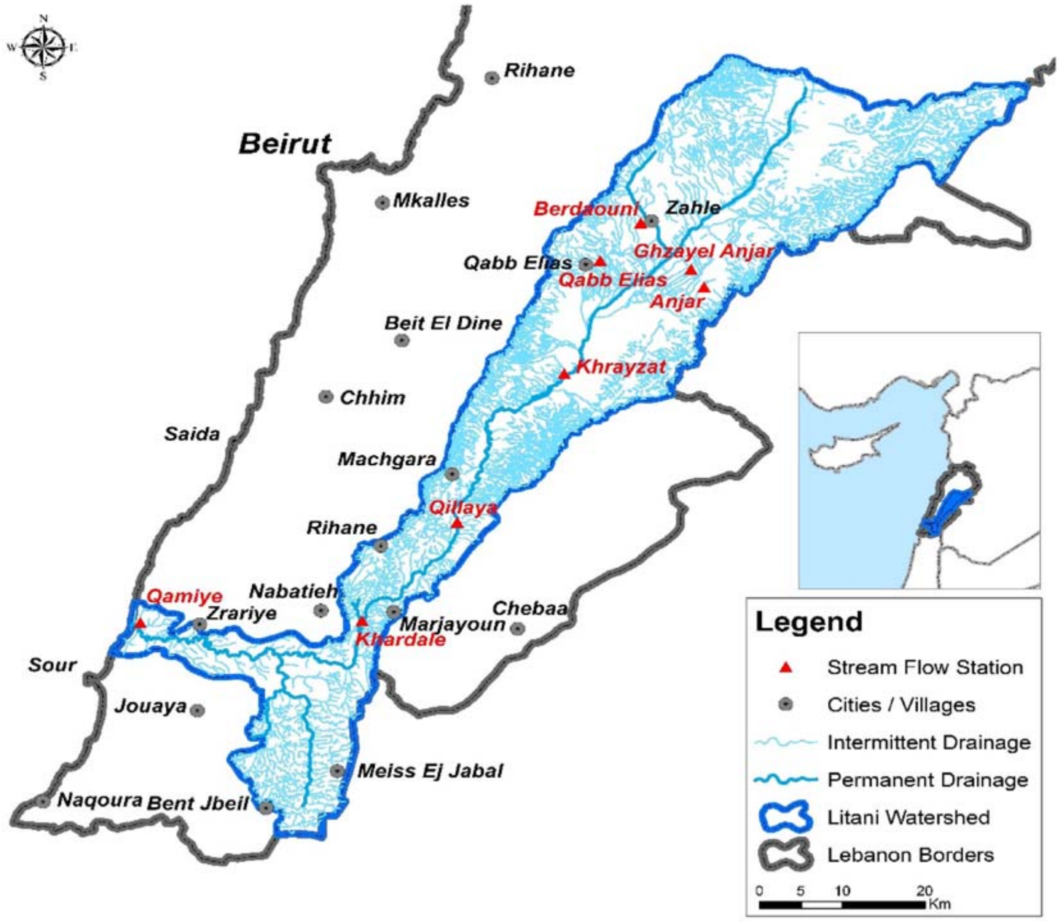

Figure 1. Location of the Lake Quaraoun and Litani basin in the map of Lebanon, East Mediterranean.

uses. It provides services worth between $75 million and $120 million annually. Agriculture is the most important use of water in the Litani Basin. However, irrigation water use efficiency must be improved to be able to save water for other sectors.

The IDRC project towards an ecosystem approach to the sustainable management of the Litani watershed (2004-2007) involved and trained local stakeholders (municipalities, universities, NGOs) in water quality assessment to launch a crowdsource based early warning system. Unfortunately, the weak hierarchy and absence of top-down support failed the sole bottom-up approach. Established by USAID, the Litani water quality management project (2009-2013), supported groundwater measurement but the monitoring system stopped functioning after the project closure due to a lack of staff and funds for maintenance underlying a structural weakness. In any case, the resident population of the Bekaa Valley is aware that the groundwater at the valley is not anymore potable and the river water is not fully suitable for irrigation. Nonetheless, trace elements loaded by irrigation using contaminated water have accumulated in local soils posing an additional problem to the soil-water-food safety nexus.

Some recent and ongoing projects like balancing water stress and human crises (2016) resulted in 3 policy briefs, 2 working papers, and two knowledge-sharing workshops with stakeholders in the area including the Bekaa water establishment. The integrating time-series ET mapping project contributed to the development and deployment of a mobile application (AgSAT) for calculating crop water use for farmers and is producing water use map.

Other recent projects focused on water accounting and water productivity (e.g. water intelligence for Near East-WIN Project). During 2017–2018 a survey was undertaken within the LRB on water accessibility, quality, and management. Besides capacity building, the second phase WIN II (2019-2020) focuses on SDGs application and stakeholder's role and active involvement in water use and protection. The national report submitted to UNOPS/UNWATER on Lebanon's involvement to develop institutional capacity for an integrated approach in SDG6 monitoring in the country focused on the challenges in water harvesting and distribution (Shaban et al., 2018). It also emphasized the lack of adequate sewage treatment facilities, data gaps, and proposed mechanisms for data monitoring.

While most listed studies focused on water quality and quantity, several aspects of water management listed in SDG6 targets (Table 2) have not been adequately considered, for example, limited information is available on access to clean water and safe sanitation, increased water use efficiency and integrated, sustainable water resources management.

Results and discussion

Major water and environmental challenges

More than 800,000 people are living under high water stress in the upper Litani basin (Jaafar et al., 2020). The situation has been exacerbated by the Syrian crisis which caused a massive influx of displaced people into Lebanon, which is hosting the highest per capita number of refugees (3:10). The displacement of this large population created additional challenges for host communities, where infrastructures for providing water and energy services were already over-stressed (Weinthal & Sowers, 2020). In this regard, a new GIS-based updated water balance and water scarcity analysis was suggested at the national and the watershed level in Lebanon by comparing current conditions to no refugee levels (Jaafar et al., 2020). A steady decrease in annual river discharge has been observed for the last thirty years associated with drought trends to short and intensive rainfall events followed by a relatively long dry period (Shaban, 2011). There are still conflicting reports on the precipitation regime in Lebanon. CNRS-L (2015) concluded that the precipitation in Lebanon is under oscillations (i.e. changing rainfall patterns, seasons shifting, etc.) rather than any remarkable changes in the amount. Besides, significant reductions in precipitation are projected for an area covering the Eastern Mediterranean, including Lebanon and Jordan. Here, annual precipitation could decline by more than 100 mm.year^{-1} (Evans, 2009 cited by WB, 2012). Therefore, the main concern of climate change is the expected increased drought and long period with unusually hot weather.

