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The Litani River, Lebanon: An Assessment and Current Challenges

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Amin Shaban · Mouin Hamzé
Editors

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Editors
Amin Shaban
Remote Sensıng Center
National Council for Scientific Research
Beirut
Lebanon

Mouin Hamzé
National Council for Scientific Research
Beirut
Lebanon

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Foreword I

"The Litani River, Lebanon: An Assessment and Current Challenges" is a much-awaited publication that confirms the importance of the river as a vital and strategic national public good and the necessity for urgent action to preserve the river that has been termed the "lifeline" of Bekaa and the South of Lebanon, and possibly Beirut as well, with the planned water-conveyance projects. This book clearly affirms the centrality of water for the sustainment of life in terms of drinking, sanitation, health, and food production. It reflects a paradigm shift in the management of the Litani River toward a nexus approach—specifically the formation of a water−energy−food nexus that builds on synergies across sectors rather than the advancement of a single sector at the expense of another—and among stakeholders, i.e., to develop a shared vision and commitment to safeguard the Litani River both in terms of quality and quantity. This approach is central to the 2030 Agenda for Sustainable Development, which was adopted recently by the United Nations General Assembly. The 2030 Agenda, with its 17 sustainable-development goals (SDGs), presents an overarching holistic vision aimed at sustainable development for the first time including the integration of economic, social, and environmental aspects as the key pillars of development. Goal 6 (clean water and sanitation), in particular, and related water goals and targets form a central issue regarding the achievement of an equitable, inclusive, peaceful, and sustained development process wherein universal access to water constitutes an important covenant of a human rights−based approach that underscores the essence and central messages of the 2030 Agenda on Sustainable Development.

Certainly, the international community has reaffirmed its commitment to the right to clean drinking water and adequate sanitation as well as sufficient safe, affordable, and nutritious food. These commitments should guide all concerned stakeholders of the Litani River Basin to address the mounting environmental, social, and economic pressure that could critically sabotage the Litani River Basin and its sustainability beyond repair.

The 2030 Agenda on Sustainable Development presents an integrated and indivisible understanding of development. Its 17 goals, 169 targets, and more than 240 indicators are designed to facilitate countries' and stakeholders' adoption of integrated solutions that are sustainable and inclusive. An approach echoed in this book addresses the management and governance of the Litani River Basin by assuming technical, socio-economic, environmental, and institutional perspectives. Therefore, access to clean water and sanitation is investigated from both quantitative and qualitative aspects. Increased water-use efficiency is also dealt with extensively without neglecting the objectives of protection and restoration of water-related ecosystems. These form the major dimensions of goal no. 6 in the SDGs. Similarly, goal no. 2—regarding zero hunger with the goal to eradicate hunger, achieve complete food security, improved nutrition, and the promotion of sustainable agricultural techniques—is evident in the, and its interlinkages to the water resources (goal no. 6) are adequately presented for the reader. Health linkages (goal no. 3) are tackled under the topic of water quality, specifically the goals of fighting water-borne diseases and decreasing the number of deaths and illnesses caused by water and soil pollution and contamination.

Furthermore, the book corresponds suitably with the priorities of the Economic and Social Commission for Western Asia (ESCWA) and its drive to promote a holistic vision for the effective governance of water resources in the region as presented in its Sixth Water Development Report. It provides an analytical nexus framework that considers the linkages that affect the achievement of water, energy, and food security through the perspective of sustainable development and in relation to the achievement of the 2030 Agenda on Sustainable Development with a view to mitigate the impact of climate change and adaptation to it by ensuring access to water, food, and sustainable energy for everyone in the context of a human-rights approach. This book presents an inclusive perspective of interlinked aspects that are vital for the survival of the sustainability of the Litani River Basin. Only through the inclusion and engagement of all stakeholders, under the spirit of the 2030 Agenda, can the Litani River Basin be brought back to life.

Beirut, Lebanon

Mrs. Roula Majdalani
Director, Sustainable Development and Productivity Division
United Nations Economic and Social Commission
for Western Asia (ESCWA)

Foreword II

Rare are national rivers that raise passions, engender numerous discussions, and arouse desire such as the Litani River has.

The main draining river in Lebanon, the Litani River is the most important of its kind whether considering the hydrological dimensions or the annual volume of water discharge. It also holds a symbolism because it forms the link between the country's interior and the coast.

It has been 100 years since the publication of Albert Naccache's first work on water planning in Lebanon and, more specifically, on the use of Litani River's waters. Illustrious names—such as Ibrahim Abd El-Al, who owes a whole series of studies and fieldworks as well as the realization of the Qaraaoun Project to the river, as well as Selim Lahoud, Maurice Gemayel, and many others—have marked the projects on the Litani River.

Where do we stand today? We have a better understanding thanks to Dr. Mouin Hamzé, Secretary General of the National Council for Scientific Research, CNRS-L, and Dr. Amin Shaban, Director of Research at CNRS-L, who took the initiative to write this book entitled "The Litani River, Lebanon: An Assessment and Current Challenges." This book aims to evaluate and pursue the stages covered since the creation of the National Office of Litani and the construction of the Qaraaoun Reservoir.

In this book, many specialists have assumed this crucial task. The subjects developed encompass a broad spectrum of themes beginning from the historical background and proceeding to the negative pressures to which the Litani River has been subjected regarding various technical and economic aspects. The result is a faithful description of the reality, a thorough reflection pertaining to the issues and challenges that must be tackled, as well as a special focus on the problems that should be solved to achieve the objectives.

I am pleased to note that this document effectively fulfills the mission entrusted to it and highlights the strengths and weaknesses that marked the path of this important natural resource over time. This book will facilitate the revision of the selected implantation as well as the consideration of new implementations for the planning and management of the Litani River's waters. The interference of many actors in the absence of genuine coordination could have a negative impact on the benefits to be derived from the socio-economic development of the Litani River Basin and Lebanon in general.

Integrated management and good governance of the basin appear to be the most suitable alternative to guarantee the quantity and the quality of water required. In this regard, the CNRS-L should be congratulated and thanked for its ingenuity and audacity to approach this problem with the sincerity and earnestness demanded by the current situation. New perspectives are proposed; unprecedented departures are envisaged; and unchartered paths require exploration to ensure the rational and sustainable exploitation of all resources of the Litani River Basin.

Beirut, Lebanon
Dr. Salim Catafago
Former Chief of the Board of Directors of the Litani
Authority, Litani River Authority

Preface

It is a unique feature that a small country like Lebanon is endowed with ten rivers spread across its territory. These sources of surface water are supposed to be the lifeline of Lebanon, and so, ideally, complaints about the water supply should not exist. It is also a common feature that water resources, such as rivers, are geographic localities where people are interested in settling. However, it is a paradox that people in Lebanon are evacuating the settlements near these rivers. One such case is that of the Litani River, the largest of its type in Lebanon, and it is no exaggeration to say that the Litani River has become a channel transporting poison between different villages and cities located in its basin. Along the river course there are tremendous accumulations of solid wastes, sewage and industrial outfalls, as well as an intolerable odour.

Thus, two major aspects of challenges are pronounced in the Litani River Basin. These are the natural challenge, as represented by the changing and variability of climatic conditions, and the anthropogenic challenges as viewed from the negative human interference affecting water quality and quantity. Sadly, these are causing the *Death of a River.*

In the meantime, the number of diseases stemming from the river-water contamination has dramatically increased. and the river has become a network of connected black swamps. It is axiomatic to ask: *Is there still time to treat the grave situation of the Litani River? Who are the polluters? Have they been identified? What actions have the government taken to rescue the inhabitants?*

Since the early 1950s, many studies and projects have been applied to the river and its basin, but no progress has been noticed, and the deterioration has exacerbated year after year. This situation has been attributed to many reasons with a special emphasis on the lack of coordination between the concerned stakeholders.

The Lebanese National Council for Scientific Research (CNRS-L) has taken the initiative to publish this book with the cooperation of several Lebanese scientists, as contributing authors, who have acquired expertise through research, management, and decision making regarding the Litani River. The authors believe that it is time to convert theories and policies into actions and serious implementations to rescue the river and its local inhabitants.

This book, as it is concerned with the river's assessment and challenges, represents a scientifically based research contribution designed to be readable by stakeholders, decision makers, students, academics, and the public.

The book comprises 10 chapters beginning with a general introduction and the history of the river followed by an introduction to its natural and anthropogenic setting. Subsequently, the pollution in the river watercourses and the major reservoir of Qaraaoun are discussed in detail. Thereby challenges to water resources in the Litani River Basin are diagnosed. This is followed by a discussion of the national plan for the river's remediation and then the socioeconomic development of the river. The last chapter concludes with highlights from the previously mentioned chapters.

Appreciation is due to all people and stakeholders who raise the issue of the Litani River every day and struggle to rescue the river and mitigate the worsening aspects of the death of a precious and priceless natural resource. We deeply empathize with the inhabitants of the Litani River Basin who suffer from the negative impacts resulting from the abuse of the river.

We extend our thanks to all authors who have contributed to this book with their valuable input and who gave their best to produce this outstanding work.

Beirut, Lebanon

Amin Shaban
Mouin Hamzé

Contents

Contributors

Iman Abd El Al Ibrahim Abd El Al Foundation for Sustainable Development, Beirut, Lebanon

Nabil Amacha Faculty of Sciences, Lebanese University, Beirut, Lebanon

Yasmina El Amine Isam Fares Institute, American University of Beirut, Beirut, Lebanon

Mohammad Awad National Council for Scientific Research, Beirut, Lebanon

Safaa Baydoun Research Center for Environment and Development, Beirut Arab University, Bekaa, Lebanon

Talal Darwich National Council for Scientific Research, Beirut, Lebanon

Ali Fadel National Center for Remote Sensing, National Council for Scientific Research, Beirut, Lebanon

Ghaleb Faour National Council for Scientific Research, Beirut, Lebanon

Nadim Farajalla Isam Fares Institute, American University of Beirut, Beirut, Lebanon

Chaden Haidar Faculty of Agriculture and Veterinary Sciences, Lebanese University, Beirut, Lebanon

Mouin Hamzé National Council for Scientific Research, Beirut, Lebanon

Ihab Jomaa Department of Irrigation and AgroMeteorology, Lebanese Agriculture Research Institute, Tal Amara, Lebanon

Nada Nehme Faculty of Agriculture and Veterinary Sciences, Lebanese University, Beirut, Lebanon

Amin Shaban National Council for Scientific Research, Beirut, Lebanon

Kamal Slim Lebanese Atomic Energy Commission, National Council for Scientific Research, Beirut, Lebanon

Summary

Different types of water resources—including rivers, springs, wetlands, lakes, and snow and groundwater aquifers—exist in Lebanon. They exist because of the geographic setting of Lebanon, which comprises two mountain ridges facing the Mediterranean Sea, thus creating a climatic barrier that enhances the humidity of the region. Therefore, rivers are the most important water resources in Lebanon because they are spread over the entire country and connect different villages and cities with agricultural lands. The Litani River is a typical example: It is the largest river in Lebanon, where it spans across different topographical and cadastral regions. The Litani River Basin, which constitutes about 20% of Lebanon's area and contributes a substantial amount of water for irrigation, represents about 24% of the total agricultural area of Lebanon.

Many projects have been built on the river. They began in the 1950s when the Qaraaoun Dam was constructed along the primary river course, thus creating a reservoir to store the largest fresh-water body in Lebanon where hydroelectric power was also generated. Later, a master plan was adopted to deliver water from the reservoir to many Lebanese regions even outside of the river basin. Thus, the river and its reservoir remained the major source of water to many Lebanese regions until recently, when the water level in the river sank to its lowest and the quality of the water became badly deteriorated, resulting in many diseases for the local inhabitants. This change also came with many negative consequences in the agricultural, health, socioeconomic, energy, and water sectors not only in the river basin, but also the entire country of Lebanon.

The current situation of the river is worse than ever before. Its impact on the people who live in its surrounding areas have become an intolerable national geo-environmental issue.

Several research studies and field campaigns have been performed to assess the challenges to the river with much attention being paid to the water quality. The latest results—most notably that the chemical and microbiological analyses obtained at different time periods have shown numeric values several times the standard norms—are extremely alarming. This is well-reflected in the predominant diseases prevalent in the regions connected to the river's hydrologic system.

The Lebanese government established many committees and programs that have been implemented along the river course to arrest the development of the problem, and thus debates have been raised lately about the polluters and how to combat continuing pollution in the river. However, the current status is still unacceptable and becoming exacerbated.

This book aims at revealing the background knowledge about the physical characteristics of the river and its basin along with the human impact on water resources and related sectors. In addition, it highlights the principal pollution aspects and their impacts in different localities along the river. Therefore, it will discuss the current status and the existing challenges for the river.

Chapter 1
Introduction

Amin Shaban and Mouin Hamzé

Abstract Litani River, the largest water resource in Lebanon, connects Lebanese regions with different physiographic characteristics, such as mountains and plains, and spans from the interior to the coastal zone of the country. In addition, Litani River occupies the Qaraaoun Reservoir, the largest of its type in Lebanon, with a capacity of about 220 million m^3. The river is an optimal nexus of water, agriculture, and energy. However, it has lately become a geo-environmental issue with certain challenges creating a severe impact on the water quality and quantity. It is a paradox that although several studies, projects, and researches have been conducted on the river and its basin to enhance its status, deterioration was still exacerbated. Recently, a national plan for the Litani River was prepared by the Lebanese government to mitigate the existing physical and anthropogenic stresses on the river water and to reduce its harmful effects on human health. This chapter aims to highlight the principal elements concerning the river and its status. It also introduces the other chapters in this book.

1.1 Location of the Litani River

The territory of Lebanon is considered a regional water divide where water flows from Lebanon through three principal drainage systems, which have catchments extended as follows: (1) from the NE-SW alignment of Mount-Lebanon with a catchment area of 2500 km^2 toward the Mediterranean Sea; (2) from the northern Bekaa Plain, represented by the Al-Assi River, northward and comprising a major tributary of the Orontes River with a catchment area of 25,300 km^2; and (3) from Hermoun Mountain, represented by the Hasbani-Wazzani River, to the south and then constituting a major tributary of the Jordan River with about 8425-km^2 catchment area (Shaban and Hamzé 2017). However, the catchment of Litani River

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A. Shaban (✉) · M. Hamzé
National Council for Scientific Research, P.O. Box 11-8281
Riad El Soleh, 1107, Beirut 2260, Lebanon
e-mail: geoamin@gmail.com

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is separated from these three drainage systems, and thus it represents the junction area for them.

Located in the middle of Lebanon and joining the inner and the coastal zones, the Litani River Basin (LRB) is located between the following geographic coordinates (Fig. 1.1):

33° 06′ 25″N and 34° 04′ 05″N and 35° 14′ 40″E and 36° 22′ 44″E.

It is elaborated in the topographic maps, 1:20.000 in combination with the digital elevation model (DEM), and the hydrological concepts; however, the area of the LRB is 2110 km^2, which is equivalent to about 20% of Lebanon's area, with a perimeter of about 433 km. The length of the primary watercourse of the river is 174 km.

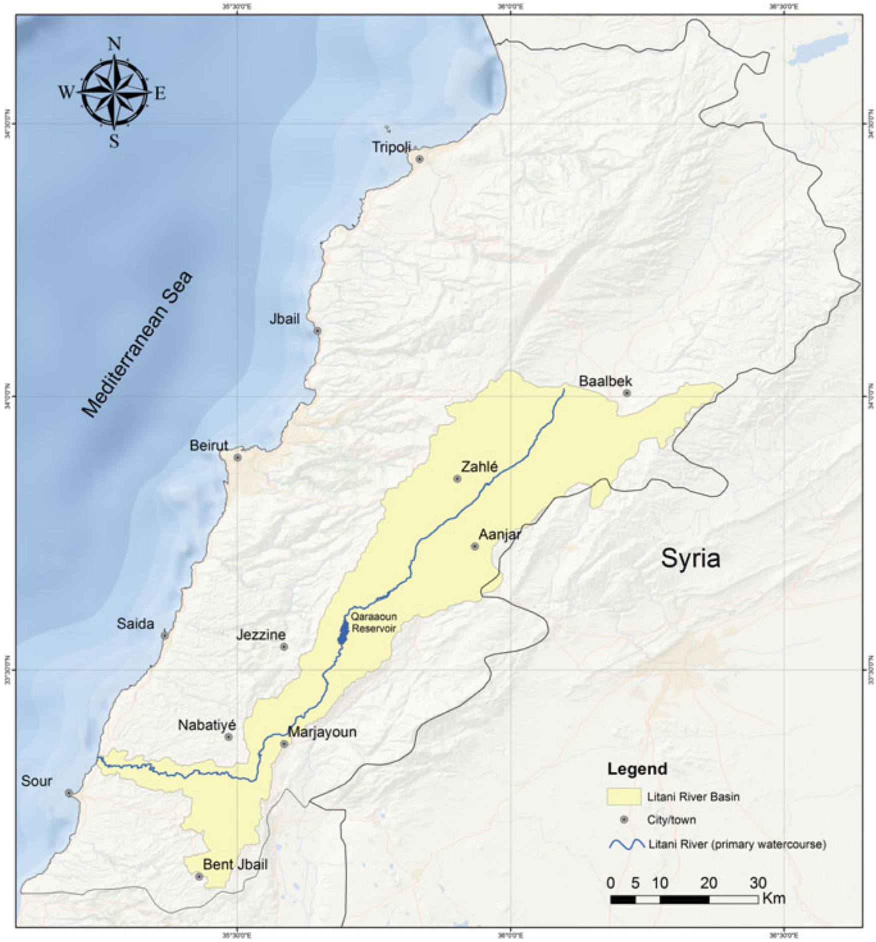

Fig. 1.1 Location of the Litani River and its basin boundary

Four Mohafazats (i.e., administrative governorates) extend within the border of the LRB. These (and their cazas) are as follows: Al-Bekaa (Baalbek, Zahle, Western Bekaa, and Rachaya), Mount-Lebanon (Meten, Alay, Baabda, and Esh-Shouf), Nabatie (Hasbaya, Nabatie, Marjayoun, and Bent Jbeil), and South Lebanon (Saida, Jezzine, and Sour). Within the LRB there are 246 cities, towns, and villages with >60% of them being located in the Bekaa region. These population entities occupy >370,000 people.