Worldwide, this situation can affect food security with over 820 million undernourished people, corresponding to about one in every nine people (FAO, IFAD, UNICEF, WFP, and WHO, 2019). With the emerging COVID-19 and complicated socio-economic problems, the number of poor people needing food supply and donation has increased further in Lebanon and reached 55% after the 04 August 2020 cataclysmic blast in the marine port (https://www.unescwa.org/news/Lebanon-poverty-2020). Thus, the right to access clean water became as important as access to safe and sufficient food. This is well pronounced in rural areas with a special emphasis on the LRB, which is the breadbasket of the country.

Changes in rainfall patterns and an increase in temperature resulted in enhanced land degradation and increased water demands due to recurrent drought. The deterioration of the river water quality and its related resources has been increased lately resulting in an unfavourable impact on the agricultural sector with resulting socioeconomic issues. There are three major pillars for the existing challenges in the Litani River, related to physical and anthropogenic aspects. These challenges can be summarized as follows:

(1) *The oscillating climatic conditions, in particular the increased temperature (i.e. 1.8 °C) and changing rainfall patterns towards torrential rains causing unaccounted for soil erosion and floods, which in turn reduces the natural recharge rate and result in less green water reserves.*

The changing climate severely influenced Lebanon's water and agricultural sectors (Hamzé et al., 2010). Thus, water discharge has declined in the river between 25-30% over the last four decades (Shaban, 2014). Similar trends are observed for the issuing springs located within the Litani river catchment. Moreover, the groundwater level has dropped more than 10 m in many parts of the basin, while many boreholes dug in shallow groundwater reservoirs have been desiccated. Agricultural and other water needs increased the pressure on renewable water resources. Based on the carbon dioxide concentration in the atmosphere between 1932 and 2007, climate models and statistical analysis, scientists were able to figure out a monthly decrease in rainfall between 10 and 30 mm (Kelley et al., 2015). The major irrigated areas are located in the Bekaa regions with 52% of irrigated lands (FAO, 2019). In its current status of embryonic water accounting and low water productivity, the agricultural sector of Lebanon is not sufficient to ensure food security and sustainability. Thus, Lebanon imports up to 80% of its food needs, notably meat products, wheat, pulses, potato, vegetables, and fruits (https://www.unescwa.org/sites/www.unescwa.org/files/page_attachments/escwa_food_and_nutrition_security_in_lebanon_final_version_high_res_en.pdf).

Lebanon possesses 39% of territory as arable lands and 29% as irrigable land (Byiringiro, 2013). However, the country is land-scarce (700 m^2 capita) and before 2010 water availability was 980 m^3 capita year^{-1} against a water demand of 220m^3 capita year^{-1} (Shaban, 2011), but following the Syrian crisis it currently dropped to less than 700 m^3 capita year^{-1} (Jaafar et. al. 2016). Nevertheless, water supply from the public sector is below 35% of water demand (Shaban, 2011). Water share for agriculture is high (70%), with indications of decrease during the last decade (AQUASTAT, 2020). Total water withdrawal for agriculture is still below the needed requirements to irrigate about 400,000 ha of irrigable lands (Figure 2). Studies using neutron probe and ^{15}N on potato, the second crop by area in Bekaa, showed water use efficiency in fertigation using drip irrigation reaching 80% versus 40% for macro sprinkler irrigation with higher fertilizer N recovery in localized irrigation technique (Darwish et al., 2003). However, more than 60% of lands are still irrigated with traditional techniques with low application efficiency.

(2) *The explosion in population in recent years due to the refugee influx multiplied the problem of pollution which is the major problem in the LRB, including the Qaraoun Reservoir and extends even to groundwater.*

Therefore, the physicochemical and microbiological quality of the water (surface and sub-surface) revealed that contamination is exceeding the normal standards (Mcheik et al., 2018; Nehme & Haidar, 2018). This can be attributed mainly to the lack of environmental controls and the increased aspects of violations of environmental regulations, notably, diversion of non-treated sewage water into the river course in addition to inappropriate solid wastes disposal practices, including dumping near arable lands and watercourses and burning in the open air (Figure 3a).

(3) *Poor agricultural practices with excessive use of fertilizers and chemicals besides the irrigation using non treated*

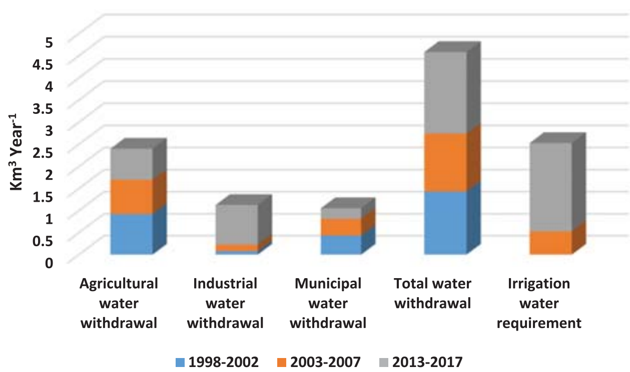

Figure 2. Water use in Lebanon between 1998 and 2017, Km^3 year^{-1} (Source: FAO, 2016).

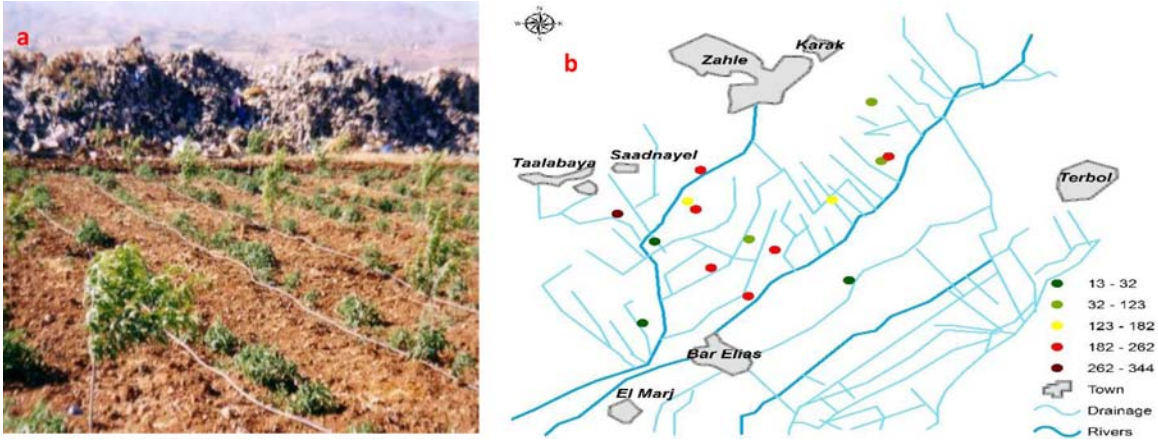

Figure 3. Disposal of solid waste near agricultural fields in Central Bekaa Plain (Photo: T. Darwish). Field inspection of nitrate content in shallow aquifers in Central Bekaa area, Spring 2002 (Source: Darwish et al., 2004).

wastewater have negatively influenced soil and groundwater quality (Figure 3b). Leaching of nitrates from the soil continuum to the shallow water table converted this water to inadequate quality for irrigation and social needs (Darwish et al., 2011; Baydoun et al., 2015). Some trace elements were accumulated in the agricultural soils (Abou Jaoude et al., 2019).