According to International Developing Research Center (IDRC), (National Council for Scientific Research-Lebanon) CNRS-L, Litani River Authority (LRA), and Development Studies Association (DSA) (2007), the river crosses through three microclimatic and physiographic regions, namely,

- The semi-arid flood plain including the Bekaa Plain upstream of the Qaraaoun Reservoir.
- The mountainous region between Qaraaoun and the coastal plain, which is generally in the temperate wet Mediterranean slopes subdivided into two zones: the higher slopes (500–800 m) and the lower plateau (300–500 m).
- The hot, humid coastal plain (0–300 m).

1.2 Previous Studies

The greatest number of applied studies and projects has been conducted on the Litani River compared with all other Lebanese rivers because it is a major source for irrigation water and spans over different lands of the country. Primarily, the river water-flow regime, hydrology, hydro-power, and irrigation were studied. Nevertheless, this was not the case after the 1990s after concerns about river water had been diverted to water-quality deterioration and volumetric regression in the discharge from the rivers and its feeding sources.

Studies focusing on the Litani River started in the early 1940s when Abd El Al published a series of documents on the river's hydrology and hydraulics, which acted as first hand-information for many consequent projects undertaken on the river and its feeding sources and tributaries. Therefore, it is not an exaggeration to say that the obtained studies by Abd El Al on the Litani River are a pioneer product on the water sector in Lebanon. They were followed by the establishment of the Qaraaoun Reservoir and its connection with the Kanan Lake and the related hydropower plants and the diverting irrigation channels over a wide portion of land in Lebanon.

However, the greatest number of the recently elaborated studies on the Litani River treat the contamination issue whether exists in the flowing water or in the Qaraaoun Reservoir. In addition, studies exist on the anthropogenic and physical challenges and stresses related to the river and its socioeconomic status.

A survey has been performed on the available studies on the Litani River and its related disciplines as shown in Table 1.1 where 60 representative studies are

Table 1.1 Representative studies obtained on the Litani River

No.	Title	Date	Type	Author(s)	Major topic
1	Series of hydrological studies	1943	Project	Abd-El-Al, I.	Hydraulics and hydrology
2	Possibility of using the hydro-power in Lebanon: application to Litani River	1944	Conference	LCE	Hydro-power
3	Hydrogeologie de la region Litani-Awali	1974	Report	LRA, FAO, UNDP	Hydrogeology
4	The Litani River of Lebanon	1992	Research	Amery, H.	Political
5	Actual irrigation plans of Litani River	1993	Conference	Owaydah, K.	Irrigation
6	The Litani River: geologic and hydrologic study	1993	Conference	Khair et al.	Hydrogeology
7	Field report on the pollution of the Litani waters	1994	Report	Mansour, H.	pollution
8	Pollution of the Litani River and Qaraaoun Lake	1994	Report	Jaafar et al.	Pollution
9	Water quality of Qaraaoun Lake	1995	Report	Jurdi et al.	Pollution
10	Preliminary considerations on the pollution of the Litani River	1995	Report	Abou-Ziad, H.	Pollution
11	Water management plan for the Litani River and Qaraaoun Reservoir	1998	Research	Srour, S.	Management and pollution
12	Modeling of the Litani River water quality in time and space	1999	Thesis	Dandan, A.	Pollution
13	Environmental Master plan for Litani River and Qaraaoun Lake catchment area	2000	Project	MVM konsult AB, MOE	Management and pollution
14	Water quality monitoring of the Litani River	2001	Article	Haddad, N.	Pollution
15	Evaluation of water quality of the Qaraaoun Reservoir, Lebanon: suitability for multi-purposes usage	2002	Article	Jurdi et al.	Pollution
16	Water quality assessment of the Upper Litani River Basin and Lake Qaraaoun	2003	Project	DIA, WESS	Pollution

(continued)

Table 1.1 (continued)

No.	Title	Date	Type	Author(s)	Major topic
17	Water quality in the Litani River and the Qaraaoun Lake. Forwarded program: integrated water and coastal resources	2003	Project	Bureau for Asia and near east	Pollution
18	Identifying sources of pollution in the Qaraaoun Lake	2004	Thesis	Ghoul, Z.	Pollution
19	Use of hydrochemistry and environmental isotopes to evaluate water quality, Litani River, Lebanon	2005	Article	Saadeh et al.	Management and hydrology
20	Restructuring water sector in Lebanon: Litani River authority facing the challenges of good water governance	2005	Conference	Catafago, S.	Management
21	Litani water quality management	2005	Project	USAID/AUB	Pollution
22	Sources and transport mechanism of pollutants in the Qaraaoun Lake	2007	Article	Shaban and Nassif	Pollution
23	Towards an ecosystem approach to the sustainable management of the Litani watershed	2007	Project	CNRS, LRA, DSA, Cadham Hayes	Pollution and ecosystem management
24	Post-conflict assessment (2006) of the Litani River	2007	Report	CNRS	Post-conflict assessment
25	Assessing water quality management options in the Upper Litani Basin, Lebanon, using an integrated GIS-based decision support system	2008	Article	Assaf et al.	Management and pollution
26	Optimal water resources management: case of Lower Litani River, Lebanon	2009	Article	Doummar et al.	Management and pollution
27	Geostatistical assessment of groundwater nitrate contamination with reflection on DRASTIC vulnerability assessment: the case of the Upper Litani Basin, Lebanon	2009	Article	Assaf et al.	Management and pollution

(continued)

Table 1.1 (continued)

No.	Title	Date	Type	Author(s)	Major topic
28	Investigation on macrophyte development in Litani River (Lebanon) subjected to human disturbances	2009	Article	Ismail et al.	Pollution
29	Chemical and environmental isotope investigation on hydrodynamics of a monomictic lake: a case study on Qaraaoun dam, Lebanon	2009	Article	Saadeh et al.	Management and hydrology
30	Litani River flood field survey report	2010	Report	USAID	Flood risk management
31	Water balance report	2010	Report	USAID	Management
32	Wet season water quality survey of the Litani River Basin Project	2011	Project	AUB	Pollution
33	Business plan for combating pollution of the Qaraaoun Lake	2011	Project	ELARD/UNDP	Pollution
34	Physicochemical evaluation of the Upper Litani River Watershed, Lebanon	2012	Article	Saadeh et al.	Pollution
35	An economic assessment of water use and water pollution in the Litani River Basin	2012	Report	USAID	Consumption and Pollution
36	Climate effects on the Litani Basin Watershed in Lebanon	2012	Thesis	Ramadan, H.	Management and hydrology
37	Preliminary assessment of macrophytic community in Qaraaoun Reservoir, Lebanon	2012	Article	Abou-Hamdan et al.	Pollution
38	Sensitivity analysis of climate change impact on the hydrology of the Litani Basin in Lebanon	2013	Article	Ramadan et al.	Hydrology
39	Qaraaoun Reservoir bathymetric survey	2013	Report	USAID	Hydraulics
40	Fault-controlled analysis for dam construction along the Lower Litani River	2013	Report	Shaban, A.	Risk management

(continued)

Table 1.1 (continued)

No.	Title	Date	Type	Author(s)	Major topic
41	Hydrologic assessment of Qaraaoun Reservoir in the view of climate change: recommendations and Legislations	2013	Thesis	Kchour, H.	Hydrology and legislations
42	Groundwater modeling within the upper Litani Basin report	2013	Report	USAID	Groundwater
43	Global warming as a driving factor for cyanobacterial blooms in Lake Qaraaoun, Lebanon	2014	Article	Slim et al.	Pollution
44	Physico-chemical functioning and development of phytoplankton in Qaraaoun Reservoir (Lebanon): application of a hydrodynamic-ecological model	2014	Thesis	Fadel, A.	Management, hydrology and pollution
45	Temporal changes in the Lebanese Litani River: hydrological assessment and recommended actions to handle with the human and global change impacts	2014	Article	Nassif et al.	Hydrological Assessment
46	Monitoring the trophic state and phycocyanin pigment of Qaraaoun Reservoir, Lebanon	2014	Article	Fadel et al.	Pollution
47	Analysis of long-term fluctuations in stream flow time series: an application to Litani River, Lebanon	2014	Article	Shaban et al.	Hydrology
48	First assessment of the ecological status of Qaraaoun Reservoir, Lebanon	2014	Article	Fadel et al.	Pollution
49	The distribution of heavy metals in the Lower River Basin, Lebanon	2014	Article	Nehme et al.	Pollution
50	Évaluation de la qualité de l’eau du bassin inférieur de la rivière du Litani, Liban: approche environnementale	2014	Thesis	Nehme, N.	Pollution

(continued)

Table 1.1 (continued)

No.	Title	Date	Type	Author(s)	Major topic
51	Évaluation de la qualité de l'eau du bassin supérieur de la rivière du Litani, Liban: approche hydrogéochimique	2014	Thesis	Haidar, C.	Pollution
52	Sources and levels of metals in the Upper Litani Basin Soils: Lebanon	2014	Article	Korfali et al.	Pollution
53	Study of physicochemical properties of colloidal sediments of Litani River in Lebanon	2014	Article	Diab et al.	Pollution
54	Spatial-temporal characterization of water quality indicators of the open irrigation canal 900 of Qaraaoun Reservoir, Lebanon	2015	Article	Amasha et al.	Pollution
55	Implantation des échantillonneurs passifs pour le suivi des pesticides dans les milieux aquatiques libanais	2015	Thesis	Al Ashi, A.	Pollution
56	Environmental factors associated with phytoplankton succession in a Mediterranean reservoir with a highly fluctuating water level	2015	Article	Fadel et al.	Pollution
57	Hydrologic Assessment of Litani River Basin in the view of climatic change	2015	Thesis	Daher, M.	Hydrology and climate
58	Spatial and temporal assessment of metal pollution in the sediments of the Qaraaoun Reservoir, Lebanon	2016	Article	Wazne et al.	Pollution
59	Assessment of the trophic state and chlorophyll-a concentrations using Landsat OLI in Qaraaoun Reservoir, Lebanon	2016	Article	Fadel et al.	Pollution
60	Sustainable land management in the Qaraaoun catchment	On-going	Project	UNDP, GEF, MoE	Land management

identified. The table shows that about 80% of the studies were conducted after 2000, and about two thirds of these studies focus on the issue of pollution and whether it is in the river water or in the Qaraaoun Reservoir. In addition, there is an obvious concern from academics on the Litani River, and hence, two thirds of the surveyed studies have also been elaborated upon by researchers and students (e.g., publications, master's theses, and doctoral dissertations, etc.). Moreover, the greatest number of applied research projects were carried out/or supported by international agencies.

In fact, funds provided by the Lebanese water sectors to conduct these studies and projects on the Litani River are few and can be considered negligible when compared with those introduced by the international agencies, especially the World Bank, USAID.

Although the elaborated studies highlight the problems of proposed solutions to enhance the river's status, there has been no remarkable improvement in the river and its basin. This can be attributed to the lack of coordination between the different institutes and stakeholders concerned with the water resources in Lebanon as well as the lack of government's attention to these studies.

1.3 Significance of the Litani River

Due to its geographic location, notably, its extent from the interior to the coastal region and then crossing over diverse topographic surfaces with a miscellany of human settlements, the Litani River has always been considered a principal component in the socioeconomic development of Lebanon. The significance of the Litani River is not limited to the basin where it flows into but rather where it extends outbound of its catchment area. Therefore, the Litani River provides water in channels over several hundreds of kilometers in and out of its basin where it irrigates large agricultural lands. The river is also a major source of energy where electricity generation from the river covers a large part of the Lebanese territory, especially when demand for energy becomes competitive. Therefore, the Litani River, which occupies about 9% of the Lebanese population, plays a major role in the development of Lebanon. This can be summarized as follows:

1. The river contributes to the irrigation system for thousands of hectares of farmland. It is also believed that the river contributes to the water needs of close to a million people and also secures wetlands, a major reservoir, and the watershed ecosystem including its soil and forests (IDRC, CNRS, LRA, and DSA 2007). This is well-reflected on food security and the conservation of the natural resources of the country.
2. The agricultural sector in the LRB is mainly governed by the Litani water, and thus 31% of the income within the basin comes from agriculture where 6% (of the 370,000 inhabitants) work in the agricultural sector. This contributes to the majority of income.

3. The running water in the river is connected to three electricity plants: the Qaraaoun, Markaba, and Al-Awali stations. They generate electrical energy averaging about 190 megawatts, which is equivalent to 10–12% of Lebanon's electricity needs.
4. The volume of water discharged from the basin is equivalent to 24% of the net rainfall received by the entire Lebanese territories. This quantity represents >40% of the total amount of running water in the internal rivers (LRA 2014).
5. Many distinguished and water-related features belong to the LRB. This includes the mountain crests, which are covered by snow for several months over the year. In addition, the river basin occupies the largest artificial lake in Lebanon, the Qaraaoun Reservoir, which has a capacity of about 220 million m^3. In addition, wetlands of different dimension exist in the LRB with the two most well-known ones being Ammiq and Kfar Zabad.

1.4 Challenges on the Litani River

It is not an exaggeration to say that the Litani River is subjected to one of the most severe geo-environmental problems not only on a national level but also on an international level. The volume of water is affected badly and its quality even more severely. Hence, encroachments on the river are everywhere including its tributaries and flood plains, the Qaraaoun Reservoir, as well as the groundwater, the water body that feeds and is fed from the river.

The existing challenges on the Litani River have been exacerbating since the last two decades as a chaotic distribution of human activities take place in the context of total lack of any control and legislation to mitigate or even reduce the unfavorable impact. Therefore, the inallenges on the Litani River compose a typical example for those on the entire Lebanon country where all water resources are under stress.

Several complaints about the reasons behind the unfavorable status in the water sector in Lebanon. Due to a lack of knowledge and misunderstanding, many people attribute this to the physical conditions with a special emphasis on the changing climatic conditions and negligence related to human interference and mismanagement of the water sector.

Several alarming challenges occur on the water resources of Lebanon. These are either physical (natural) or anthropogenic (man-made) in nature. Both aspects of the challenges negatively influence the volume and quality of the Litani River system. Combined with these challenges, water management is also at a weak level regarding stablisation of the current situation in the water sector. This is attributed to many political issues acting on Lebanon and the region as a whole. In addition, adaptation measures to conserve water and to equilibrate water demand/supply are still inefficient.

1. Physical challenges: These are related to the natural setting from which water is demanded. If this setting is not favorable for the water regime or for storage, a physical challenge on water occurs (Shaban 2014). In the LRB, the existing physical challenges can be summarized as follows:
   - The existing climatic variability with a special focus on the torrential rainfall regime and the resulting low infiltration rate. In addition, the increased temperature by about 1.8 °C created an increased water demand, notably for irrigation purposes (Shaban 2011). This accelerates the melting rate of the snow, which has doubled lately due to the increased temperature and sunlight radiation resulting in faster stream flow (Shaban et al. 2014).
   - The geomorphology of the LRB, as an elongated catchment, makes it lack water-flow uniformity from the upstream to the confluences and then the outlet, which often reduces the infiltration rate and enhances flooding.
   - A very gentle slope occurs in the Bekaa Plain, comprising the Upper Litani Sub-basin, resulting in slow stream-flow energy. This in turn buys time for evaporation processes as well as for sediments and pollutants to settle.
   - The existence of karstification often results in groundwater loss in deep/undefined rock stratums, as in the case of Mount-Lebanon and Anti-Lebanon chains, which confine the largest part of the Litani River. Moreover, the considerable number of karstic springs results in fast water discharge from these springs, which is accompanied by less exploitation of these resources.
   - The existence of fault systems with several sets and aspects adds a negative role to water loss through these faults, and the resulting water seeps into undefined and very deep aquifers.

2. Anthropogenic challenges: These represent the negative impact of human interference on water resources compared with the physical challenges. In addition, the anthropogenic challenges can be controlled or regulated, which is not always the case for the physical challenges.

In the LRB, the challenges on water resources are tremendous, which severely influence the general status of the river. In addition, these challenges are being dramatically exacerbated without any concurrent mitigation. They can be summarized as follows:

- Pollution is the major problem in the LRB. This includes the river water, water in the Qaraaoun Reservoir, and groundwater. In this respect, three chapters in this book discuss these aspects of pollution. However, the microbiological and chemical analyses of the river water (surface and sub-surface), which was performed several years ago, show that contamination is doubly exceeding the normal standards. Results on the water analysis from the river tributary of the reservoir of Qaraaoun and from the groundwater are discussed in Chaps. 4–6 in this book. Hence, the reason behind this severe condition is the lack of control and the increased aspects of violations, notably, in delivering sewages, including liquid and solid wastes disposal, into the river course. Moreover, the uncontrolled use of fertilizers in agriculture negatively affects the water quality, especially that of the groundwater (Darwich et al. 2011; Baydoun et al. 2015).

- Increased population is well pronounced in Lebanon and adds to the challenges regarding the different socioeconomic elements including the water sector. This also affects water supply and demand as well as food security in the LRB. Hence, the annual population increase in Lebanon fluctuates between 0.20% and 4.18% and stands at 1.70% (UN 2012). The greatest population increase is often reported in the rural areas, like that of the LRB, which can be estimated at 2.6%. In this case, an annual increase of 9000 people in the LRB can be estimated. If the annual water demand (220 m^3/capita/y) is considered, then it amounts to 2 million m^3 water that is additionally needed every year.

  This is not the only aspect of increased water demand. There are also the increased new requirements for water, which have become a new aspect of water consumption including water not accounted for water as well as virtual water.

- Waste disposal is a major problem faced by Lebanon. This is attributed to many factors with politics being a major one. Therefore, the lack of favorable sites to dispose of wastes results in a chaotic distribution of waste disposal (liquid and solid) and landfills of different dimensions. This status affects water resources where these disposals are dumped, and they reach the groundwater reservoirs as well.
- Lack of legal controls and environmental legislations to govern several water-related issues whether on the exploitation or conservation aspects. Therefore, several controls should be applied such as monitoring borehole drilling, fixing water meters, and applying tariffs and other economic policies.