In its current status, the Litani River represents a threat to public health, as long as bacteriological and chemical contamination is not treated or managed, as water pollution propagates to soils, crops (Mcheik et al., 2018), and animals, and represents an obstacle to the socio-economic development and well-being of riparian communities (USAID, 2014). Recently, Hmede et al. (2019) showed evidence of multidrug and colistin (last resort antibiotic) resistance in irrigation water isolated from locations within the Bekaa valley, which could be attributed to colistin use in animal farms. That was the first study to report the persistence of the colistin-resistance carrying the gene (MCR-1) in irrigation water in Lebanon and also the Middle East and North Africa Region (MENA). The MCR-1 gene was also isolated from domestic water and sewage water from refugee camps in the Bekaa (Alhaj & Kassem, 2020), and earlier in pre-harvest poultry from three major farms in Lebanon (Hmede & Kassem, 2018). With solid waste and wastewater management being two major problems in the Bekaa, the microbial water quality of the Litani River is the major threat to food safety and a major cause of water-borne diseases in the country. It was shown to be a threat to water quality in the Eastern Mediterranean, which could also lead to the MCR-1 gene being circulated with the sea currents (Sourenian et al., 2020).

The soil-groundwater contamination with trace elements and nitrates was the subject of several studies including the hazard to human health through dietary intake. The experiments run by the project ‘Protection and sustainable management of the soil and groundwater’ using the chlorine tracer technique in 4 different cropping systems prevailing in the Bekaa Plain (i.e. leaf vegetable monoculture, wheat-potato rotation, fruit trees, and grapevine production) showed the rate of transfer of soluble pollutants from the soil surface to a depth of 65-75 cm occurred during one irrigation season (BGR, CNRS, and ACSAD, 2003).

After one rainfall season, the pick of chlorine disappeared completely from the unsaturated soil zone and joined the shallow water table, which revealed to be less than 2.0 m in some areas of Fayda, near Zahle (Figure 4). Checking the quality of the water table showed relatively high content of both nitrates and trace elements. However, only the relatively deep wells (100-150 m) were well protected from trace elements. The depth of the water table was measured through direct dug-well with fine tube augers reaching 7 m depth and showed a large area of the plain in front of Zahle city to be highly vulnerable to all sources of contamination (Darwish et al., 2008).

Pollution in the river affected the quality of water in the Qaraoun Reservoir, which shows increasing trends towards contamination with harmful effluents ejected and accumulated without prior treatment. In the absence of collective irrigation networks, the practice of irrigating crops with a mixture of non-treated sewage water with seeping drainage water collected either in open earth reservoirs (Figure 5a) or traditional boreholes results in the accumulation of suspended materials from wastewater (i.e. sedimentation) on the soil surface (Figure 5b and c).

The input from one irrigation event with raw municipal water containing industrial emission and domestic wastes was analyzed for trace elements content (Figure 5b) and showed a level of Pb, Cd, Ni, and Cr competing with the permissible level of annual load to arable lands (Table 3) recommended by the German Act on soil protection (1998). The level of N and P in the Qaraoun reservoir is increasing and the development of cyanobacteria became a real problem for aquatic life, swimmers, and animals. During the dry season, the concentration of these cyanobacteria is often above 200 $\mu g.l^{-1}$ (Fadel et al., 2017), much higher than the concentration of 10 $\mu g.l^{-1}$, recommended by the World Health Organization (WHO). These cyanobacteria were shown to produce cyanotoxins that can threaten both human health and the reservoir ecosystem (Fadel et al., 2015).

Irrigation with Qaraoun water containing cyanotoxins can impact the growth and development of irrigated vegetables like tomato and cucumber (Temsah et al., 2016). Moreover, the irrigation of seeds, fruits, and vegetables with water containing cyanotoxins has the potential to carry these toxins over into the food chain, thereby representing a risk to human health (Chen et al., 2010).

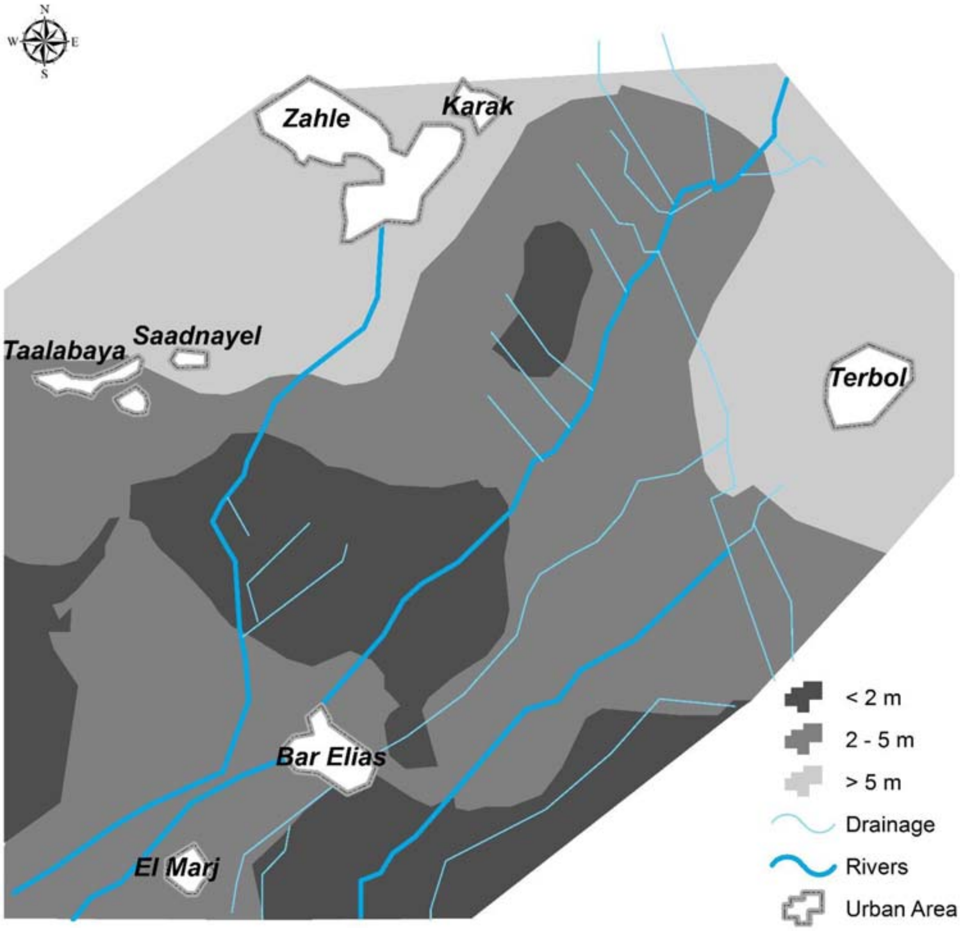

Figure 4. Shallow water table depth in the Central Bekaa Plain of Lebanon reveals high vulnerability to contamination (Source Darwish et al., 2004).