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Chapter 2
Historical Background on the Litani River

Iman Abd El Al

Abstract This chapter traces the emergence and interventions of the Litani River Authority (LRA) as the main agent of development of the Litani River. Notwithstanding the numerous problems that the LRA faces today—including the unclear division of responsibilities in the sector, administrative weaknesses and a long list of shortcomings it has in common with the Lebanese administration—it remains an institution with a long history, a vision, and the potential to address the ecological crises of the Litani River. After a brief overview of the history of LRA, this chapter lays out a broad framework for action that should allow the LRA to step up to the developmental challenges faced in the Litani River Basin (LRB), and Lebanon in general, as well as overcome its own administrative shortcomings to improve its efficiency.

2.1 General Overview

Ibrahim Abd El Al was a prominent Lebanese engineer whose ideas, works, and studies in the realm of water resources continue to be influential even today. He graduated from the Faculty of Engineering at St. Joseph University in Lebanon and went on to specialize in Electrical Engineering at SUPELEC, Paris, and in Hydraulics at the University of Grenoble, France. His research in the water sector and his developmental approach made an important contribution to the Lebanese state building project and led to his appointment, in 1955, as the Director General for Water and Electrical Affairs in the Ministry.

Throughout his career, Abd El Al focused on water resources in the Arab region and in Lebanon. He is credited for many accomplishments in the field of water management. His approach to research and projects in the 1930s presaged what is today called “integrated water-resources management.”

I. Abd El Al (✉)
Ibrahim Abd El Al Foundation for Sustainable Development, Beirut, Lebanon
e-mail: abdelal@cyberia.net.lb

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As the basis for his work as well as to ensure accurate data, he established and supervised the publishing of the climatological bulletin, equipped the Lebanese rivers with monitoring stations, published pluviometric maps on a yearly basis, and established, with the cooperation of French experts, geological maps.

His practice was guided by a large planning vision for potable water, irrigation, and hydro-power generation. He executed two pilot projects for wastewater plants, three projects concerning artificial ponds for irrigation, and one pilot project for artificial groundwater recharge.

He also played a major role defending Lebanon's water rights, especially with regard to the LRB. He conducted, as a personal initiative, a scientific study on the river basin, which was carried out during a span of 15 years and culminated in his 1948 publication entitled, "Le Litani: Etude hydrologique." He supervised the technical studies of the American experts who were appointed to execute the Litani project and succeeded in getting financing from the World Bank for this national project. He also supervised the American experts' studies on the Lebanese rivers.

He played a strong advocate and defender of Lebanon's rights on the Hasbani-Wazzani River, the source of the Jordan River, in the framework of the Johnston Plan, by establishing a holistic and comprehensive report defining the needs and potential projects on this river for the socio-economic growth of Lebanon.

Presciently Abd El Al wrote in the 1930s what still holds true today: "The water issue is vital for the Middle Eastern countries. The future of these countries depends on the rational use of their water resources."

2.2 Litani River Basin (LRB)

The Litani River Basin (LRB) of 2110 km^2 is the largest watershed in Lebanon and equals about 20% of the total Lebanese territory.

The Litani River runs in Lebanon, along 174 km, and has 60 km of tributaries. The basin encompasses a variety of climates ranging from coastal subtropical to dry continental. It comprises 263 villages that are part of 12 districts in 4 governorates. Water flowing in the Litani River equals about 30% of the water running in all Lebanese rivers.

Two natural wetlands and one reserve lie in the Litani River watershed, which are as follows:

- KfarZabad (60 ha) is a mixture of marshland, constant springs, riparian woodland, and pine woodlands.
- Ammiq (280 ha) lies in one of the most important bird migration routes in the world where <250 species of birds have been recorded. Ammiq is on the list of World Natural Reserves.
- Al Shouf Cedar Nature Reserve (55,000 ha) is the reserve whose eastern part falls within the LRB.

Elaborated and reliable data related to underground water in the Litani watershed is yet unavailable. The aquifers can be summarized in three important groups, which are as follows:

- The eastern slope of the western chain (Mont-Lebanon): The nature of the rocks constituting the mentioned chain is limestone karsts. These rocks permit water infiltration in deep springs that exist along the Yammouneh fault. In LRB, the main springs are Qaa El Rim, Qab Elias, Khrayzat, Mashghara, and Ghalleh (from north to south).
- The western slope of the Eastern chain (Anti-Lebanon): It has the same characteristics regarding the rocks' nature and water infiltration. In LRB, the main springs are Al-Oliek, Chamsine, and Anjar.
- The middle region of the Bekaa valley: The most important spring is Ain Ez-Zarqa.

The LRB aquifers have no connection with the surrounding basins, notably, the Al-Assi and Hasbani-Wazzani basins. The intercalations of marls in the dolomites and dolomitic limestones of the Cenomanian, for instance, play an important role in separating the Litani basin aquifer (Anti-Lebanon, aquifer no. 3) and the Hasbani-Wazzani basin.

Water projects implemented by the Litani River Authority cover 40% of the Lebanese territory. It is responsible for 77,000 ha of current, ongoing, and proposed irrigation schemes as well as tourism and domestic water.

The Litani is also an important source of hydro-electric power generation providing about 10% of national energy production as environmentally clean hydro-power.

2.3 Litani River Authority (LRA)

2.3.1 Historical Background

Few irrigation projects existed before 1943 and during the French Mandate, except the studies between 1931 and 1940, which were conducted for irrigation of 11,000 ha in the Bekaa Valley.

After Lebanon's independence in 1943, the Kasmieh irrigation project was implemented with the help of the Alliance Forces.

In 1948, several studies were published concerning the economic and infrastructural development of Lebanon. They are as follows:

- A study by the British foundation Alexandre Gibb (1946).
- A study by engineer Joseph Najjar on the National Economic Equipment and the program of large infrastructures for Lebanon, in which he submitted proposals on the hydro-electrical equipment from Lebanese rivers including the Litani River. The main outcome of this study was to establish authority with

public and private participation with the mandate to implement irrigation and hydro-power projects in the country.
- A hydrological study by engineer Ibrahim Abd El Al on the Litani River, in which he presented the potential of the river for irrigation and hydro-electrical installations.

In 1951, engineer Albert Naccache published the Master Plan for Water in Lebanon. Moreover, a delegation of experts from the US Bureau of Reclamation, known as the "Point 4," was sent to Lebanon.

In 1954, the Point 4 submitted a report on Lebanon's needs for energy until 1980 with fully detailed annexes for the implementation of the projects related to this target. In additionally, a World Bank delegation came to Lebanon to study the implementation of projects on the Litani River. In the same year, a synthesis report was published gathering the Point 4, the World Bank, and the hydrological study be engineer Ibrahim Abd El Al of the Litani River.

The government prepared a draft law to establish a joint public–private company with the mandate to execute all energy, irrigation, and domestic water in the country as was proposed in the report by engineer Joseph Najjar's mentioned previously. The Lebanese parliament amended this law by issuing a new law prioritizing projects on the Litani River and then establishing the National Master Plan including the related studies and research.

In 1955, the Litani River Authority (LRA) was officially established. Here, the role of Abd El Al in issuing this law is worth mentioning. After studying the LRB for 15 years and establishing the data, the guidelines, and the plans and major infrastructures to use every drop of the river's water, mainly through multi-purpose reservoirs, Abd El Al pursued the idea of prioritizing the Litani projects, before establishing the National Water Master Plan, stressing the socio-economic benefits for the country and the political and strategic importance of the Litani River for Lebanon. Abd El Al (the Director General of Water and Energy in the Ministry) was also a member of the committee that visited the US to solicit a loan from the World Bank related to the implementation of Litani River projects. This visit culminated in getting the loan for LRA in 1955. This loan also had a strategic meaning for Lebanon that the US government approved. It supported the implementation of Litani River projects as studies on a national river in the country. Abd El Al believed that by implementing the first phase of Litani River projects (e.g., hydropower), LRA would be able to pay back the World Bank's loan and finance the second phase of the projects (i.e., irrigation and domestic water).

2.3.2 Difficulties in Implementing the Litani River

Notwithstanding the importance given to potable water and irrigation projects, complementing them with hydro-power project development faced numerous challenges. Their implementation encountered some technical constraints requiring amendments in building the Qaraaoun Reservoir along with challenges in constructing the Markaba-Jezzine-Al-Awali tunnel (17 km). Many political constraints —such as the turmoil of 1958 and the increasingly unstable militarized situation in the south of Lebanon, the civil war until 1990 including the Israeli invasion in 1982, and the occupation of southern Lebanon until 2000—were present.

- These events delayed the construction of many projects until 2000 when the LRA began negotiations to implement the South Lebanon Irrigation project (otherwise known as the "Canal 800" because the project starts at an elevation of 800 m) on the Litani River. It should be noted that three hydropower plants with a capacity of 190 mw represented 50% of the total electricity production in the country (1969–1973). Now, with the increase of production capacity, they account for 8% of total production.

2.4 Mandate of LRA

The Litani River Authority is responsible for executing the Litani River Master Plan for irrigation, drainage, and domestic-water supply production, managing the main structures (reservoirs, conveyers, tunnels, etc.), and performing hydraulic measurements on all Lebanese rivers as well as studying and executing plans of different mountain lakes (outside the LRB) such as Kawachra in Akkar, Kfar Houna in Jezzine, and others. Other responsibilities include implementation of technical land surveys and studies on reservoirs. The law reforming the water administration, law 221 from May 2000, further added the management of existing irrigation schemes in south Bekaa and south Lebanon. In 2006, the LRA created an internal water-quality department and launched a water-quality awareness program for local communities.

2.5 Projects and Their Implementation

2.5.1 Qaraaoun Reservoir and Reservoir (Fig. 2.1)

In 1958, construction on the reservoir was started by a company from Yugoslavia. The works stopped in 1959 due to political instability and technical problems. A delegation of French experts from Electricité de France (EDF) came to Lebanon to help the LRA solve the technical issues.

Reservoir Characteristics:

Building material: rocks + cement waterproof layer
Total length: 1090 m
Height (from ground level): 62 m
Altitude (water level surface): 858 m

Fig. 2.1 Dam side of the Qaraaoun Reservoir as observed in winter 2017

Storage capacity: 220 million m^3 (static)
Area: 12.3 km^2
Width at top: 6 m
Width at bottom: 162 m
Concrete mask area: 50,000 m^2.

2.5.2 Hydropower Plants

Ibrahim Abd El Al power plant and Qaraaoun Tunnel

Located 6400 m from the Qaraaoun Reservoir, with a 200-m waterfall, the water is carried through an underground tunnel at the western bank of the river and is connected with the power plant by a steel pressurized pipe. Its maximum flow is 22 m^3/s. The power production capacity is 34 MW.

The power plant is built inside a rocky mountain. The power plant was inaugurated in 1962.

Paul Arcache Power Plant and Al-Awali Tunnel:

The plant is located on the Bisri river basin at an elevation of 22,850 m with a 400-m waterfall. It receives water from the Ibrahim Abd El Al power plant (eau turbinée), the Ain Ez-Zarqa spring from precipitation during winter, and from other springs inside the tunnel. The tunnel length is 17 km, which runs through the Niha mountain chain and ending in the Kanan artificial lake at a 610-m elevation. Its flow is 23 m^3/s. The capacity is 108 MW. It was inaugurated in 1965.

Charles Hélou Power Plant in Joun

The plant is located on the right side of Al-Awali River at an elevation of 32 m with a 194-m waterfall. It takes water from the Paul Arcache power plant, and from the Bisri River, through a 6800-m tunnel. Its maximum flow is 33 m^3/s. The capacity is 48 MW. It was inaugurated in 1968.

The energy from these power plants requires high-voltage lines for circulation and distribution on the national electrical grid. For this purpose, the LRA established high-voltage lines (66 KVA) to link the hydro-power plants together and feed production into the national electrical network. Moreover, the LRA ensured human technical resources for the maintenance and operation of the reservoir and the three power plants with the assistance of EDF. Electrical production depends on the annual precipitation in the river basin. The LRA uses annually 70% of the water from the lake for irrigation and hydropower, and the remainder (60 million m^3) remains in storage through the dry season.

It is worth noting that the Litani power plants, as renewable energy sources, are environment friendly and contribute to the national economy, especially during years with high precipitation, by supplying substitute renewable energy to the National Electric Utility (EDL), thus allowing the latter to economize its hard-currency need for imported fuel oil for the thermal power plants. The LRA sells the total electrical production from the three hydro-power plants to EDL at a very low price (41 L.L./KW/h).

2.6 Irrigation Projects

Between 1951 and 1954, and based on Abd El Al guidelines and supervision, Point 4 experts established the Irrigation Master Plan for the Litani River. In the 1960s, the LRA began to prepare preliminary studies for the Development Project of South Lebanon between 800- and 500-m elevation.

In the 1970s, the LRA launched the Hydro Agricultural Development Project of South Lebanon (35,000 ha) in collaboration with UNDP and FAO. In 1974, the LRA collaborated with Canal de Provence to establish studies for the infrastructures related to this project. In 1977, the FAO submitted the complete technical report related to the Water and Agricultural Development Project for South Lebanon.

LRA Potable and Irrigation Master Plan (Fig. 2.2)

Kasmieh irrigation project—Coastal Plain and Agriculture lands: between 100 m and sea level

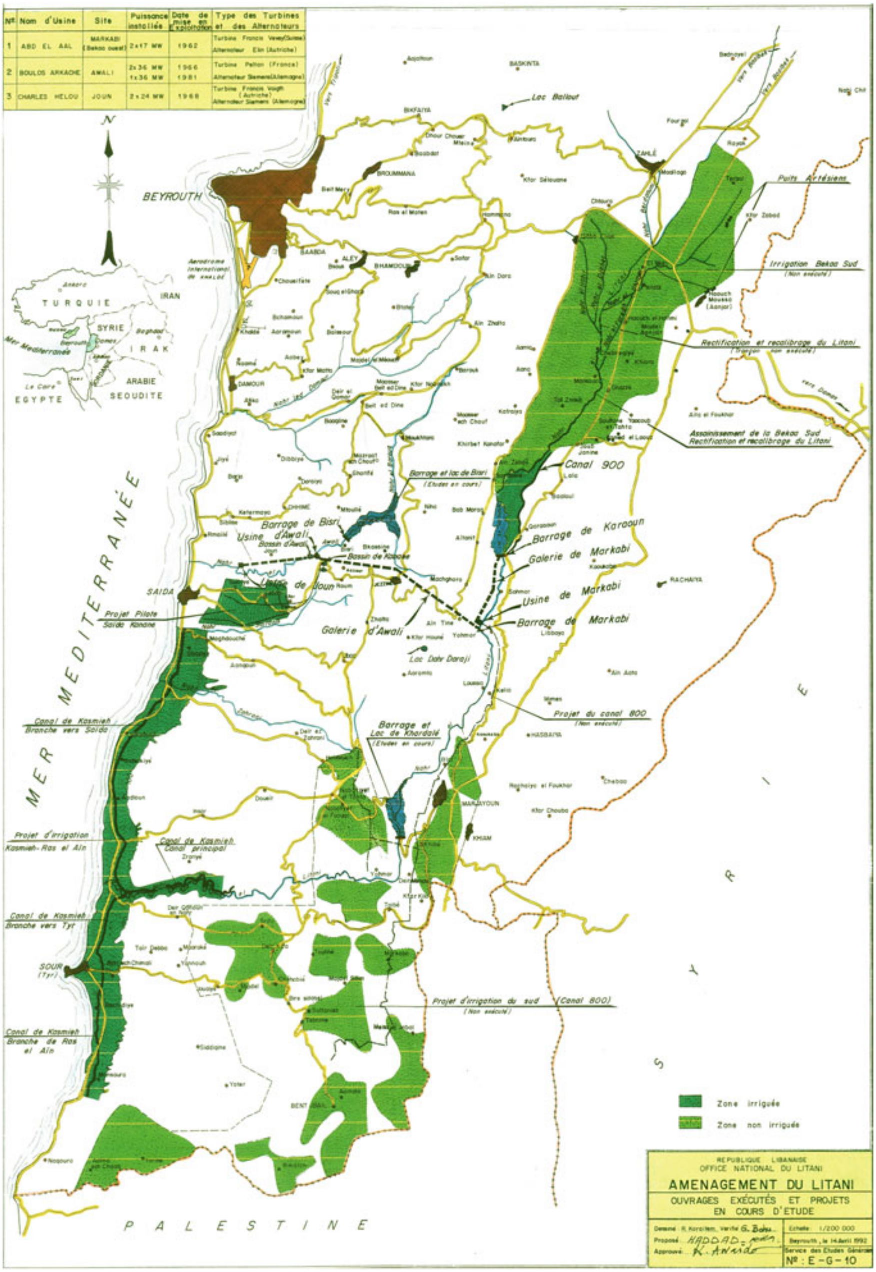

Fig. 2.2 Litani River master plan (Archives of the Ibrahim Abd El Al Foundation for Sustainable Development 2017)

Canal 900—Bekaa Irrigation Project: at 950 m elevation
Canal 800 Project: Between 800- and 500-m elevation
Khardali Reservoir: Between 400- and 150-m elevation
Shoumarieh Reservoir: Between 200 m and sea level
Bisri Reservoir: For potable water (Larger Beirut Area).

In 1969, the main infrastructures for the Pilot Irrigation Project were executed. In 1974, the LRA was, by law, assigned the responsibility of managing the Kasmieh and the Ras El Ain irrigation projects. Consequently, a new department within the LRA was created to manage the irrigation projects. This department organized the Kasmieh projects and improved its management and its administration.

Kasmieh Irrigation Project

The Kasmieh Irrigation Project comprises coastal irrigation of 4000 ha with 1280 subscribers. The LRA succeeded in acquiring a loan from the World Bank to extend the project to secure the irrigation of lands at an elevation ≤ 100 m.

Kasmieh Canal: The length of the main canal is 9 km. It originates from the small reservoir in Zrariye village. At the main distributor, it is divided into two separate canals: the north section (25 km) to irrigate the lands from Kasmieh to Saida and the south section (9 km) to irrigate the lands from Kasmieh to Sour.

Ras El Ain Canal: Tis canal is also divided in two sections, north (5 km) and south (7 km) to irrigate the agricultural lands in this region.

Pilot Irrigation Project

This project was designed to irrigate 1200 ha east of Saida (Kanan to Saida). Now it irrigates 350 ha from Kanan Lake, with 770 subscribers, most of them being small farmers.

Canal 900—Bekaa Irrigation Project

This project was ready to be launched in the 1970s but was stopped due to political instability and the civil war. Initially, this project was designed to irrigate 28,000 ha between the elevations of 900 and 800 m comprising adjusting the river bed and including the drainage works.