This green–blue biomass appeared in winter 2020, while its distribution in the reservoir used to be restricted to warm summer months (Figure 6). As previously highlighted by Slim et al. (2014), this emerging situation demonstrates the effect of global warming and adaptation of bacteria to moderate winter temperature in Qaraoun Lake (Slim, personal communication). This finding can negatively reflect on the capacity of the reservoir for self-recovery and aquatic biodiversity due to the high BOD level.

Despite the described hazards, laws and regulations are still either absent or not fully implemented, which contributes to increased risks to the environment and public health, as observed from the increase of stomach diseases and cancer on the banks of the Litani River. With 45 people recently diagnosed with the cancer disease in the town of Hawsh (Asharq Al-Awsat, 2018) and 800 cancer cases registered out of 16.000 inhabitants in Bar Elias (The Beirut Report, 2020) a worrying fact and warning reality arises. The social, economic, and environmental damage caused by water and soil/food contamination in the LRB is still not completely assessed. There is a clear need to treat the sewage waters and improve the standards for fertilizer and pesticide import and controlled use to sustain good water, soil, and food quality and protect public health. Moreover, there is a need to strengthening institutional capacity and promoting policies of good governance and good farmer's practices for integrated and sustainable management of the water sector in the country in general and in the LRB in particular.

Figure 5. Irrigation of fruit trees using non treated sewage water, mixed with collected shallow water table (drainage water) in Central Bekaa (a and b). Sediments on soil surface after irrigation using non treated sewage water in Central Bekaa (c).

Table 3. Tolerable annual load of trace elements to agricultural soils and their limit content in sludge.

Elements	Permissible annual Load ($g.ha^{-1}$) *	Applied with one irrigation event using non treated sewage water in Central Bekaa ($mg.kg^{-1}$)**	Limit content in sludge (($mg.kg^{-1}$) dry matter)***
Lead	400	21	800
Cadmium	6	0.28	20
Chrome	300	40	1000
Cupper	360	31	1000
Nickel	100	30	200
Zinc	1200	147	3000

* German Act on soil protection; 1998;
**measured in dried suspended material (Darwish et al., 2004);
***Arrêté du 8 Janvier 1998 du Journal Officiel, France.

Mechanisms for SDG 6 contextualization to LRB

Stakeholders involvement

It is of utmost significance to assure the availability of sufficient data and information on the LRB in the context of the illustrated indicators of SDG-6. This is needed to identify the aspects of the existing problems including their reasons, temporal and spatial dimensions, and the negative consequences on people and society as well. This will be a helpful tool to highlight the most crucial issues and how the indicators of the SDG-6 can apply to these problems wherever they may fit. It also provides first-hand information on the optimal solutions that can be proposed in the context of SDG-6 (Shaban et al., 2018).

For this purpose, defining the stakeholders in the basin is important to cover the technical and socioeconomic factors affecting land degradation and prospect the possible solution of improved water governance and management. Following a bottom-up approach, the players in the water sector are farmers (plant production, animal husbandry), households, industrial clusters (milk, cheese, paper, glass, plastics, tanneries, etc.), decision-makers (employers in water and public sector, Mayor, Director General, etc.), other water users (schools, restaurants, car washing, etc.). A field questionnaire that was conducted focusing on water and sanitation and covering the SDG-6 indicators revealed that the majority of stakeholders refer to institutional constraints (Figure 7), corruption, and lack of governance as the main causes of deterioration in the water sector (Shaban et al., 2018).

There is a need to strengthen national capacities and water users' ability to manage water input into crops in a high seasonal evapotranspiration area like Bekaa, where two-three vegetable seasons are practiced and the irrigation amount can exceed 10,000 $m^3ha^{-1}year^{-1}$. Excess water application and fertilization lead to nitrates leaching in a high amount when farmers use traditional irrigation systems, while a restricted amount of nitrogen loss by leaching is registered when farmers use a drip system (Figure 8). While households and farmers contribute to water contamination, the problem of industrial sources of contamination identified by only 15% of the questioned people poses a question on people and decision-makers' awareness of the amounts and composition of industrial wastes injected in raw conditions into the Litani River. These sources encompass paper factories, hospitals, tanneries, gas stations, ceramic and glass workshops, chicken, and cow farms production.

Figure 6. Green-blue water coloured by cyanobacteria pigment in the reservoir of Quaraoun, collected on February 2020 (Source: LRA, 2020).

Prioritization and monitoring of SDG 6 indicators

Several SDG 6 indicators and targets apply to the LRB, notably the proportion of the population using safely managed drinking water in Bekaa is 68% (337,000 people are connected by water establishment from a total of 495,000 inhabitants). With network efficiency less than 70% (MOE/UNDP/ECODIT, 2011), the safely managed drinking water becomes even less and needs to be improved.

The proportion of safely treated wastewater is still very low and does not exceed 10% in the basin (Table 4). The entire Upper Litani Basin can be considered of low water quality with high coliform and streptococcal content. The LRA produced a map showing a high number of outlets pouring non treated sewage water into the river (Figure 9). A total of 69 villages and cities eject 47 $Mm^{-3}.year^{-1}$ of raw sewage water directly into the Litani River. The Lower Litani represents better ambient water quality due to lower population density, different land use, a favourable hydrogeological regime, and an abundance of springs.

Therefore, an estimated value of 40% was allocated to the overall water use efficiency in the plain. Even though a large water part of the LRB is used for hydropower (100-120 Mm^3) during the winter season, less than 20% of the surface water is used for irrigation at the west Bekaa scheme (2000 ha) and coastal Qasmieh scheme (4000 ha) consuming together 30 Mm^3, 15% of the Qaraoun Reservoir useful capacity of 200 Mm^3. Groundwater is excessively used by the agricultural sector, and then the groundwater level is in continuous drawing down. This means the groundwater recharge rate is far below the pumping intensity.