In 2000, the LRA, with funding from the World Bank, succeeded in rehabilitating the infrastructures to irrigate 2000 ha in the Bekaa valley using new irrigation technologies. Moreover, the LRA established the hydraulic infrastructures for phase II of the project (which will cover 6500 ha).

From the Qaraaoun Reservoir, water is pumped at a rate of 6 m^3/s (30 million m^3/y) through a reinforced steel pipe to Canal 900. The canal receives additional volumes from wells and springs. Along the canal, three pumping stations raise the water to a 950-m level in reservoirs of various capacities. These reservoirs supply the irrigation networks with pressurized water.

2.7 Present and Future Projects

Rehabilitation of LRA main and regional offices

After the civil war and destruction of the LRA offices, the authority rehabilitated the main office and created regional offices. Moreover, the LRA worked to improve its human-resource base, to ensure technical expertise for project implementation, and rehabilitated the Abd El Al and Charles Hélou hydro-power plants (Fig. 2.3) and computerized their operation. Notwithstanding the adverse context of operation during the civil war, the occupation, and the periods of political instability—which caused physical destruction and a substantial degradation of its administrative capacity—the LRA has managed to operate and maintain these projects throughout.

Canal 800—South Lebanon Irrigation Project

This project was originally launched before the civil war but was interrupted in 1976 due to political instability. It was only in 2002, after a reviewed and updated pre-design and feasibility study of the Canal 800, that the Lebanese Government decided on the execution of the project with the two main components being irrigation and -water supply.

Fig. 2.3 Rehabilitated control room relates to the Abd El Al power plant

A loan agreement, for the execution of the project's main structures, was agreed upon with the Arab Fund and Kuwait Fund for Development. A law for the loan and the contribution of the Lebanese government to the project budget was promulgated.

The project was launched in 2012, and the first section of the project is now nearing completion, which includes a small hydro-plant with a capacity of 5 MW.

The complete first phase consists of the main conveyors starting with a bridge and the Qaraaoun tunnel to reach the area of Bent Jbeil in south Lebanon. The project is to transport 90 mm^3/y from the artificial lake for irrigation of 15,000 ha in the Marjayoun and Bent Jbeil area and 20 mm^3/y to provide potable and domestic water for approximately 100 villages in the project region.

The second phase will put in place the secondary and tertiary irrigation networks, although this phase still requires studies to develop the cadastral plans, soil classification, land-reclamation works, network and hydrant plan designs, and the construction of agricultural roads for land access.

Khardali Reservoir (Fig. 2.4)

This multi-purpose reservoir has a capacity of around 80–100 mm^3 depending on the technical studies. The purpose of this reservoir is to irrigate 9000 ha, to secure potable water (9 mm^3) to villages situated between 400- and 150-m elevation, and to produce hydro-energy (10 MW). The technical studies are ongoing, with the collaboration of the EDF, and the LRA will begin to search for funding.

Shoumarieh Reservoir

Earlier known as "Kfar Sir Reservoir," its planned capacity is 28 mm^3 at a 110-m elevation. This reservoir will irrigate the lands in the region and provide additional volumes to the Kasmieh Irrigation Project. This project will irrigate additional 2000 ha (4000 ha already exist in the Kasmieh Project with an additional 2000 ha of pressurized water coming from the reservoir). Moreover, the reservoir will produce hydro-energy (6 MW).

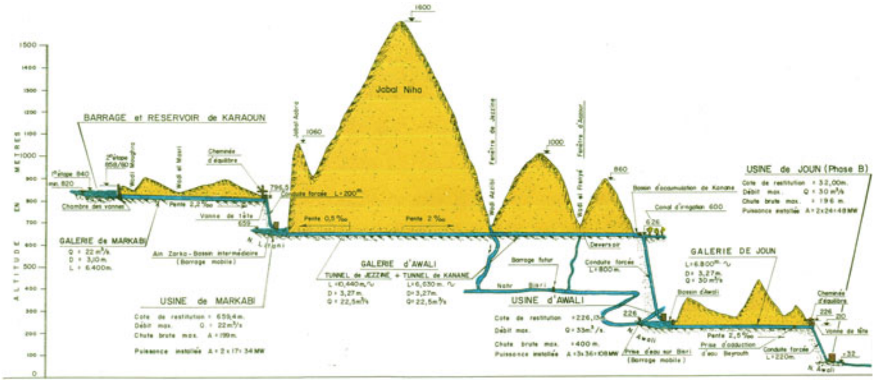

Fig. 2.4 Major elements of the Litani River master plan (Archives of the Ibrahim Abd El Al Foundation for Sustainable Development 2017)

Bisri Reservoir (Fig. 2.4)

The LRA first launched a study for this project in 1987. Responsibility for the construction of this mm^3 reservoir was transferred to Beirut and Mount Lebanon Water Establishment in cooperation with the Council of Development and Reconstruction (CDR) and the World Bank because it is conceived to supply potable water to the capital. Given the LRA's experience in managing reservoirs, transferring the operation and maintenance responsibility to the LRA should be considered.

Moreover, because the reservoir is at a 450-m elevation, and the Al-Awali Hydropower Plant is at a 228-m elevation, this difference in elevation will allow connection to the plant and extension of its capacity by adding two new generators to produce energy (10 MW) before transporting the water to Beirut.

2.8 Projected Outcomes of the Master Plan

2.8.1 Energy Production

31 MW on the river flow:

- 5 MW from 800-m project
- 10 MW from Khardali Reservoir
- 6 MW from Shoumarieh Reservoir
- 10 MW from Bisri Reservoir.

This energy production will contribute an additional 0.8% to the total national energy production, which is equal to a total benefit of around 15 million dollars for Lebanon.

2.8.2 Agriculture

Agricultural lands, 27,000 ha, specifically the most important productive region beginning at the Bekaa and ending in the south coast are contributing to the socio-economic benefits of the regions, reducing rural migration, ensuring land-reclamation works, and contributing to the national economy by developing the agriculture sector. This also contributes in securing the national food security and securing fertile lands from urbanization.

2.8.3 *Potable Water*

It supplies domestic water for south Lebanon (20 million m^3) and 9 mm^3 to villages situated between 400- and150-m elevation.

2.8.4 *Industry*

Contribution to ensuring cheap energy (0, 03 $/KWh) for industrial sector to help to reduce the cost of the production.

2.8.5 *Exploitation*

Exploitation of sufficient water from the river taking into consideration ecosystem needs as well as long-term strategies to secure water availability for future generations.

2.9 Future Vision

The post-civil war period has seen a constant degradation of the environment across Lebanon, and the state of the Litani River is one of the more prominent examples of the ecological crisis the country is facing today.

The Litani River today resembles a sewage channel due to the lack of sanitation infrastructures in the river basin's villages. It is estimated that it receives around 40,000,000 M^3 of wastewater a year.

The Litani River is affected by a number of unsustainable productive activities, such as the current agricultural practices, namely, the excessive use of fertilizers and pesticides, the lack of control and proper treatment of industrial effluents before their release into the watercourse, and the stone-cutting industry introducing large quantities of dust, sand, and stone sediments into the river (84 quarry sites were identified in the area of the basin, of which only 16 are licensed). Open dumping and burning of solid wastes near the banks, garages, petrol-station wastes, and touristic wastes all contribute to the toxicity of the water.

Further affecting the flow are small reservoirs built by some farmers to facilitate the extraction of irrigation water in the dry season.

These same processes also affect the groundwater in the basin, which suffers from pollution and dramatic overexploitation. Quantitative and qualitative data regarding groundwater are not collected in a continuous and coherent way but are produced piecemeal for different purposes and reports.

Officially, the responsibility for qualitative and quantitative groundwater-monitoring across Lebanese territories, including the Litani River Basin, is assigned to the Ministry of Energy and Water.

This lack of information is due to the following causes:

- No unique institution is responsible for the management of the LRB.
- Data related to the LRB are spread among many institutions or are sporadic.
- Very little was invested by the state to produce a systematic approach to the production of such data.
- Historically, the wars and occupation (before and during 1975–1990 and 2006) and security conditions have perturbed the regularity of data collection.

To allow for a better water-management policy inspired by IWRM ideas, it is necessary to build a monitoring system in the basin. The conflict and overlapping of responsibilities regarding LRB management between many stakeholders hinder these objectives.

Related to the degradation of water resources, a parallel process of land degradation reinforces the environmental crisis. This is due to poverty, limited economic opportunities, unplanned urban sprawl rooted in a state policy promoting the real estate sector with very laissez-faire land zoning regulation, quarrying, intensive agriculture, deforestation, improper water management, overexploitation of ground water resources, and policies that aggravate the effects of environmental events such as flash floods and droughts.

According to various estimates, the Lebanese water balance will turn negative by 2020 if concerned entities in the water sector do not reform their approach to the management of the resource.

In response to the dramatic pollution and resulting ecological destruction in the LRB, the Lebanese government has initiated a large-scale infrastructure investment program to depollute and secure clean water in the river. Legislation was promulgated to allocate funding for this project and to provide the legal framework for its implementation.

Law 63 allocates funding to fight pollution on the LRB. This law defines the municipal sewage infrastructures and the treatment of waste, industrial, and agricultural waste investments to be executed by specifying the responsibilities and allocation of the various agencies. In article 2 of this law, the LRA was given the responsibility of the governance component of the project.

Law 64 was issued to define the loan agreement (Qaraaoun Reservoir Pollution Project) between the Lebanese Republic and the International Bank for Reconstruction and Development dated 02 September 2016.

The objectives of the project are to reduce the quantity of untreated municipal sewage discharged into the Litani River and to improve pollution management around the Qaraaoun Reservoir. The project consists of the following parts:

- Part A: Improvement of municipal sewage collection
- Part B: Promotion of good agricultural practices (including integrated pest management)

- Part C: Solid-waste management, water-quality monitoring, capacity building, and project management. Part C contains a clause that specifies LRA as the recipient of technical assistance to improve the water quality, monitor the network, perform water-resources modeling, and raise awareness on the cleaning-up of the Litani River.

The Ministry of Energy and Water (MoEW) is responsible for the water policies, and the water authorities are responsible for executing the National Water Master Plan. At the national level, legislation, law enforcement, research and education, and creation of an equitable tariff policy are all tasks that must accompany infrastructure investments to allow costly infrastructure projects to produce beneficial developmental outcomes that outweigh the debt-interest burden that such capital expenditure represents. Without these non-material components, these investments will not be able to provide the targeted benefits but rather will turn into a burden for future development.

The laws mentioned previously—as well as the sum (even if relatively small, i.e., about US$2 million) allocated to the LRA—provide an opportunity to review and improve the LRA's governance strategy to generate positive project outcomes and to adapt it to the challenges facing the basin.

The principles often gathered under the heading "Integrated Water Resources Management (IWRM)" can provide useful ways forward if applied critically and in a locally adaptable manner.

The idea of IWRM emerged in the 1970s and began to be formalized in the Mar del Plata Conference in 1977. The concept evolved with time through several conferences (Rio 1992, Dublin, Rio+5 CSD 1998, WWF in Marrakesh 1997, WSSD Johannesburg 2002). It was adopted in the UN Millennium Goals and flowed into the development of the UN Sustainable Development Goals. IWRM was also incorporated into the European Union's Water Framework Directive (2000).

Theoretically, IWRM aims at reconciling the provision of water with its demand, along with the competing demands themselves, to make water use economically productive, socially equitable, and environmentally sustainable. Practically, these concepts are too often reduced to a search for the right price for water and a reliance on markets to balance the tensions between these three components (economic, social, and environmental). An overemphasis on the economic aspect, reduced to productivity, will not only blunt the effectiveness of an IWRM approach but actively undermine the sustainability and social-justice considerations.

To improve national water-resource management, there is clearly a need to deepen the democratic process by increasing transparency and involving multiple stakeholders, including the most disenfranchised (e.g., owners of small farmers), in the decision-making process and management. For example, the absence of water user-association legislation or well-funded agricultural-extension services makes an improvement of individual water use for irrigation a daunting task.

The LRA, as the leading authority in implementing the Litani River projects, should restructure and extend its responsibilities to establish an overall waste-management strategy for the entire basin integrating the environmental, social, and economic parameters (UN Sustainable Development Goals).

Law 63, as mentioned previously, will provide the LRA an opportunity to restructure its mandate and to establish a progressive governance strategy as a component of its Master Plan Strategy. Such a strategy would accomplish the following:

- Create win–win policies for the three components of sustainable development noting that the benefit for each water user will be larger if all users cooperate.
- Provide a clear legal framework and strong regulations to issue and control the license of water withdrawal (surface and underground) in the LRB and monitor and control the discharge of treated and untreated wastewater into the river bed.
- Create mechanisms for enforcements supported by local and national powers.
- Secure financial sustainability (combining tariffs, government-budget allocations, other forms of cross-subsidization to address social justice considerations).
- Develop administrative capability to manage the water resources.
- Improve cooperation and accountability among the different institutions involved in water management in the LRB.
- Establish capacity-building and awareness-raising campaigns to guarantee ownership through stakeholders' (from different user groups and sectors) ongoing information, consultation, participation, and dialogue during and after the policy-establishment phase. This will increase the LRA's transparency and, consequently, accountability.

Any governance process put in place must be understood as a dynamic process that should evolve with time and the needs of that time (based on data and information) to assess and improve water policy and to achieve water security and sustainability.

The LRA will have to practice adaptive management by identifying mechanisms for the ongoing evaluation and review of policies for monitoring as well as assessment and may perhaps re-adapt its policies. An important component of the strategy will be the LRA's communication, which would include sharing the results of implementing the water policy with the public (media campaigns) along with the involvement and coordination between the different stakeholders of the LRB.

2.10 Conclusion

Water resources in Lebanon are under pressure from numerous directions. Processes (e.g., uncontrolled urbanization, the production of ever-growing mountains of trash and rivers of wastewater, industrial pollution, and the loss of agricultural land) run parallel with a constant intensification of agriculture and the corollary of fertilizer, pesticide, and insecticide overuse, as well as the over-extraction of groundwater, make water management a daunting task. These problems, rooted in the structural problems of the Lebanese state, are further exacerbated by the unpredictability of climate change.

Given these enormous challenges the state is facing today regarding the safeguarding of water resources, the Lebanese government will need to strengthen its administration, the legal framework, and its ability to enforce regulation. The Lebanese government will have to fight corruption; reinforce transparency, accountability, integrity, and equity; and achieve equitable and sustainable development of water-service delivery.

With its half century of experience and expertise, the Litani River Authority has an obligation (toward its founders and the Lebanese public) and an opportunity to transform itself into an organization that leads this process and does so innovatively. The LRA should seize the opportunity provided BY law 63 to initiate a process of administrative renewal.

Management of the LRB will require an approach that is water centered and holistic and that takes into consideration the relationship between water and energy, food, livelihoods, health, urban planning, production, ecology, and government.

Amendment of the LRA's mandate will be an important step toward the good management and governance of the LRB. Although this will require the support of the Ministry of Energy and Water and the government, other actions can be undertaken by the LRA immediately.

Improvements in transparency and participation will go a long way to ensure stakeholder support. The LRA should insure the water actors' involvement and ownership (including women) of projects to gain public trust. The publication of all data and information on water management to the public and community groups (water storage, allocation of water for different sectors, and the environment) would be an easy first step in that direction.

Furthermore, the LRA will have to devise adequate policies, laws, and regulations at the river-basin scale with an overarching approach toward national policy. The LRA will also have to establish a land-use strategy on the LRB to secure the ongoing irrigation projects on the basin.

In developing its governance strategy, the LRA will need to adapt to the national and local conditions. It must acknowledge the political, social, economic, and cultural particularities of the regions in the basin and the nation as a whole without reproducing the existing failures.

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Chapter 3
Physical Characteristics and Water Resources of the Litani River Basin

Amin Shaban, Ghaleb Faour and Mohammad Awad

Abstract Litani River, with a 2110-km^2 catchment area (about 20% of Lebanon) and a 174-km length, releases an average annual discharge of about 385 mm^3/year. The river in its northern part flattens between the Mount-Lebanon and Anti-Lebanon mountain chains, thereby spanning between several mountain ridges in the southern part. Consequent streams are connected to its primary watercourse. The Litani River Basin (LRB) comprises an elongated catchment where it gently slopes from the north Bekaa Plain extending southward where it meanders westward to outlets into the Mediterranean Sea. Therefore, the river transits into the inner and coastal zones of Lebanon comprising two major drainage systems (described as the Upper and Lower Basins) occupied into one watershed. The Qaraaoun Reservoir, the largest of its type in Lebanon (about 12 km^2), is located in the southern part of the Upper Basin. Before 1959, the site of the reservoir comprised a natural depression. However, when large volumes of water started to accumulate there, a dam was built. Snow has a significant contribution to feeding the river. The extension of the Litani River among the carbonate rocks and alluvial deposits makes it an open hydrogeological system that is fed from and feeds on the permeable and porous lithologies. This chapter introduces the major physical characteristics of the Litani River including the catchment and drainage properties as well as the water resources and land cover.

3.1 Geomorphology

The majority of the Litani River, situated between two elongated rock masses, makes it a territory with distinguished geomorphology. Thus, it is characterized by diverse geomorphological features including mountain chains with different altitudes, shapes, and aspects as well as the flat surfaces extending between these

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A. Shaban (✉) · G. Faour · M. Awad
National Council for Scientific Research,
P.O. Box 11-8281 Riad El Solh, Beirut 1107 2260, Lebanon
e-mail: geoamin@gmail.com

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mountains. Thus, the extension of topography between the elevated areas, hills, and flat terrains is represented mainly by the gradational landforms, which are connected by various drainage systems with different hydrological characteristics. Although the anomalous orientation of LRB, such as its L-shape, is mainly controlled by the existing geologic structures, i.e., the graben structure is well pronounced, resulting in irregular lithological distribution.

Most of the physiographic setting of the Litani River controls its topography where it is embedded between two parallel mountain chains in the Bekaa region. Here it occupies a wide flood plain and then a narrow flood plain in the coastal zone. Thus, it is classified as the Upper Litani River Basin (ULRB) and the Lower Litani River Basin (LLRB).

Figure 3.1 shows the major topography of the LRB where altitudes range from >2400 m up to sea level with an average altitude of about 905 m. The topographic surfaces, as altitude-related features, are classified in Table 3.1.