To improve water supply services, the responsible agencies for the water sector set plans to improved water distribution networks and irrigation schemes. The percent of lands irrigated with groundwater in the basin exceed 95% of the irrigated lands. This is due to the absence of collective irrigation schemes, which are limited to the South Bekaa irrigation scheme (phase 1), located to the north of the Qaraoun reservoir, covering an area of 2000 ha, irrigated with canal 900 m (filed crops and vegetables). Currently, farmers are reluctant to use the contaminated water from the Lake and prefer to use groundwater.

This area will be expanded to the West Bekaa and Central Bekaa to cover an additional 23000 ha with field crops, fruit trees and grape wine. The other currently functional irrigation network is located on the coastal area Qasmieh-Ras El Ein irrigation perimeter providing irrigation water to 4000

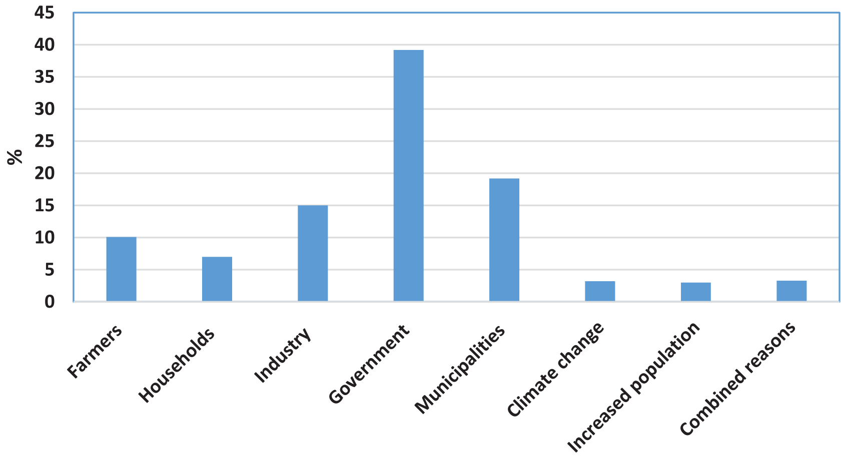

Figure 7. Driving forces of water sector regression in water supply and sanitation services defined by the questioned stakeholders of the Litani River Basin (Source: Shaban et al., 2018).

ha (i.e. fruit trees and vegetables). The under execution Litani Project Level 800 m (phase 2) will convey irrigation water to 30,000 ha in South Lebanon.

Water supply

Groundwater level decline represents a very important indicator, which is caused by rising the need for water pumping, poor water accounting, and water productivity, notably in agricultural practices with reliance on private wells. The planned collective irrigation schemes in South and Central Bekaa can alleviate pressure on excessively pumped groundwater and allow to maintain the environmental flow of the Litani River, which is affected by the drawdown of the groundwater level. Observing the change in groundwater level in Central Bekaa between 2012 and 2016 proved a negative average annual change in storage of the upper Litani basin by 330 mm (roughly 0.9 mm.day^{-1}) (Jaafar et al., 2020). Based on water level drop in the studied monitoring well by 11.7 m over three years, this deficit is equivalent to a depletion of groundwater of 473 Mm^3 year^{-1} over the upper Litani basin.

The reported significant decline in groundwater storage in the upper Litani basin, reaching sharp regression and fluctuation in the range of 12 m (Amacha et al., 2015) can be reversed. Local water governance showed that, after 2014, the water table north of the Qaraoun reservoir rose to the previous level as a result of the closure of individual wells after the establishment of a 900 m canal and provision of pressurized irrigation water directly to the gate.

A recent investigation of the groundwater depth in five monitoring wells in the Upper Litani River Basin (Hackett, 2020) showed a dropdown of groundwater depth in Ammiq and trends of groundwater table rise in Khrayzet (Figure 10). In long term, with the accomplishment of the 900 m canal, which is supposed to provide irrigation water for 25,000 ha, the groundwater level in the Middle LRB

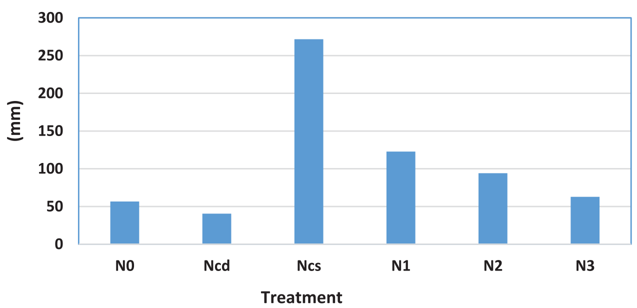

Figure 8. Amount of water leaching (mm) as a function of irrigation technique and nitrogen application (N0-Control drip no nitrogen; Ncd- Control drip nitrogen soil application; Ncs- Control macro sprinklers nitrogen soil application; N1-3- Full Fertigation with nitrogen in N2=Ncs) (Source: Darwish et al., 2003).

Table 4. Contextualization of SDG 6 to the Litani River Basin.

Target	Indicator	Average SDGs implementation by 2019	Source of information
6.1. Drinking Water	6.1.1 Proportion of population using safely managed drinking water services.	37.5%	Ratio of annual yield of legal wells to total well water including illegal in Bekaa; MOE/UNDP/ECODIT, (2011)
6.2. Sanitation and Hygiene	6.2.1 Proportion of population using safely sanitation services.	<20%	Based on LRA map on treatment stations functionality (Figure 7)
6.3. Water Quality and Wastewater	6.3.1 Proportion of wastewater safely treated	10%	LRA
	6.3.2 Proportion of water bodies with good ambient water quality	30%	Lower / Upper Litani basin
6.4. Water Use and Scarcity	6.4.1 Change in water use efficiency over time	40%	Darwish et al. (2003, 2006); Karam et al. (2003)
	6.4.2 Level of water stress	30%	Freshwater withdrawal as a proportion of available freshwater resources
	6.4.2.1 Surface water	15%	Area irrigated with collective irrigation schemes (6000ha)/ total irrigated land in the basin.
	6.4.2.2 Groundwater	20%	Seasonal Pumping/seasonal recharge. Water metres installed only on domestic wells.
6.5. Water Resources Management	6.5.1 Degree of integrated water resources management implementation (0-100)	40%	Shaban et al. (2018)
6.6. Ecosystems	6.6.1 Change in the extent of water-related ecosystems over time	−40%	Author's estimation based on the deterioration of water quality and its impact on ecosystem services.