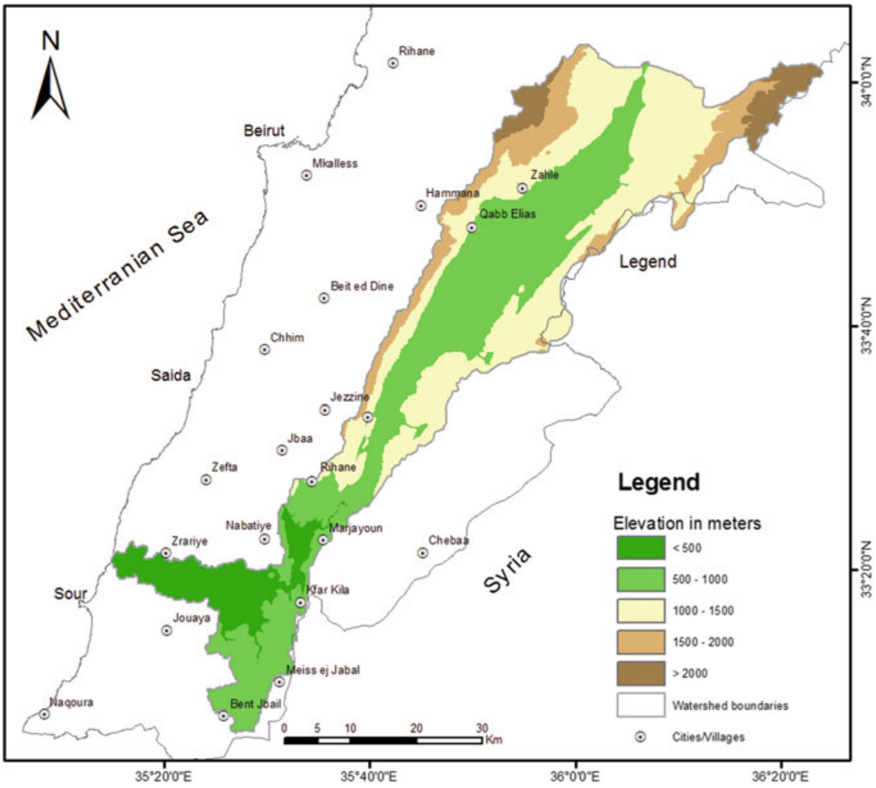

Fig. 3.1 Topographic surfaces of the LRB

Table 3.1 Major topographic surfaces in the LRB

Elevation (m)	Area (km^2)	Ratio of the catchment area (%)	Sub-basin	Major localities
>2000	104	5	ULSB	Partially on the crests of Mount-Lebanon and Anti-Lebanon
2000–1500	232	11		Elongated stretches parallel to the Bekaa Plain
1500–1000	723	34		Elongated stretches parallel to the Bekaa Plain till the contact between the ULSB and LLSB
1000–500	844	40	ULSB and LLSB	Extension along the maximum length of the catchment
<500	207	10	LLSB	Almost among the east − west catchment orientation

The geographic distribution of surface altitudes is structurally controlled. Therefore, there are two aspects of basin uniformity. These are as follows:

(1) Uniform gradational altitude, which occurs among the Bekaa region including the plains and the surrounding mountains. This is shaped by the two elongated parallel ridges where the altitude decreases towards the Bekaa Plain, which has an average altitude of about 920 m. This uniformity remains continuous to the south of the Qaraaoun Reservoir.
(2) Irregular altitude distribution, with a predominant sloping westward, having an average altitude of about 670 m exists. This irregularity starts from the region of Khardaleh and extends southwest.

Based on the understanding of topographic uniformity/irregularity for the LRB, the basin can be divided into two main basins: the Upper Litani River Basin (ULRB) and Lower Litani River Basin (LLRB).

3.2 Climate

The region where the Litani River Basin is situated represents the main two climatic conditions of Lebanon as it extends from the inner region to the coastal zone. According to Shaban (2003) and Shaban and Houhou (2015), the coastal zone is characterized by humid climate, whereas the inner zone among the Bekaa Plain is sub-humid. Thus, the cold air masses rise along the slopes of the coastal zone. In the Bekaa region, the wind blows downward along the rain–shadow area of the western side of the Bekaa Plain and then blows up along the eastern side resulting in turbulent rainfall.

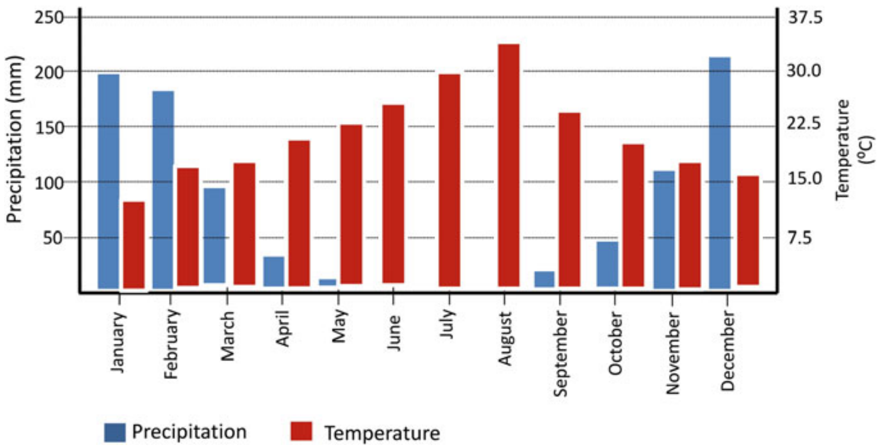

Fig. 3.2 Average annual precipitation and temperature in the LRB

1. Precipitation

According to several sources, the average annual rainfall in the LRB ranges between 1400 and 550 mm (Climatic Atlas of Lebanon 1982; CNRSL 2015) with an average rainfall of about 875 mm. The highest rainfall rate exists on the crest located on the northern side of the Litani catchment, whereas the lowest occurs on the northern side of the catchment. Moreover, snowfall occurs, most notably in regions above 1200 m. Thus, about 25–30 days of snow exist per year at the altitude >1200 m.

The duration of the rainy season averages between 60 and 70 days/year, and it often extends from October to March reaching its climax in December (Fig. 3.2). According to CNRSL (2015), there was an abrupt decrease in the rainfall rate by about 225 mm for the period between 1950 and 2015 in the middle Bekaa region (near Zahle area). In addition, there was an increase in rainfall for the same period, which ranged between 150 and 200 mm in the region between Jeb Jannine and Deir Mimes in the middle and south of the catchment, respectively.

2. Temperature

According to the diverse topography, the temperature is characterized by an abrupt difference in the catchment of the Litani River (Fig. 3.2). Hence, the mean monthly temperature is about 21.5 °C (CAL 1982; CNRSL 2015). The average maximum temperature ranges from 15 to 28 °C, and the average minimum is about 12 °C. Temperature in the LRB is governed by the altitude, and the mean annual values can be distributed as follows:

- 23–24 °C at the coastal stretch
- 23–21 °C at an altitude between 500 and 1000 m

- 20–17 °C at an altitude between 1000 and 1500 m
- 18–16 °C at an altitude between 1500 and 2000 m
- 16–13 °C at an altitude >2000 m.

3. Relative humidity

Relative humidity along the coast is almost constant. However, occurs in the mountainous areas. In general, it oscillates between 55 and 80% with a mean value of about 65%. Thus, the variation ranges between 60 and 80% in winter, and it is between 40 and 60% in summer.

3.3 Basin Geometry

The geometry of the drainage basin (i.e., watershed) is a function of the surface-water flow and the accumulation mechanism. It deals with the behavior of the outer border of the basin regardless of the objective inside it (e.g., streams, perennial watercourses, etc.).

Many formulas characterize the geometry of the water basin. They analyze and assess the processes of run-off from behavior and energy between upstream, along slopes, and downstream to the outlet. The characterization of the basin shape governs the branching process of tributaries and thereby the flow regime (Black 1991). Thus, a basin with a funnel-like shape has regular water flow that reaches the outlet, and water from different directions arrives to the outlet almost at the same time. However, this is not always the case for other basin shapes where differences in the water-flow energy exists.

1. Length/width ratio (L/W)

This is a function of water-flow energy between upstream and downstream. Thus, the length/width ratio controls the time of water flow from the upper reaches to the outlet. In an ordinary basin, however, the average L/W ratio is 0.5, which means that the basin length is equal to about twice its width (i.e., almost funnel-like in shape). Simply, it can be expressed as follows:

$$\frac{\mathrm{L}}{\mathrm{W}} = \frac{\text{Basin length}}{\text{Basin width}}$$

For the LRB, the L/W ratio equals 6.8 (126/18.5). This means that the catchment area of the basin is non-uniform and that the water arrives to the outlet at different time.

2. Relief gradient (Rg)

This geometric formula of the water basin deals with terrain maturity. Hence, a basin in the youth stage shows a frequency distribution skewed toward a lower elevation and vice versa. According to Pike and Wilson (1971), the degree of dissection is evidenced by a relief gradient, which expresses the ratio of upland to lowland elevations within the catchment area. This is expressed as follows:

$$\mathrm{Rg} = \frac{\text{Mean elevation} - \text{minimum elevation}}{\text{Maximum elevation} - \text{minimum elevation}}$$

For the LRB, Rg equals 0.3 (743 − 0/2412 − 0), which means that the dissection of the catchment is almost moderate.

3. Relief ratio (R_r)

The basin's average slope is described as the relief ratio. It provides an approximate estimate of the topographic gradient of the entire basin terrain. It affects the horizontal distribution of groundwater and moisture in near-surface saturated zones. Chorley et al. (1984) considered Rr as a function of infiltration, which also can be positively correlated with the rate of sediment loss from a basin. Rr is expressed as follows:

$$\mathrm{Rr} = \Delta\mathrm{H}/\mathrm{Lb}$$

where ΔH is the altitude difference, and Lb is the horizontal distance along the longest dimension of the basin parallel to the main stream line.

For the LRB, the relief ratio equals 19.1 m/km (2412–0/126). The resulting ratio almost reveals a low to moderate relief slope.

4. Elongation ratio (E_r)

The elongation ratio represents the property of one-direction stretching with respect to the basin area, which controls the flow regime of surface water in a basin. Er equals 1 for a perfect circle shape, and it is zero for a straight line. According to Schumm (1956), the elongation ratio is expressed by the following formula:

$$\mathrm{Er} = \frac{2}{\mathrm{Lb}} \times (\mathrm{A}/\pi)\, 0.5$$

where Lb is the maximum length of the basin, and *A* is the basin area. Hence, the elongation ratio for the LRB is 0.38, which is considered as a moderately straight basin elongation.

5. Circularity ratio (C_r)

The formula for the circularity ratio is a comparison between the basin perimeters and a circular area containing the basin (Miller 1953). It can be calculated as follows:

$$\mathrm{Cr} = \mathrm{Bp}/\mathrm{Pc}$$

where Bp is the perimeter of the basin, and Pc is the perimeter of the circular area confining the basin.

For the LRB, the Cr equals 0.98 (433/440). This indicates that the LRB circularity is almost of the ordinary type.

3.4 Drainage Morphometry

The morphometry of a river or a drainage system deals mainly with the interrelation of the streams (or the primary watercourse) included in the basin area of the river (i.e., catchment). This includes the behavior of streams, their orientation, and their extent. Figure 3.3 shows the drainage system of the LRB. In this respect, several morphometric formulas are used to evaluate the streams' behavior and characterization. In this study, four main ones are estimated for the LRB.

1. Channel slope (Cs)

The slope gradient (degree of channel inclination) is a significant morphometric property because it controls the flow energy of water in the primary watercourse.

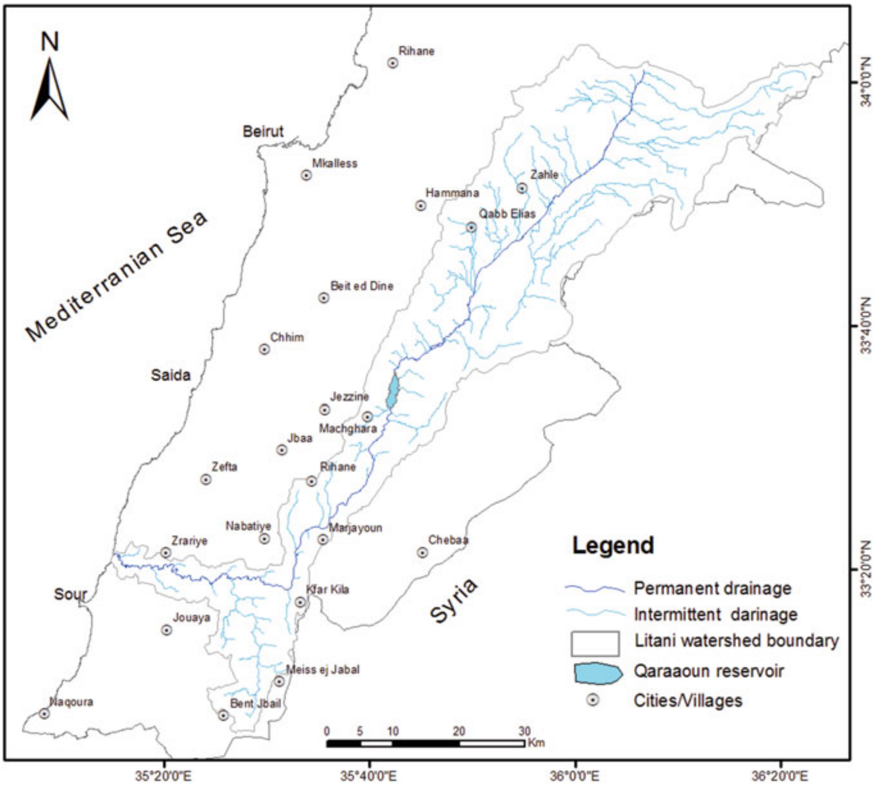

Fig. 3.3 Drainage system of the LRB

In addition, the flow rate is an essential factor in discharge rate. Thus, the higher the channel slope, the higher the discharge rate and vice versa.

According to Morisawa (1976), the channel slope can be calculated as follows:

$$\mathrm{Cc} = \frac{(\mathrm{E}\,0.85\,\mathrm{L})-(\mathrm{E}\,0.10\,\mathrm{L})}{\mathrm{E}\,0.75\,\mathrm{L}}$$

where E is the elevation; L is a point along the channel; and E 0.85 L (for example) is the elevation at 85% distance from the upstream.

For the primary watercourse of the LRB, the cannel slope equals 1.06, which almost represents a low to moderate channel slope over the entire catchment area.

2. Drainage density (Dd)

Based on the general understanding of streams' density, it is known that dense streams indicate a low infiltration rate, which results in surface run-off and overland flow. In contrast, rough (or fine stream density) evidences a low rate of water percolation to the substratum. The drainage density can be simply calculated as follows:

$$\mathrm{Dd} = \frac{\text{Total length of streams}}{\text{Catchement area}}$$

Therefore, the drainage density of the LRB equals about 0.68 km/km^2. Hence, it can be considered as having a low-density rate.

3. Meandering ratio (Mr)

Several meanders occur along the primary watercourse in a basin. Thus, the degree of meandering has several influences on the run-off rate and sedimentation process. It is controlled mainly by the slope's lithological characteristics, geologic structures, along with many other factors.

Normally, the meandering ratio is measured by calculating the ratio between the straight length of the main stream and its length within the existing curvatures using the following equation:

$$\mathrm{Mr} = \frac{\mathrm{Ls}}{\mathrm{Lm}} = \frac{\text{Length of primary stream (meandered)}}{\text{Length of primary stream (straight)}}$$

The meandering ratio of the LRB is found to be 1.28, which can be considered a low ratio.

4. Texture topography (Tt)

This represents the spacing of drainage lines, which is a factor for determining the quantity of relief. This available relief may vary greatly with differences in stream spacing (Douglas 1933). Hence, Tt indicates the tendency of a terrain to shrink water because of the lithological and structural characteristics of the terrain.

Accordingly, to Smith (1950), texture topography is classified into three classes. These are the soft, moderate, and rough for the values <4, 4–10, and >10, respectively. Tt is expressed by the following formula:

$$\mathrm{Tt} = \sum \mathrm{Nu}/\mathrm{Bp}$$

where Nu is the number of tributaries (scale: 1:50.000); and Bp is the basin perimeter.

After considering the existing streams among the LRB, the texture topography is equal to 235/433 = 0.54. The resulting value indicates a soft topographic terrain.

3.5 Catchment Hydrology

The geomorphological orientation of the Bekaa Plain where the Litani River originates makes it a funnel-like shape that can collect surface water and groundwater from the funnel flanks (Mount Lebanon and Anti Lebanon) and then diverts the water southward to the Qaraaoun Reservoir. Therefore, water from the reservoir runs-off southward, along which the river water is again fed from different sources (i.e., springs and groundwater interflow).

The relatively large areal extent of the Litani River watershed receives a considerable amount of water directly from precipitation as rainfall and snow. Therefore, the entire LRB, with an area of about 2110 km^2 and a precipitation rate of 875 mm, receives the following estimated volume of water:

$$\text{Precipitated water volume} = \text{Area} \times \text{precipitation rate}$$

$$2110 \times 10^6 \times 875/1000 = 1846\,\text{million}\,\mathrm{m}^3/\text{year}$$

The orientation of LRB is considered as an anomalous catchment because it is characterized by two abrupt and almost perpendicular terrain bodies, each representing a basin (Fig. 3.4). This orientation is structurally controlled, and the virtual outlet of the Litani River is southward along the extension of the Yammouneh Fault. Therefore, groundwater is supposed to flow along the Yammouneh Fault alignment to the southern regions of the Palestinian territory.

The width of the Litani River catchment exceeds 40 km in its northern part and becomes less than 10 km at its contact between the Upper and Lower Basins. This results in turbulence in the river run-off because all captured waters from the upper parts reach a narrow outlet near the Khardaleh region. Hence, this configuration between width and length controls the travel time of the surface water. However, this turbulent flow regime is controlled and often decreased by the existence of the Qaraaoun Reservoir, which is naturally located in a low-land terrain where a depression exists. After the establishment of the dam in 1956, the reservoir was built.

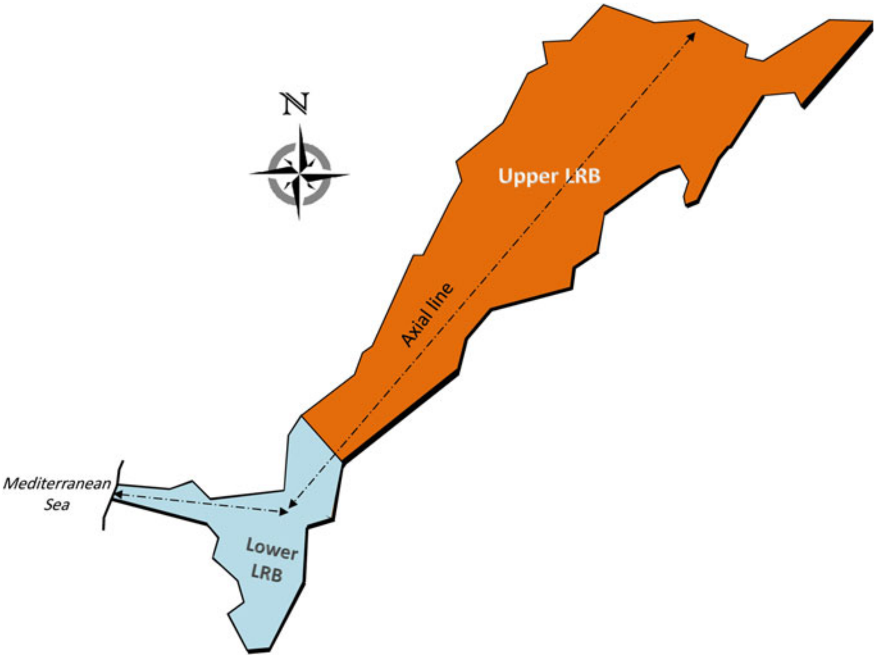

Fig. 3.4 Schematic figure for the LRB with its axial lines

Table 3.2 Major hydrological characteristics of the sub-basins of the Litani catchment

Sub-catchment	Upper Basin	Lower Basin
Areal extent	1602 km^2	538 km^2
Prevailing flow direction	NNE–SSW	E–W
Slope gradient	5–8 m/km	40–45 m/km
Run-off rate (%)	22–25	18–20
Infiltration rate (%)	25–28	30–35
Run-off velocity (km/h)	5–10	25–30
Volume of discharged water (Mm^3/year)	410 (at Qaraaoun Reservoir)	320 (at the Kasmieh outlet)

The ULRB is mainly situated among the Bekaa Plain, and the LLRB extends from east to west facing the Mediterranean Sea (Fig. 3.4). The major hydrological characteristics of the basins of the Litani catchment are shown in Table 3.2.

However, many other classifications for the catchment area of the Litani River exist. This area is sometimes divided into two basins where the Qaraaoun Reservoir is the joining point between both (Nehme and Haidar 2015). In addition, the entire river basin was also divided in more detailed classification by Shaban (2007), who classified it into four sub-basins: Upper Bekaa, Middle Bekaa, Lower Bekaa, and the coastal sub-basin.

The primary watercourse of the Litani River, which is around 174 km (i.e., 132 in the ULRB and 44 km in the LLRB) is characterized by low meandering, but it has connections with a considerable number of small and large water tributaries where the meandering changes abruptly.

The gentle slope of the ULRB, which ranges between 5 and 8 m/km and averaging only about 6.25 m/km, plays a role in water-flow regime. It results in a very slow run-off rate and decreases the velocity of the water flow (i.e., 5–10 km/h), whereas the sedimentation processes increase, notably along the meanders.

In addition, there is much acute slope gradient in the LLRB, which ranges between 40 and 45 m/km with an average of about 46.5 m/km. Therefore, run-off velocity is higher (i.e., 25–30 km/h), and sedimentation is less along the primary watercourse.

Nineteen major tributaries make confluences with the primary watercourse of the Litani River (Table 3.3). Twelve of these tributaries span from the west side of the river; 3 tributaries extend from the east; and 4 tributaries extend from the south. The first 16 tributaries belong to the ULRB, and the southern tributaries are located in the LLRB.

The angle of confluence has diverse values that range between 4° and 88° averaging about 40. The length of these tributaries ranges between 4 and 22 km with an average length of about 9.7 km.

3.6 Geology

According to Beydoun (1988), the eastern Mediterranean basin, including Lebanon, represents a terrain mass for the unstable tectonic shelf of the Middle East Region, which is affected by plate tectonic movements of the Dead Sea Rift System and has its extension forming the Bekaa Plain. Therefore, the folded mountain ranges with uplifted blocks created the three elongated and parallel physiographic units of Lebanon (Mount-Lebanon, Anti-Lebanon, and Bekaa Palin).

The Bekaa depression (wide plain), where the LBR is extended, is almost a graben structure located between the two uplifted mountain chains. The western side of the graben structure is marked by a well-defined fault boundary (i.e., Yammouneh Fault). Beydoun (1972) described the eastern side of this graben is as a sharp flexure, in place, that was partly formed by en-echelon faults.

The exposed stratigraphic rock sequence among the LRB is similar to the one representing the entire sequence of Lebanon. It reveals rocks from Middle Jurassic up to the quaternary deposits. This stratigraphic rock sequence shows sedimentation in a marine environment until the Middle Eocene with carbonate rocks building up the largest part of the stratigraphic column separated by continental clastic rocks at the Lower Cretaceous and some intercalated volcanic rocks up to the Pliocene.

Table 3.3 Major confluences of the Litani River

Major tributary[a]	Length (km)[b]	Confluence Direction	Confluence angle (degrees)[c]	Confluence site[d]	Source area
Wadi Houchbai	2.6	NW–SE	88	Houch Sneed	Houchbai
Wadi Yahfoufa	14.2	E–S	23	Houch Hala	Yahfoufa and Serghaya (Syria)
Haner Hbeiss	7.3	NW–SE	79	El-Ghab	Daher El-Kessiseh and Forrzol
Naher El-Berdaouni	8.6	NW–SE	61	Dehmieh	Ka'a Al-Reem
Naher El-Ghzayel	19.5	NE–W	26	Tell Al-Akhdar	Ras Al-Ain and Terbol
Naher Niha	10.2	NW–SE	83	Tell Amara	Ain Al-Naas
Naher Zabdool	11.5	NW–SE	27	Tell Al-Akhdar	Gdita-Chtoura
Naher Al-Reyashi	8.6	NW–SE	18	Cheberkiyeh and Ammiq	Saalouk
Naher El-Hafier	12.1	NW–SE	33	Cheberkiyeh and Ammiq	Qoub Elias
Naher Sehem Ej-Jamiaa	8.3	NW–SE	47	Mansourah	Ammiq
Naher El-Khrayzat	7.3	NW–SE	84	Tahoun Abou Aissa	Ain Bou Fdayel and Nabaa Al-Khrayzat
Naher Ech-Chite	8.2	SW–NE	31	Nar Qaraaoun Dam	Jabal El-Jbayb and Machghara
Wadi En Nasser	8.1	SE–NW	9	Deir Saleh	Kfer Mechki
Wadi Markaba-Wadi Sendyani	16.5	NW–SE	38	Kfer Houna	Kelieh-Zelaieh
Wadi Safaa	4.4	W–S	05	Quardiye-Blatt	Khalet Khazen
Wadi Babour	4.3	NE–SW	34	Jeser Al-Khardali	Marjayoun
Wadi Saquiet Deir Mimes	6.2	SW–NE	04	Near Deir Mimes	Kfer Kela
Wadi Ayza'aneh	4.1	S–N	12	Deir Mimes	Adiesseh
Wadi Es-Slouki	21.8	S–N	07	Mazra' at Zeiya	Aytaroun

[a] Names are sometimes changed, but the illustrated names have been adopted from topographic maps of the 1960s

[b] Length from source area to the primary watercourse of the Litani River

[c] Angle between the major tributary and the primary watercourse of the Litani River

[d] Sites represent the connection and localities between the tributary and the primary watercourse of the Litani River

1. Stratigraphy

Fourteen rock formations and 2 basalt intrusions exist within the LRB, as well as in Lebanon, that are characterized mainly by carbonates composed of the largest past of the geologic sequence and occupying >65% of the LRB. The exposed rock formations have several aspects of lithologies including limestone, dolomite, and marl. In addition, sandstones, shale, marls, and volcanic rocks and tuffs also exist. The geographic distribution of the exposed rock formations is controlled by many geologic structures.

Table 3.4 lists the lithological description of the exposed rock formations. The geographic distribution of these lithologies is shown in Fig. 3.5. Thus, it is clear that the rock formation of the Cenomanian−Turonian (C_{4-5}) occupies most of the widespread lithology, occupying 605 km^2, which is equal to about 29% of the LRB. Then it is followed by the Eocene limestone formation (e_2) with an area of about 457 km^2 (22% of the LRB).

2. Structures

Several aspects of rock deformations exist in the LRB. They are considered as complicated as the geological structures, notably because the area of concern is affected by the presence of the Yammouneh Fault, which is characterized by lateral displacement accompanied by diagonal sliding of the adjacent rock formations. The orientation of the ULRB is mainly controlled by the presence of the extension of the Yammouneh and Serghaya faults along the western and eastern sides of the Bekaa Plain, respectively (Fig. 3.5). As a result of these two major faults, however, several secondary fault systems, with different scales and magnitude, have developed and sometimes show diagonal/or lateral displacement. However, the existing faults among the LRB in the southern part are different from those in the Bekaa area, and they are often of the wrench type. These faults cut for several tens of kilometers from outside the Litani catchment and almost terminate in the sea.

In the LRB, there are many other aspects of rock deformation including small and moderate-scale faults; folding flexures structures, which are often accompanied by intensive fissuring; and jointing systems. Additionally, sharp dips of bedding planes exist in several localities.

Karstification is well pronounced among the carbonate rocks in the LRB. These are on surface karsts with special emphasis on sinkholes and lapis. In addition, subsurface karst is well developed including the cavities, conduits, and galleries, which are characterized by water transport water for long distances and water that creates many karstic springs such as the springs of Berdaouni, Anjar, Yammouneh, and Khrayzat.

Table 3.4 Stratigraphic sequence of rock lithologies in the LRB

Era	Period	Epoch	Sub-age	Lithology	Symbol	Thickness[a] (m)	Area in LRB (km^2)
Cenozoic	Quaternary	Holocene		Marine deposits, river terraces	Q	Variable	358
		Pleistocene		Dunes, alluvial deposits			
	Tertiary	Pliocene		Limestone, marl, volcanics	P	360	3
		Miocene	Vindobanian	Conglomeratic limestone	m_2-ncg	320	214
			Burdigalian	Marly limestone	m_1	80	18
		Eocene	Lutetian	limestone, chalky limestone	e_2	800	457
Mesozoic	Cretaceous	Upper	Senonian	Chalky marl	C_6	400	131
			Turonian	Marly limestone, marl	C_5	200	31
		Middle	Cenomanian	Limestone, dolomitic limestone, marl	C_4	700	605
			Albian	Marly Limestone, marl	C_3	200	31
			Aptian	Dolomitic limestone	C_{2b}	50	27
				Argillaceous sandstone, marl, limestone	C_{2a}	250	11
			Neocomian-Barremian	Quartzite sandstone, mixed with clayey	C_1	Variable	45
	Jurassic	Upper	Portlandian	Oolitic limestone	J_7	180	3
			Kimmerdjian	Dolomite, limestone	J_6	200	161
		Middle	Oxfordian	Volcanic materials, marly limestone	J_5	Variable	9

[a] Cumulative thickness (exposed and hidden)

Note Cretaceous basalt was not mentioned because it does not often exist

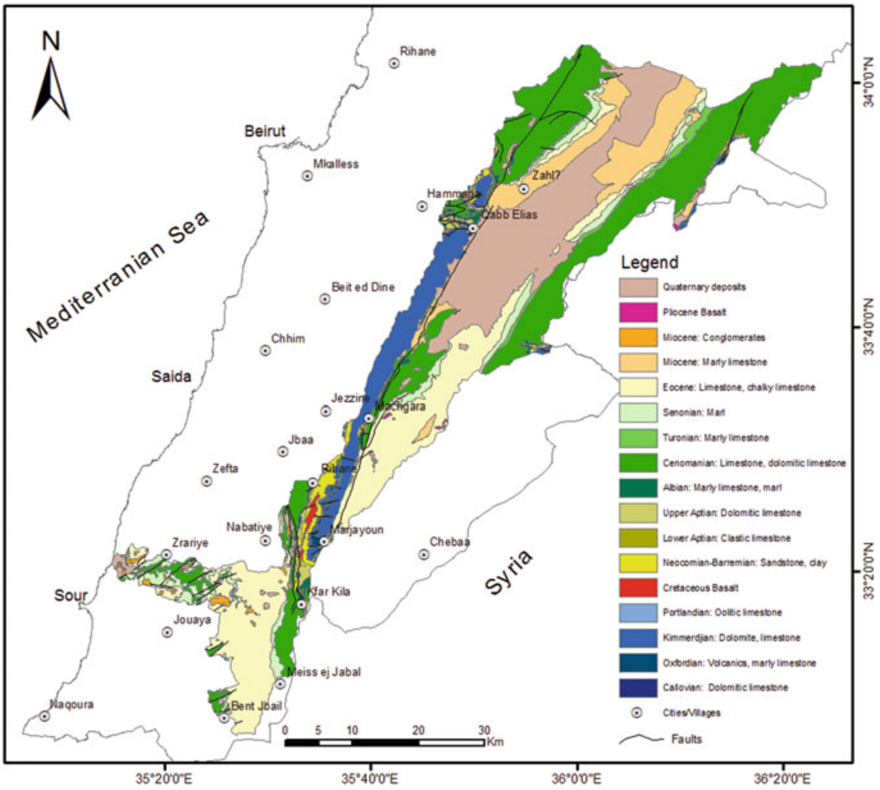

Fig. 3.5 Geological map of the LRB

3.7 Surface Water

3.7.1 Stream Flow

Regarding river-water discharge, it has been plotted by many reports and studies, even though the Litani River Authority (LRA) stated that the maximum discharge is 750 mm^3/year, whereas the calculated average discharge has been about 385 mm^3/year over the last four decades. However, many contradictory estimates still exist, and this contradiction is attributed to many reasons with a special emphasis on the following:

– Difference in the measurement dates, which started around 1947. This results in fluctuating volumes of running water. Thus, the discharge in 1954 was about 1 billion m^3, whereas in 1970, it was about 184 million m^3 (Soffer 1999). In this view, the applied new statistical methods show several anomalies (peaks), which were identified in the long-term trends of the major streams of the Litani River (Shaban et al. 2014a, b).

- The diverse geography between the localities of the measuring sites and the resulting difference in the discharge rate, which is not harmonized well. This is the reason behind the undefined value for the river discharge.
- Climatic variability and anthropogenic impact. Hence, the variability in the climatic conditions affects rainfall and snow-pack distribution. This is also accompanied by human interference through direct pumping from the tributaries and the related feeding sources. Thus, a run-off decrease of about 45% in the river discharge has been reported (Nassif et al. 2014).

Many measuring stations (i.e., flow-meters) are situated along the river course. The most important ones (from north to south) are Berdaouni, Ghzayel-Anjar, Koub Elias, Mansourah, Khrayzat Qaraaoun (Reservoir), Qelieh, Khardaleh, and Kasmieh (sea mouth). The average discharge from these stations are listed in Table 3.5 based to many data sources with special emphasis on the Litani River Authority (LRA). Hence, the diversity in the discharge is obvious between these stations (between 0.45 and 27.50 m^3/s), whereas the average discharge was calculated at 12.2 m^3/s.

The river discharge is mainly dependent on two major feeding sources including the issuing springs and the snowmelt, which are hydrologically and hydrogeologically interrelated with the water cycle. In addition, rainfall has very temporary impact on the stream flow continuity and even in feeding groundwater resources. The latter is well pronounced in the Bekaa Plain where thick alluvial deposits occur, which then acts to decrease the infiltration rate from the top soil to the sub-stratum.

Table 3.5 Major flow-meter stations along the Litani River

Station	Discharge (m^3/s)[a]	Altitude (m)	Flow-meter site	Coordinates	
				Latitude	Longitude
Berdaouni	3.80	880	Spring	33°46′42″N	35°53′26″E
Ghzayel-Anjer	2.80	891	Confluence	33°43′56″N	35°56′52″E
Koub Elia	2.45	924	Confluence	33°47′45″N	35°49′25″E
Mansourah	9.30	862	Tributary	33°40′47″N	35°49′06″E
Khrayzat	0.55	953	Spring	33°37′49″N	35°43′08″E
Qaraaoun (Reservoir)	13.25		Dam	33°46′42″N	35°53′26″E
Qelieh	0.45	851	Tributary	33°26′08″N	35°38′49″E
Khardale	22.30	240	Confluence	33°20′22″N	35°32′33″E
Kasmieh (sea mouth)	27.50	3	Outlet	33°19′48″N	35°15′30″E

[a] Average discharge over the last four decades

3.7.2 Springs

Several springs replenish the Litani River. Some directly flow into the primary tributaries, and others feed indirectly through percolation into the groundwater reservoirs. These springs are characterized by a diverse discharge magnitude and different hydrologic regimes. Hence, the largest part of these springs is temporary and, in some instances, only surface seeps exist. They are governed by many controlling factors including meteorology, geology, and geomorphology According to IDRC, CNRS, LRA, and DSA (2007), about 80% of them are located at altitudes >900 m. Therefore, the exiting springs among the LRB are found mainly in the Jurassic and Cenomanian rock formations, where the karstic spring type is dominant, and reveals abrupt fluctuations in the discharge between different seasons. Moreover, fault and ordinary springs are also found among these two rock formations but with more stable flow regime.

Table 3.6 lists the average discharge from the major issuing springs in the LRB as elaborated by different sources, especially the LRA. According to the Meinzer classification (1923), the largest number of the existing springs in the LRB are of the fourth magnitude (i.e., 6.31–28.3 l/s), but springs of the third magnitude (i.e., 28.3–283 l/s) also exist. In addition, springs at an altitude >1200 m, where there are carbonate rocks of the Jurassic and Cenomanian rock formations, are characterized by a high discharge rate. These are Ain Ez-Zarqa, Anjar, and Ghaleh, which issue 77.63, 63.50, and 31 million m^3/year, respectively.