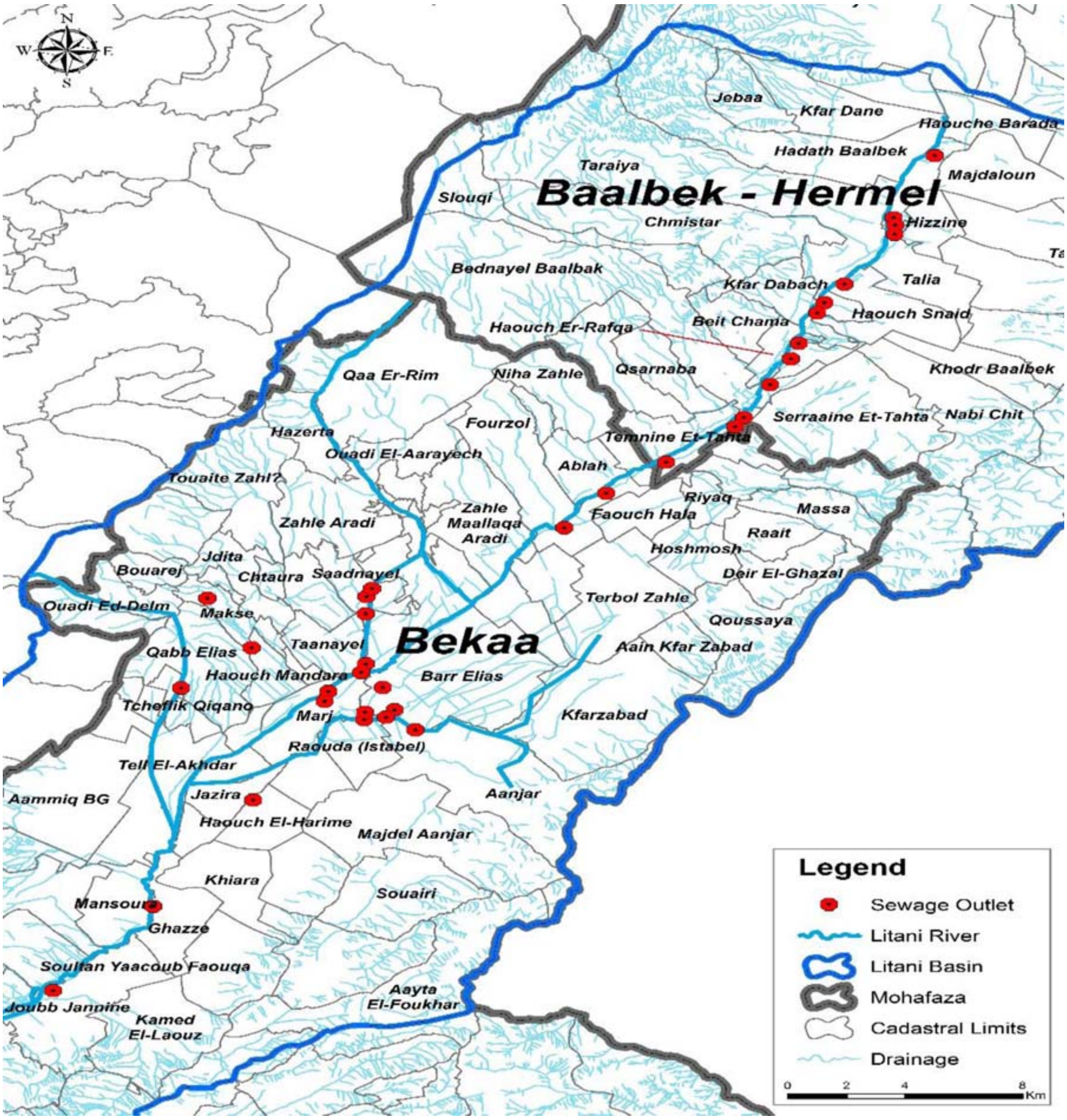

Figure 9. Outlets of non-treated sewage water (spots in red) ejected directly to the Litani River (Source Litani River Authority, 2020)

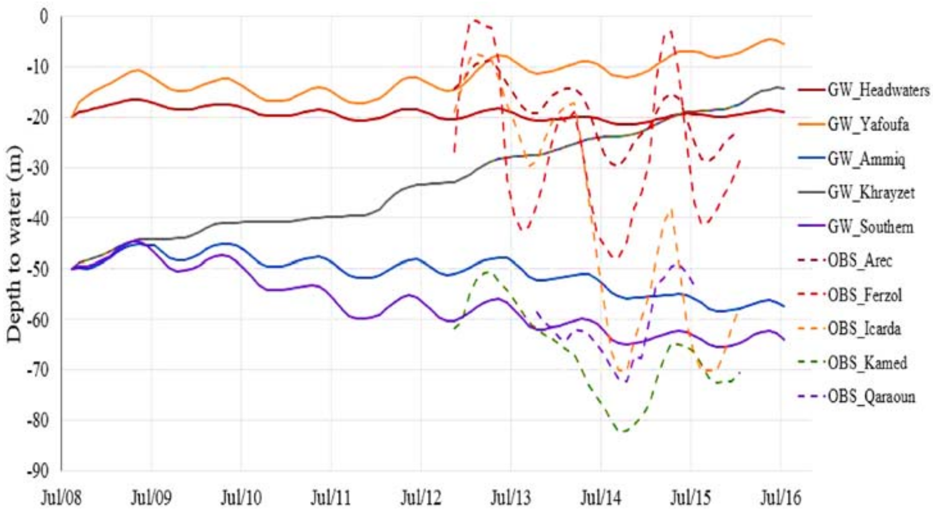

Figure 10. Depth to groundwater (m) in several groundwater nodes vs. the five monitoring wells in the Upper Litani Basin (Source: Hackett, 2020).

can be restored to previous levels considering the recharge from irrigation and renewability of water resources from snowfall amounts in the surrounding region.

However, several policies related to measures must be undertaken like monitoring borehole drilling, fixing water metres, and applying tariffs, encouraging low water demanding crops, supporting higher water productivity besides other economic measures and incentives. According to the State of the Environment Report (MOE/UNDP/ECODIT, 2011), only 26% of the potable water transmission network and 23% of the distribution network were built after the year 2000. The fact that 53% of these networks were constructed more than 30 years ago indicates the poor conditions (i.e. lack of periodical maintenance) and enormous water losses (e.g. leakages) during the water supply process. Therefore, water partitioning has been applied, and then water supplies are only 3 h day^{-1} versus 13 h day^{-1} in the dry and wet season in Beirut and Mount Lebanon respectively. The conditions in the Bekaa Governorate show 10 h day^{-1}, regardless of the season versus 7.6 and 13 h day^{-1} for the whole country.

The state of the Lebanese environment (SoLE, 2011) concluded that:

> Many Lebanese do not rely on the public water supply networks for their drinking water needs. Records show that about 22% of households (and 18% of the population) are not connected to public water supply systems. Yet, over 70% of total household expenditure on the water goes to private suppliers of water, distributed as follows: 35% water gallons (18L containers), 21% water tankers, and 16% small water bottles. The unit price of public water supply ranges from 0.3–0.8 \$.m^{-3} (depending on the region), compared to 3–6 \$.m^{-3} for water tankers and 400–500 \$.m^{-3} for small bottles.