Table 3.6 Major issuing springs in the LRB

Spring	Wet season (m^3/s)	Wet season (m^3/s)	Average annual discharge (Mm^3/year)
Ghalleh	18.90	12.36	31.25
Amiq	16.78	5.44	22.22
Qab Elias	16.03	5.48	21.51
Jdita	3.40	0.74	4.14
Khrayzat	5.47	3.98	9.45
Chtoura	9.10	5.39	14.49
Anjar	40.70	22.80	63.50
Chamsine	7.81	6.99	14.70
Ras El-Ain (Terbol)	5.25	1.77	7.02
Ain El-Bayda	4.30	3.91	8.21
Ain Ez-Zarqa	46.63	30.42	77.05
Sheitta	7.59	2.10	9.69
Berdaouni	35.43	9.08	44.51
Al-Oliek	1.22	0.45	0.67
Al-Faour	2.70	0.91	3.61

3.7.3 Snowmelt

According to the geomorphology of the LRB, mountain chains with >1500-m snowline occupy about 16% of the basin area (Table 3.1). These chains frequently receive a considerable amount of snow, notably in the ULRB (Fig. 3.6). The accumulated solid precipitation surrounding the LRB is the integral feeding source of water, which is stored temporarily in the form of snowpack. Therefore, a substantial portion of snowmelt recharges the terrain where the Litani River flows, whether directly from the running melted snow or from the issuing springs, which are also fed mainly from snow.

Above the snowline within the LRB, snowfall of different magnitude ranges between 60 and 70 days/year where a snow depth of about 40–50 cm exists. Therefore, the processed daily MODIS satellite images over the last decade revealed that the average areal coverage of snow that falls on the mountain chains surrounding the LRB is about 550 km^2 (about 26% of the entire catchment of the Litani River).

Many estimates have been plotted for the snowpack contribution to water resources in Lebanon. However, the general understanding is that snow contributes

Fig. 3.6 Space view showing Mount-Lebanon ranges facing the Bekaa Plain and Qaraaoun Reservoir (*Source* Tannouri 2010)

about 2787 mm^3/year for Lebanon, which is equivalent to about 58% of the total water volume (Shaban and Darwich 2013). In this respect, it was estimated that snow contributes to about 24% of the total hydrological budget in the LRB.

The Qaraaoun Reservoir is a considered as a hydrological confluence where the water level always evidences interflow from precipitated water. In this regard, it was estimated that any decrease in the precipitation (rainfall and snow) >40% of the normal rate will substantially lower the water level in the reservoir, affect the irrigation systems, and also postpone the hydropower plant. In addition, the increased precipitation by 55% of the normal rate will result in a water-level increase, thus creating floods and increasing turbidity, which in turn would close the channels of the hydropower plant (Shaban et al. 2014a, b).

3.8 Groundwater

There is an obvious coincidence between the geomorphological and geological frameworks of the LRB. This diverts the flow regime of water, whether in surface or sub-surface, in almost similar orientation. Therefore, the parallelism of the two mountain chains in the ULRB, as a result of the graben structure, creates two hydrogeological regimes. The first is the flow of groundwater along the dips of the bedding planes from these chains toward the Bekaa Plain, and the second is diverting groundwater along the major fault alignments from north to south and from the secondary faults again toward the plain. Also, the first flow regime exists in the LLRB where several bedding planes are inclined toward the river basin.

Yet, groundwater in the region where the Litani River flows remains with less concern until the level in the river decreases and there are exacerbated contamination problems. Consequently, attention has been given to groundwater, and then boreholes have become dominant, notably in the Bekaa Plain where shallow aquifers occur only in few tens of meters depth. Therefore, the number of drilled wells in the LRB is still undefined. However, several estimates have been plotted, and between 6000–8000 and 4000–5000 are reasonable numbers for operational boreholes in the ULRB and LLRB, respectively.

The hydro-stratigraphic rock sequence in the LRB, where a variety of rock strata with different hydrogeological characteristics exist, is well recognized. The carbonate rocks (i.e., limestone and dolomites) build up the largest part of the stratigraphic rock sequence with intervention of sandy, clayey, argillaceous, and volcanic rock facies.

There is a miscellany of groundwater-bearing rocks stratum (i.e., aquifers) in the existing rock formations in the LRB where they reach different depths (Fig. 3.7). However, not all of these strata are suitable for groundwater in terms of economic value. From the aspect of depth, there are two major groundwater levels, which belong to four aquiferous strata in the LRB. These are as follows:

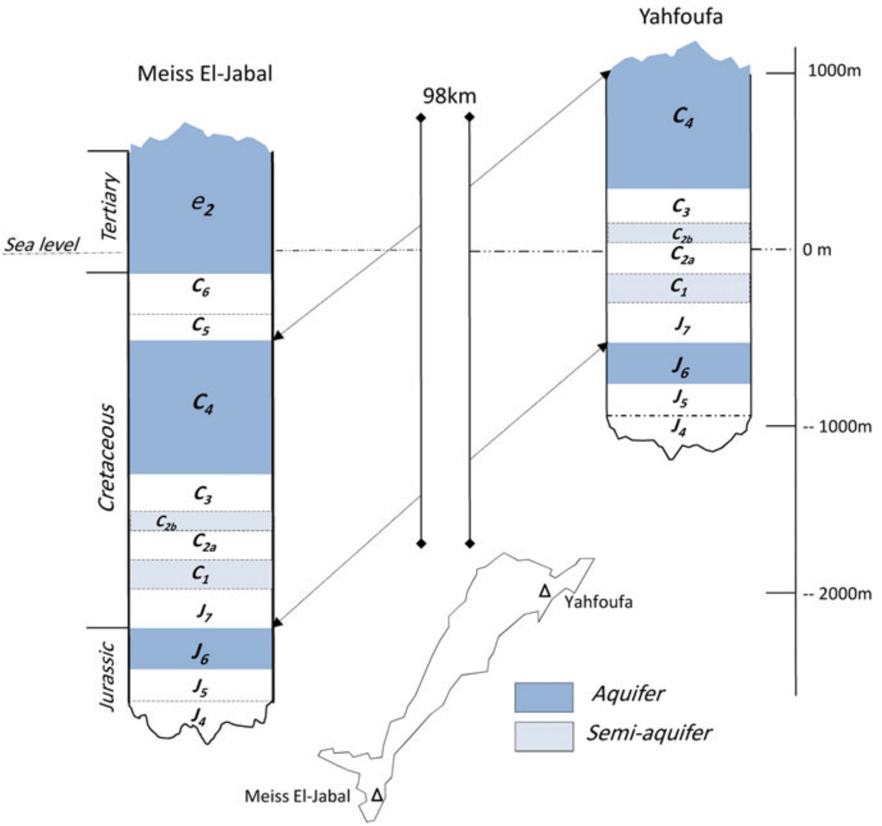

Fig. 3.7 Two correlated hydrostratigraphic sequences in the LRB

1. Shallow-depth aquifers: These are well pronounced in the Bekaa Plain where thick soil sequences with dominant alluvial deposits occur, thus resulting in local and isolated groundwater-bearing strata with shallow water table depth (i.e., almost <50–60 m). They also are found, in many instances, as perched aquifers. However, the shallow aquifers are usually with limited yield, and no continuous pumping can be achieved due to the restricted areal extent and thickness of the water-bearing strata.
2. Deep-level aquifers: These represent water-bearing strata at depths exceeding several hundreds of meters but with considerable water volume and continuous discharge. These aquifers are mainly found among the carbonate rocks, which are represented by the Eocene (e_2), Kimmeridjian (J_6), and Cenomanian (C_4) rock formations (Fig. 3.7).

Table 3.7 General data on the discharge and water table from the aquiferous stratum of the LRB

Aquiferous stratum	Average discharge[a] (m^3/s)		Average water table depth* (m)	
	Before 2006	2016	Before 2006	2016
Quaternary deposits (Q)	0.038	0.023	45	65 (fluctuating)
Eocene (e_2)	1.30	1.25	475	515
Cenomanian (C_4)	0.150	0.11	315	340
Kimmeridjian (J_6)	0.125	0.120	375	385

[a] The estimated data were elaborated from 72 boreholes within the LRB

> These rock formations occur usually as massive and thick-bedded formation with highly fissured and jointed limestone and dolomitic limestone, which are interbedded at some depths with marl and marly limestone. Therefore, secondary porosity is the principal hydrologic property for water retention among these rocks. In addition, karstification is well pronounced among these two rock formations, thus resulting in cavities, galleries, shafts, conduits, and grottos, which are filled with groundwater.

A number of aquiferous rock formations occur in the territory of the LRB, but they are considered as semi-aquifers (Fig. 3.7). These are the Neocomian–Barremian rock formation (C_1) and the Upper Aptian (C_{2b}). Therefore, the intervention of clay and other argillaceous rocks in the C_1, as well as the limited thickness (<50 m) and the predominant open exposures, decrease the C_{2b} property as ordinary aquifers. The rest of the rock formations, which are embedded among the hydrostratigraphic succession of the LRB, imply either aquicludes (do not retain groundwater) or aquitards (bearing groundwater to some extent only).

Hydrogeological data are often rare, most notably for the private wells. Few data can be reached on the discharge, and the water-table depth forms different boreholes, which are mainly dug into the known aquifers (i.e., Quaternary, Cenomanian, and Kimmeridjian). Table 3.7 lists the most collected data in the LRB and their changing status over more than one decade.

3.9 Land Cover

As one of the major tools characterizing terrain surface, the land-cover map reveals the existing natural and artificial elements, which can be interrelated to water resources in terms of water demand and allocation as well as the estimation of water-source proximity to human clusters. Therefore, land-cover maps are often elaborated for different purposes (e.g., change detection, human expansion, monitoring green-cover behavior, etc.), and it plays a significant role in diagnosing water budge.

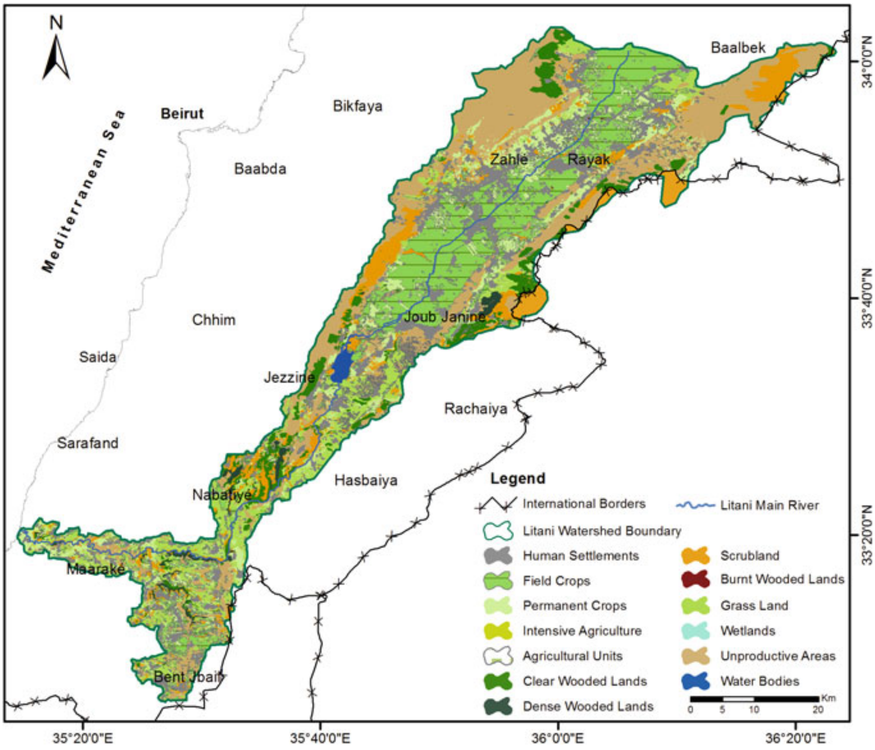

Fig. 3.8 Land cover map for the LRB (year 2013)

Due to its geomorphology, however, the LRB encompasses diverse terrain surfaces. Thus, it has different land forms that occupy a miscellany of land-cover components. Thus, the established land-cover map of the LRB was extracted from the processed GeoEye-1 satellite images of the year 2013 (Fig. 3.8). These images have a spatial resolution of 0.41 m, which enables the identification of small terrain components, and then calculates their areas (Table 3.8). For this purpose, classification at level 2 was applied where 13 major classes were established. The identified classes were also verified in the field.

It is clear that the principal land-cover components of the LRB are represented by unproductive areas (583.8 km^2), field crops (526.3 km^2), permanent crops (258.2 km^2), and grass lands (236.6 km^2). Therefore, the non-used areas occupy about 56% of the LRB, whereas different aspects of the agricultural areas occupy about 37%.

If compared with the total agricultural areas of Lebanon, however, the LRB represents about 24% of these areas. It is also noticed that the areas of different human settlements represent about 6% of the LRB (Table 3.8).

Table 3.8 Major land-cover components as extracted from satellite images (Geoeye-1, 2013)

Land-cover component	Area (km^2)	Area (ha)	% of total LRB
Human settlements	128.7	12,870	6.09
Filed crops	526.3	52,630	24.94
Permanent crops	258.2	25,820	12.23
Intensive agriculture	2.3	230	0.10
Agricultural units	1.6	160	0.07
Clear wooded lands	153.8	15,380	7.28
Dense wooded lands	37.1	3710	1.75
Scrubland	169.5	16,950	8.03
Burnt wooded lands	0.2	20	0.009
Grass land	236.6	23,660	11.21
Wetlands	0.02	2	0.0009
Unproductive areas	583.8	58,380	27.66
Water bodies	12.0	1200	0.57

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Chapter 4
The Physical, and Chemical and Microbial Characteristics of Litani River Water

Nada Nehme and Chaden Haidar

Abstract The major physiochemical and microbiological properties of water were analyzed from 13 representative sites along the Litani River tributaries. The results indicated significant levels of pollution in many of the investigated sites. This has been observed in the upper and lower basins of the Litani River. Although some physiochemical variables were within the WHO and Libnor norms, there still remains severe contamination in the river water. Coliform and all genres of bacteria are highly and positively present in the investigated sites indicating unacceptable pollution input from untreated sewage outfall directly into the river. In addition, there is a high nitrite ratio beyond the permitted global range. Increased cadmium and iron contents were found, which also revealed a risky aspect of contamination. Physical variables also showed metal particles in the river water, and microbial and chemical contamination was visible in all sites. It can be concluded that the measured variables are indicative for water-quality assessment. The urgent mitigation of wastewater dumping into the river is highly recommended.

4.1 Introduction

The Litani River is the largest water body in Lebanon with an estimated average total discharge of 252 million m^3 (Nehme et al. 2013). This perennial watercourse originates from the Al-Oliek Spring in northern Bekaa Plain and flows to the south until it outlets in the Mediterranean Sea. The Litani River discharges about 20% of the water of Lebanon as well as water collected among a watershed of about 2.110 km^2. Hydrologically, the Litani River Basin (LRB) is divided into two major sub-basins (i.e., Upper [ULRB] and Lower [LLRB]). The Qaraaoun Reservoir is located almost in the southern part of the ULRB (LRA 1999; Mansour 1994).

There is well-developed agricultural activity in the ULRB, but it is not equally developed in the LLRB where arable lands are rare and mountainous ridges are

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N. Nehme (✉) · C. Haidar
Faculty of Agriculture and Veterinary Sciences, Lebanese University, Beirut, Lebanon
e-mail: nadanehme530@hotmail.com

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dominant (Khoury et al. 2006). Thus, the most important irrigated crops consist of bananas and citrus crops, where they are dominant at the coastal zone on both sides of the Litani River, in addition to olive trees, fruit trees, vineyards, and protected agriculture.

Water-quality indicators provide baseline information and help to identify temporal changes in water quality across different climatic conditions. They aid scientists in investigating problems, such as nonpoint-source pollution and nutrient enrichment, and can identify factors causing the contamination. However, they only provide limited information on the geographic extent of pollutants that impact fauna and flora Elewa and Gober (1999).

They also provide information on how specific water-quality indicators characterize river health and the factors affecting it. These parameters supply indicative data providing an early warning for potential sources of water pollution (APHA 1995).

The ultimate objective of the imposition of water-quality indicators (which may need full treatment before use) is the protection of the consumers, whether humans or animals. The main consideration concerns safeguarding public health and protecting the whole aquatic environment. Both have high-quality considerations that are necessary in our lives (Wisconsin 2003).

The relatively large areal extent of the LRB, which crosses through a miscellany of land types with different uses—mainly agricultural ones—makes it vulnerable to many aspects of pollution (Haidar et al. 2014). In general, there are two major sources of pollution: either by organic materials and/or by chemicals.

Pollution by organic materials mainly comes from wastewater effluents, more specifically from domestic residues where a mixture of wastewater and surface water percolates into soil and rocks and then mixes with groundwater. This significantly pollutes the existing aquifers. Additionally, solid wastes from industries and other sources are dumped into the river without any treatment. This is a widespread phenomenon by which these wastes end up over fissured rocks and then contaminate groundwater in the river basin. Additional wastes include waste from animal farms and slaughterhouses, hospital waste, and waste from agricultural fertilizers and food processing, which result from food factories such as those producing dairy, soft drinks, alcoholic beverages, jams, molasses, and any other materials produced in these factories or similar ones (Fawaz 1992; Jaber 1993; Hajjar 1993, 1997).

The development of organic pollution in the Litani River is attributed to the fact that Litani River and its streams are the nearest open outfalls for wastewater and liquid wastes derived from the villages' existing the river's flanks, notably in the absence of treatment plants. Chemical pollution is due to the presence of factories—including the paper factory in Berdaouni, the sugar factory along Ghzayel River, and battery factories located in the industrial zone of Zahle—located on river floodplains. Some toxic elements found are also due to the use of fertilizers and pesticides.

Chemical pollution, in contrast, originates from fuel stations discarding polluted water and used fuel and oils into sewage-canal systems. Industrial wastewater results mainly from tanning and battery factories as well as car-repair workshops. In addition, chemical pesticides and fertilizers, which are used in agricultural purposes, are additional pollutants. Olive presses also produce liquid wastes that are harmful in some regions (Haidar 2014).