Irrigation water demands for Lebanon were estimated at 810 Mm^3.year^{-1} for the country's total water need of 1.473 Mm^3.year^{-1} (MoEW, 2010), of which 35% represents the share of Bekaa Plain where LRB occupies the largest part. With the increase of water demands and pressure from refugees, a crisis-induced rise in water stress increased the number of people under extremely high water stress from 2.45 to 6.56 million (Jaafar et al., 2020). Network improvements can reduce the population living under extremely high water stress by 10%. Wastewater generation in the Bekaa Plain was 34 Mm^3.year^{-1} for a population of 490,000 persons (WB, 2009). With the population increasing by 1.63% per year, the appropriately treated wastewater could provide up to 5% of total Bekaa Plain irrigation water needs besides the beneficial effect of water quality protection.

Waste management and sanitation

Lack of poorly selected or suitable sites for domestic wastes disposal and the insufficient number of functioning wastewater treatment plants results in chaotic waste disposal (solid and liquid) and the stockpile of uncontrolled landfills. Municipal wastes and wastewater management and disposal influence soil and water resources in and around the places of dumping. Leakage can reach and contaminate surface water, soil, and groundwater reservoirs. Similar deterioration of soil and groundwater quality was attributed to inappropriate solid waste disposal, excess application of fertilizers and pesticides, and the uncontrolled discharge of wastewater to the soil surface (Alfarra & Hamada, 2019).

An additional risk can emerge from pathogens, pharmaceuticals, and personal care products found in wastewater and sludge, which can pose a problem for soil, water, and food quality with resulting in public health and environmental threats (Mahjoub et al., 2020). The applied trace elements from wastewater and solid wastes can cross the Quaternary arable soil surface and reach the water table in Fluvisols (Belaid et al., 2019) (Figure 4, Figure 5a). A similar observation of trace elements accumulation, notably Pb, was observed on the soil surface located in the vicinity of riverbanks in Hama Plain (Syria), irrigated with river water receiving untreated industrial wastes and wastewater (Husein et al., 2019).

Since 2015, Lebanon has been experiencing a waste management problem related to the irregular waste collection (Hilal et al., 2015). Thus, solid wastes are accumulated on streets, neighborhoods, near agricultural and water sites representing unpleasant views and environmental threats. Besides, waste incineration releases toxins and threatens air quality and public health, as it may contribute to enhancing diseases like asthma, cancer, gene deformation, congenital abnormalities. The feasible solutions could be based on integrated solid waste disposal encompassing pollution prevention and sorting at source and resource conservation based on the collection, sorting, recycling, and energy creation, composting to enhance carbon sequestration, waste reduction, and save disposal.

Environmental legislation to govern several water-related issues whether on the exploitation or conservation aspects are still lacking or weakly enforced. Therefore, several controlling measures should be applied such as solid waste sorting and recycling, ensuring the technical basis and human resources for the normal functioning of wastewater plants. For wastewater treatment plants, data show the planning of 11 plants in the Litani basin, of which only two were operational (CDR, 2013; Shaban & Hamzé, 2018). The rest are only planned or under construction.

In many cases, the plant was constructed before the network was completed, and when the network is ready for loading, the discharge was not enough to start the operation of the plant. There is a specific lifestyle for a proportion of the Lebanese population consisting of spending the summer in the native rural areas and winter in the big cities where the business is concentrated. Therefore, the plants cannot meet the excess discharge in summer during the top irrigation water demand. They lack sufficient wastewater flow during the winter season. Planning of these stations should have considered this seasonal variation in water treatment needs and water supply and demands. Another issue is vital when farmers extract water from the broken tubes carrying raw sewage water to the plant to irrigate summer crops under water scarcity and the absence of collective irrigation schemes. Therefore, assessing water demands and providing capacity building on the safe use of treated wastewater in agriculture is a pending task addressed to water managers and water users in the country.

Funding in water supply, irrigation, and water sanitation comes mostly (between 56% and 80%) from foreign sources (WB, 2009). Therefore, the country must rely on its resources, like governmental funding and/or PPP (public-private-partnership) involvement to meet the challenges of water sanitation and save water supply in the country.

Water governance

Based on the dimensions of pollution affecting the Litani basin, the LRA whose initial mandate was to carry water monitoring and irrigation water provision, delegated by the MoEW, became acting like basin authority despite the pending promulgation of the corresponding law by the Lebanese Parliament. The acting power is mostly derived from the political decision to clean the River and the Reservoir undertaken with the World Bank loan to depollute the river. This project became more than necessary following the launching of the construction of the 800 m canal, which will convey water to South Lebanon for domestic and irrigation use.

Currently, the LRA is undertaking all necessary legal and administrative measures to sue and fine polluters from industrial and farming sectors in the upper basin, who are forced to treat their effluents before dumping into the stream. These undertakings will lead to the reduction of pollutants in the LRB. Nevertheless, full reclamation of the River and the Reservoir is still a tedious task that needs political and administrative will and serious follow up by local and central authorities for the monitoring and controlled use.

On top of the LRA mandate, there is a conjunction of tasks carried out by other public and private institutes such as the Bekaa Water Establishment, Ministry of Environment, Council for Development and Reconstruction, and municipalities, which participate in water distribution, wastewater treatment plants design, construction, and functioning. LRA activities are supported by local research centres and universities as well as international and UN organizations carrying studies, measurements, and elaborating monitoring approaches for the Litani River catchment and the Qaraoun Reservoir. These studies and training provided by some projects like the WIN project became a very essential tool in upgrading the capacity of the LRA staff to improve water accounting and water productivity control. The outputs of the FAO open access WAPoR portal, which uses remote sensing technologies to monitor and report on agricultural water productivity, are useful tools enabling the LRA to take the right decision and measures to assess water availability and demands, control water allocation and conserve the river and its tributaries. In this respect, the role is taken by the international entities (e.g. WB, UNDP, FAO, IHE-Delft, etc.) is always appreciated by the Lebanese government, especially these entities are often introducing the needed financial and technical resources.

In general, the institutional framework for the water sector in Lebanon is characterized by numerous players like water-related ministries, regional water establishments, public agencies like Green Plan and LARI, municipalities, and farmers' associations. The first drawback in sustainable water management is the multiple actors involved in the water sector with duplicating instead of complementing mandate (MOE/UNDP/ECODIT, 2011). Players of the water sector in the LRB need to operate in harmony, with strong communication and responsibility, to support the water policy adopted by the MoEW as the leader of the water sector in Lebanon.

In this respect, Lebanon has started joining the activities belonging to SDG 6, aiming to reach the objectives of the SDG Agenda 2030. Therefore, the Lebanese institutes, namely CNRS-L, LRA, LARI, AUB, and the Lebanese Ministry of Energy and Water, are involved. There are continuous communications and joint activities between Lebanon and the international custodians including UN-Water, UN-Environment, FAO, UNICEF, UN-Habitat, UNSD, OECD, UNECE, and WHO. Hence, the Lebanese partners are now involved in preparing and monitoring the baselines for several indicators of the SDG 6. However, numerous steps and measures must be undertaken to secure sustainable water management like:

(A) Decontamination efforts must be completed to help maintain water quality and recover ecosystem functions. With the 900-950 mm precipitation in 2019 and 2020, exceeding the annual average precipitation (600 mm), the river showed trends to self-recovery and the LRA reported the detection of three sensitive fish species to the Qaraoun lake. However, the continuous and recent flow of untreated sewage water made water quality in the lake worse than ever. The LRA succeeded to stop the industrial pollution by imposing the laws, but the yearly flow of 47 Mm^3 of raw wastewater into the river from 69 settlements areas significantly deteriorated water quality. A very high biological oxygen demand and emerging high content of cyanobacteria negatively affected aquatic life and water quality. Therefore, the LRA decided in 2019 to prohibit water use for animals, irrigation, and sport. Fulfilling the technical demands for the well-functioning wastewater treatment plants with completed networks and permanent skilled staff are the prerequisite for the continuous production of additional amount of treated wastewater suitable for the use in agricultural production and meet other ecosystem functions.

(B) Protecting water quality is the prerequisite for the right to access clean water, food security, and food safety. Until the risk from land-based sources of contamination is sustainably solved, the target of the right for clean water must be prioritized to effectively use the 220 Mm^3 of water stored in the Qaraoun lake. This is a stressing need giving the economic drawback in the country, which imports 80% of food consumption and struggles to achieve the minimum of food security. Awareness for food safety is rising and local consumers are more than ever interested in the tracing back of products in search of safe food. Access to clean water is the first lever of a sustainable agricultural economy. This can prevent diseases and further deterioration of soil and water quality and conserve soil-water ecosystem functions. To accomplish this task, the country needs to invest more than 25% in wastewater treatment from the total annual capital expenditure in the water sector of 140 Million US $ (WB, 2009) and increase its contribution to total expenditure, which is mainly foreign fund (MOE/UNDP/ECODIT, 2011).

(C) Increase the efficient use of water. Improving water use efficiency requires the support and use of modern irrigation systems whose higher application efficiency can allow for water-saving and to cope with water scarcity and drought. The country must increase spending in the water sector to develop the irrigation sector. With deteriorated water quality in the collective irrigation scheme, farmers are getting back to activate and exploit the private wells, which were closed for years, with uncontrolled pumping rates. In the absence of water metres, achieving water accounting and sustainable water productivity in the basin is possible only through capacity building of end-users and the use of remote sensing to map crop distribution, monitor water demands, assess actual water use from the estimation of biomass production, and soil moisture to control water abstraction and overuse. Nevertheless, capacity building for water users and farmers on modern irrigation techniques and orienting government subsidies towards the support of localized irrigation systems (drip, mini-sprinklers) are prerequisites for sustainable water use and agricultural production with maximal economic profit and minimal impact on the surrounding environment.

(D) Direct, real-time service to water users on water demands and use to support sustainable water quality monitoring and decision support systems. It is the right time to change the national technical base of water management and modify water allocation and distribution policy. The current water allocation, pricing, and management practices can be converted into a new paradigm based on real-time remote sensing (satellites, drones), internet of things, land-based climatic stations, and soil moisture sensors, to estimate soil moisture content and crop water demands and provide recommendations to farmers. A decision support system (DSS) can be built, whose concept is related to the estimation of needed water amounts depending on measured soil moisture and plant water needs concerning plant stages of growth and production. Under this platform, the right amount of water is distributed to the farm gate, with due consideration of actual ET and soil characteristics for irrigation scheduling. The DSS platform can also target plant health and environmental water quality with real-time remote and land-based monitoring of water quality to launch and support participatory early warning systems based on public-private partnerships, the internet of things, and crowdsourcing to maintain the access to clean water and support food safety. These targets require input from the national remote sensing centre, upgrading the LRA technical capacity, the use of open-source satellite imagery, and algorithms to solve water management issues in Lebanon.

Conclusion

Several administrative, financial, and manmade driving forces affect water quality, water quantity, and sustainable water use in the LRB. The implementation of several SDG6 indicators like the right to safe water, sanitation, and water use efficiency is still at the embryonic stage due to weak governance, and overlapping responsibilities, lack of funding, and political influence. Improved water quality and management can be achieved through effluent treatment and good agricultural practices, supporting healthy water-soil functions and ecosystem services, as well as continuous water supply with appropriate quality. Safe sanitation services (SDG6 indicator 6.2.1) must encompass the whole cycle of sanitation until secondary and tertiary treatment and safe water reuse (indicator 6.3.1), and thus targeting to reach acceptable amount (most needed) of water with good ambient water quality (indicator 6.3.2).

It is imperative to promote sustainable land management targeting improved water governance through water and soil conservation and the application of 5R principles: reduce, reuse, recover, recycle, replenish. Hence, there is a need to improve the technical base and farmer's capacities to manage modern irrigation methods (e.g. choice of suitable crops on suitable soil types, use of soil and water measurement and monitoring techniques, irrigation scheduling, etc.). Coupled with a real-time information sharing platform based on interactive information system about the plot location and borders, soil type, cropping pattern, crop water requirements, water allocation and conversion into water productivity (m^3 ha^{-1} and m^3 ton^{-1} product to sustain value chain) will support increased water use efficiency and better economic returns for sustainable agriculture (Indicator 6.4.1). Achieving this indicator will require policy change to invest in supporting the marginalized small and medium farmers to enable the uptake of technical innovation in water use and management. It is essential to apply water accounting at the decision making and end-users levels to maintain sustainable, quantified water withdrawals and allocation based on crop demands (Indicator 6.4.2).

Strategic planning for integrated and sustainable water resources management (Indicator 6.5.1) will secure pressurized household water and irrigation water at the farm gate through increasing the collective irrigation schemes and alleviating the pressure on groundwater. The current national water strategy in Lebanon needs to mainstream the emerging causative factors, with a special emphasis on changing climate and increased social water demands. Thus, implementing this strategy addressing improved water harvesting and distribution, stable functioning of wastewater plants, the provision of clean drinking water to all population, securing irrigation water with standard quality to all farmers, water allocation under water accounting and water productivity guidelines, will contribute to meet the implementation of SDG 6 targets. The strong governmental policy, sufficient funding, the participation of end-users, and the local population in the elaboration and implementation of mitigation and prevention measures can ensure adequate water sanitation, sustainable water management, and durable development. Performing the contextualization of SDG 6 will create the baseline for the continuous monitoring of measured indicators in the basin.

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