Quarries, rock debris, pavement, and rock-cutting manufacturers produce dusts and clayey-fill rock fractures, which act on water infiltration and storage. This type of pollutant affects flow rates and increases the concentration of river pollution (Haidar 2014). In addition, the population in the ULB has increased lately, especially in Houch El-Rafica, due to the presence of Syrian refugees.

Increasingly, various water consumers—such as the municipal, agricultural, and industrial sectors and improved living standards—must be controlled and integrated into the overall water management of the region. Sustainable pure water quality, safe public health, environmental conservation, and economics are the key factors in this context.

This study aims to evaluate the physical, chemical, and microbial characteristics of LRB water. It is concerned with analyzing representative sites along the river's tributaries.

4.2 Water Sampling

In Lebanon, rarely is a source of surface water found to be pure. This can be well identified just from observing the water in rivers and lakes. This is well pronounced in the Litani River and its related lake, the Qaraaoun Reservoir. Thus, many studies have analyzed the quality of river water and the reservoir. However, the exacerbated pollution level makes it necessary to apply periodical sampling and water analysis for optimal quality monitoring.

This study performs the physicochemical and microbiological analysis of water samples from the river located at 13 different sites along the river tributaries (Table 4.1). It aims to identify the numeric values of the physicochemical and microbiological composition as well as monitor the geographic and temporal variability in water quality. It also assesses the extent to which water quality can affect aquatic life and then compares the results of periodical analysis with the known standards.

Sampling was carried out three times each year (i.e., summer, spring, and winter) during a 3-year period.

Based on work done by Haidar (2014), 18 water samples from the surface water were collected in a 1-litre polyethylene bottles soaked overnight with 10% (v/v) nitric acid, which was used for the water sampling. Water samples (with a defined volume of 300 ml) were also gathered in borosilicate glass bottles for microbial testing. The samples were filtered through 45-mm Whatman Millipore filter paper. The sampling procedure is in accordance with Standard Methods of the APHA, AWWA, and WPCF (1992). The samples were transported to the laboratory in portable coolers. The temperature, pH, electrical conductivity (EC), and total

Table 4.1 Sampling sites and their geographic location

Sites	Sample code	Coordinates		Altitude (m)
		Latitude	Longitude	
Al-Oliek	S1	36°05′54″N	34°00′53″E	1000
Houch El-Rafika	S2	36°02′56″N	33°55′32 ″E	957
Beddnayel	S3	36°01′40″N	33°53′31″E	925
Berdaouni-1	S4	35°53′07″N	33°52′00″E	1150
Berdaouni-2	S5	35°54′49″N	33°50′05″E	923
Deir Zannoun	S6	35°38′55″N	33°46′40″E	890
Masabki	S7	35°51′09 N	33°48′56″E	934
Qelieh	S8	33°26′21″ N	35°38′5″ E	510
Khardali	S9	33°20′34″ N	33°32′34″ E	257
Kakaiet El-Jesser	S10	33°18′31″ N	35°26′18″ E	159
Tair Felsay	S11	33°19′10″ N	35°20′27″ E	172
Abou Abdallh	S12	33°19′26″ N	35°15′50″ E	15
Kasmieh	S13	33°20′ 22″N	35°15′04″E	3

dissolved solids (TDS) were tested directly in the field, and the other nutrients were investigated in the laboratory.

4.3 Water Analysis

Conductivity, pH, and total dissolved solids (TDS) were tested directly in the field (Fig. 4.1). pH measurements were taken using a Hanna instrument, pH Meter Model HI 98103, with a pH range varying from 0.00 to 14.00 at a resolution of 0.01 pH. The accuracy of the pH meter is ±0.2 pH at 20 °C. Temperature, EC, and TDS were also investigated directly in the field using the Hach Model 44600 Conductivity/TDS Meter (resolution conductivity 0.1 µS cm^{-1}, TDS 0.1 mg L^{-1}).

Fig. 4.1 Examples of devices used in the field survey. **a** EC/TDS meter. **b** Tracer pocket tester. **c** Digital pH meter

Similarly done as Haidar (2014), the collected water samples were filtered in 0.45-μm pore size cellulose acetate syringe filters (Millipore filters), and then they were acidified with nitric acid ($pH < 2$) and stored at 4 °C for metal analysis (iron [Fe], zinc [Zn], copper [Cu], chromium [Cr], aluminum [Al], barium [Ba], lead [Pb], potassium [K], nickel [Ni], and manganese [Mn]) using an atomic absorption spectrophotometer with an air/acetylene flame and background correction with a deuterium lamp to remove solid impurities (AOAC 974.27). A hydride generator mercury (Hg) vaporizer unit was used to identify arsenic [As], selenium [Se], and Hg. Spectrophotometer Methods EPA 352.1 and EPA 354.1 were used for nitrates NO_3 and NO_2. The ISO 6878:2004 was used to determine the total phosphate content, and the sulfate was determined by AOAC 973.57.

The alkalinity was determined by the phenolphthalein method (ISO 7980 1986) as for calcium carbonate ($CaCO_3$). The biochemical oxygen demand over 5 days (BOD_5) as oxygen (O) was tested by EPA 405.1 and ISO6060 1989 and the chemical oxygen demand as O.

All water-quality concentrations are expressed in ppm except for pH, EC (μS cm^{-1}), temperature (°C), the CT, GMA, staphylococcus, salmonella (MPN/100 ml), and CF (MPN/200 ml). Standard reference material was used for quality assurance. The mean concentrations of cations and anions, as determined by the standard reference material, were within their certified concentration ranges. Each sample was measured in triplicate. For microbiological analysis, 500-ml samples were collected, and the method of sampling and collection followed the Standards Methods of WHO and Lebanese Norm for drinking water (1999), Libnor (1999).

Water samples for the microbiology test were also collected from the 13 investigated sites. Standard Method Total Coliforms NF EN ISO 9308-1. ISO 4831, and R1/FT/04 were applied to measure the total coliforms and (NF EN ISO 9308-1) for FC, salmonella by (NF V08-052), and *Staphylococcus aureus* (NF V08-057-1/2 R1/FT/O6).

4.4 Results

Monitoring water quality in the Litani River was regularly conducted during a period of 2 years (between 2012 and 2014) at the 13 selected sites. All the samples were investigated for various parameters including physical and chemical parameters and microbiological properties. The results were compared with the water standards given by WHO (2006).

1. Physical Characteristics

The analyzed physical characteristics for the 13 selected sites included 4 elements: pH, temperature, TDS, and EC. The results are listed in Table 4.2.

pH is an indicator of water quality and tends to be at acceptable levels in many of the investigated sites because it ranges between 7.6 and 8.5 (Table 4.2). The increased temperature favors self-purification and increases the rate of

Table 4.2 Physical characteristics of selected water samples from the Litani River

Sites	Sample code	PH	T	TDS	EC
Al-Oliek	S1	7.8	18	259	516
Houch El-Rafika	S2	7.6	16.6	547	890
Beddnayel	S3	7.6	17	573	945
Berdaouni-1	S4	7.6	17.7	219	441
Berdaouni-2	S5	7.7	17.3	227	457
Deir Zannoun	S6	8.5	19	518	1036
Masabki	S7	7.8	18	223	439
Qelieh	S8	8.1	19	339	658
Khardali	S9	8.	18.8	260	496
Kakaiet El-Jesser	S10	8.3	22.4	296	430
Tair Felsay	S11	8	22.8	244	453
Abou Abdallh	S12	7.9	21.6	303	600
Kasmieh	S13	7.6	21.7	258	479
WHO (2006)		**6.5–8.5**	**15.5–21.1**	**<500 mg/l**	Max **1500 µs/cm**
Libnor		**6.5–8.5**	**15.5–21.1**	**<500 mg/l**	Max **1500 µs/cm**

sedimentation. Hence, the results show changing temperature, which is normal due to the changing seasonal heat, and this indicates multi-source water flowing into the river.

EC of water is a function of its ability to conduct electrical current. Measuring the conductivity allows rapid and approximate assessment of the mineralization of water and its evolution. Therefore, the EC measured along the Litani River varies from 430 to 1036 µs/cm. A high level of conductivity was observed in Deir Zannoun, Beddnayl, and Houch El-Rafika. This can be attributed to the dominant industrial activities as well as farming, which both route wastewater in the river. This is also influenced by the Syrian refugees who are located in Houch El-Rafika where the sewage outlet directly discharges into the river.

The increased TDS is also found to be consistent at similar sites with an increased EC (e.g., Deir Zannoun, Beddnayl, and Houch El-Rafika). This can be attributed, in addition to the natural leaching of rocks, to similar factors acting on the increased EC (Haidar 2014).

2. Chemical Parameters

The 15 chemical elements analyzed along the Litani River include NO_3, NO_2, PO_4^{3} $^{-}$, K, Cl, SO_4^{2-}, $CaCO_3$, Na^+, Cr^{3+}, Cu^{2+}, Fe^{3+}, Cd, Mg, BDO_5, and COD. Table 4.3 lists the obtained results.

The distribution of chemicals at the selected sites in the Litani River is listed in Table 4.3. In this respect, nitrites and nitrates are often associated due to the transformation of one into the other by the effect of bacteria (nitrobacter) in soil and

Table 4.3 Chemical parameters of selected water samples from the Litani River

Sites	NO_3	NO_2	PO_3^4	K^+	Cl	$SO_4{}^{2-}$	C_aCO_3	Na^+	Cr^{3+}	Cu^{2+}	Fe^{3+}	Cd	Mg	BOD_5	COD
Al-Oliek	11.5	0.8	0.3	22.3	102	23	265	8	0.16	0.3	0.2	0.1	3	20	55
Houch El-Rafika	40	19.2	1.2	12.5	7.58	98	210	33.5	0.07	0.11	0.08	4	0. 8	12.4	
Baeddnayel	44.5	1	0.9	11.7	120	14	283	9	0.19	0.09	2.7	0.01	5.4	9.5	50
Berdaouni-1	47.5	0.5	0.4	7.38	47	6	412	6	0.01	0.08	1.13	0.01	4.6	5	20
Berdaouni-2	21.3	0.7	0.4	8	42	7	310	4.4	0.13	0.08	1.7	0.01	3	5	20
Deir Zannoun	19	2.2	0.5	10.4	92	12	294	4	0.27	0.07	1.5	0.01	2.6	13	49
Masabki	15	0.7	0.46	7.6	58	4.3	280	6.5	0.09	0.08	1.7	0.01	2.8	9.4	36
Qelieh	30.7	2.6	0.1	3.5	34	0.2	483	6.8	0.03	0.1	3	0.003	1.2	12	29
Khardali	20.5	0.5	0.3	10.5	23.5	4.5	493	5.8	0.04	0.06	4.4	0.003	1.5	5	20
Kakaiet El-Jesser	20.8	0.3	0	10.5	25.4	4.5	394	4.4	0.12	0.06	2.7	0.003	1.5	5	20
Tair Felsay	18.7	2.5	0.14	10.3	14.3	5.5	423	6.6	0.12	0.05	2.2	0.005	2	5	20
Abou Abdallh	18.7	0.9	0.1	10.5	26.3	4.5	432	8.6	0.08	0.05	3.2	0.006	2.9	7	37
Kasmieh	33	2	0.2	7.2	26.6	8.5	434	5.8	0.1	0.05	1.8	0.007	3.2	12	33
WHO (2006)	Max 50 ppm	Max 0.1 ppm	Max 1 ppm	Max 12 ppm	Max 250 ppm	Max 250 ppm	Max 200 ppm	150 ppm	0.05 ppm	1 ppm	0.3 ppm	0.005 ppm	50 ppm	25 ppm	25 ppm
Libnor	Max 45 ppm	Maz 0.05 ppm	Max 1 ppm	12 ppm	200pppm	250 ppm	200 ppm	150 ppm	0.05 ppm	1 ppm	0.3 ppm	0.005 ppm	50 ppm	25 ppm	25 ppm

water. They generally result from the excessive use of fertilizers and chemicals as well as from food industries.

The nitrate content in water is generally higher (the standard value given by the WHO is 50 mg/l) than that of nitrite. Nitrate was found acceptable at all sites, except in Berdaouni and Beddnayel, where it was near the maximum value due to the intensive agricultural activity (Table 4.3).

Higher nitrite and phosphate levels were found in Houch El-Rafica, Beddnayel, and Berdaouni, which indicate the presence of organic pollution (Table 4.3 and Fig. 4.2). However, no problems were observed with sulfate and chlore at all the sites.

Generally, sodium compounds are water soluble and tend to remain in aqueous solutions. Thus, water in contact with igneous rocks (i.e., basalt) will dissolve sodium from these rocks. Higher Na^+ ion in irrigation water may cause salinity problems. The range of Na^+ ions in water samples varies from 4 to 33.5 mg/l. On comparison with WHO (2006) norms, the Na^+ concentration of all tested samples was found to be within the acceptable limit.

Potassium (K^+), as a major cation, has a significant role in the intermediate metabolism. K^+ is a principal source of nutrient for both plant and human life. However, ingestion of excessive amounts of K may prove detrimental to human beings (Haidar 2014). The K^+ concentration of the analyzed water samples ranges from 7.6 to 22.3 mg/l as shown in Fig. 4.2. The concentration of K^+ exceeds the standards in Al-Oliek, Beddnayel, and Berdaouni (Table 4.3). Figure 4.2 shows an example of the distribution of some chemicals in the selected sites located in the ULRB.

Results also show that carbonates and bicarbonates exist almost in complete association with Ca and Mg^{2+}. The carbonate content of the analyzed water samples ranges from 210 to 483 mg/l as listed in Table 4.3. It is obvious that the concentration of carbonates at all investigated sites exceeds the acceptable limit (200 mg/l). This is also well pronounced in the investigated sites of the LLRB.

Chromium, which derives mainly from multiple chemical and industrial applications, was found in all the sites, and sometimes it occurs at concentrations exceeding the acceptable limit (0.05 mg/l). This is well observed at the Al-Oliek, Beddnayel, Berdaouini-1 and Berdaouni-2, Deir Zannoun, Kakaiet El-Jesser, and Tair Felsay sites.

The iron concentration of the tested water samples ranges between 0.08 and 4.4 mg/l as listed in Table 4.3. The concentration of carbonates at 80% of the sites is high, and they sometimes exceed the acceptable limit (0.3 mg/l), as is the case at the Beddnayel, Khardali, and Kakaiet El-Jesser sites.

The amount of dissolved oxygen (BOD) is usually expressed in milligrams of O consumed in one liter of sample during 5 days of incubation at 20 °C. It is often used as a surrogate of the degree of organic pollution of water (Sawyer et al. 2003).

To assess the contamination level in the LRB, the values of BOD_5 (norm 25 mg/l) and COD (norm 25 mg/l) were analyzed during a period of 2 years for all selected sites.

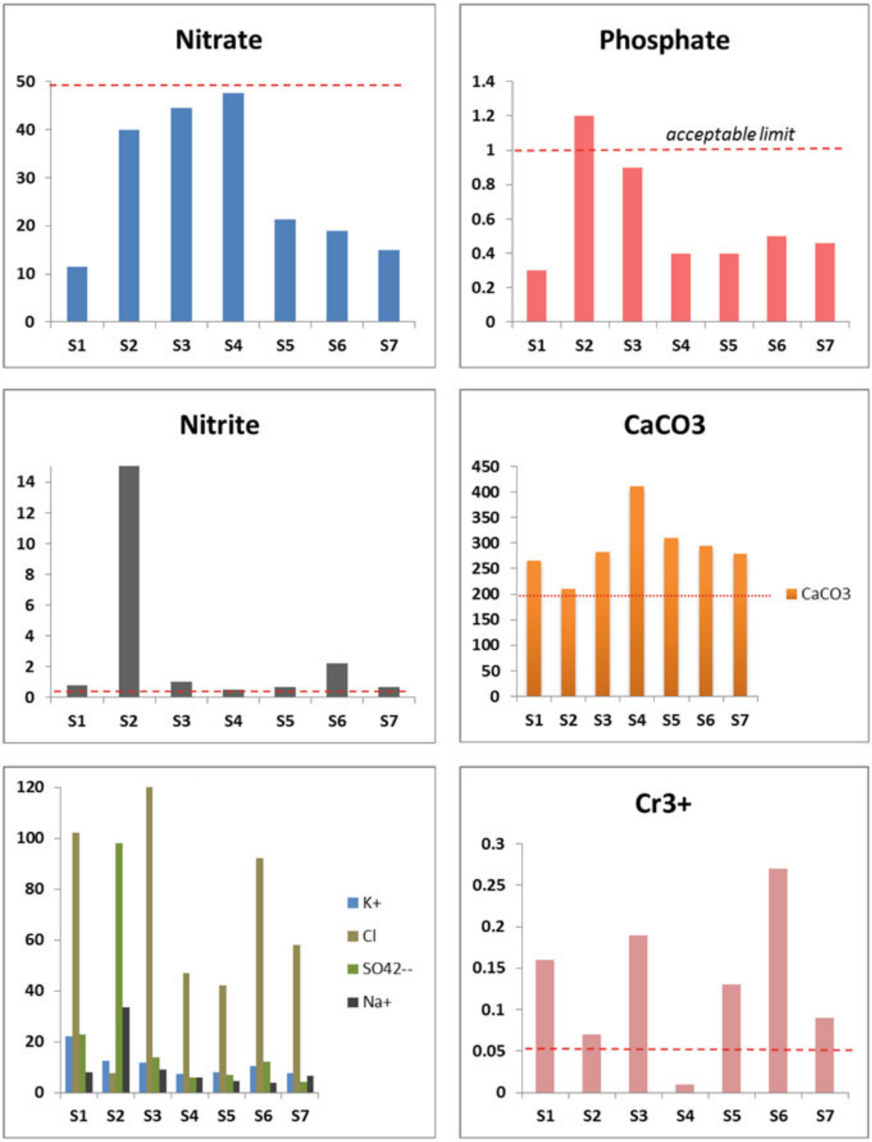

Fig. 4.2 Distribution of selective chemicals in the sites located in the ULRB (ppm, mg/l)

Table 4.3 and Fig. 4.3 show that BOD_5 is high at the Al-Oleik site, but it is still under the limit. COD at most sites exceeds the acceptable limit, sometimes doubling it, such as at Al-Oleik, Beddnayel, and Deir Zannoun sites.

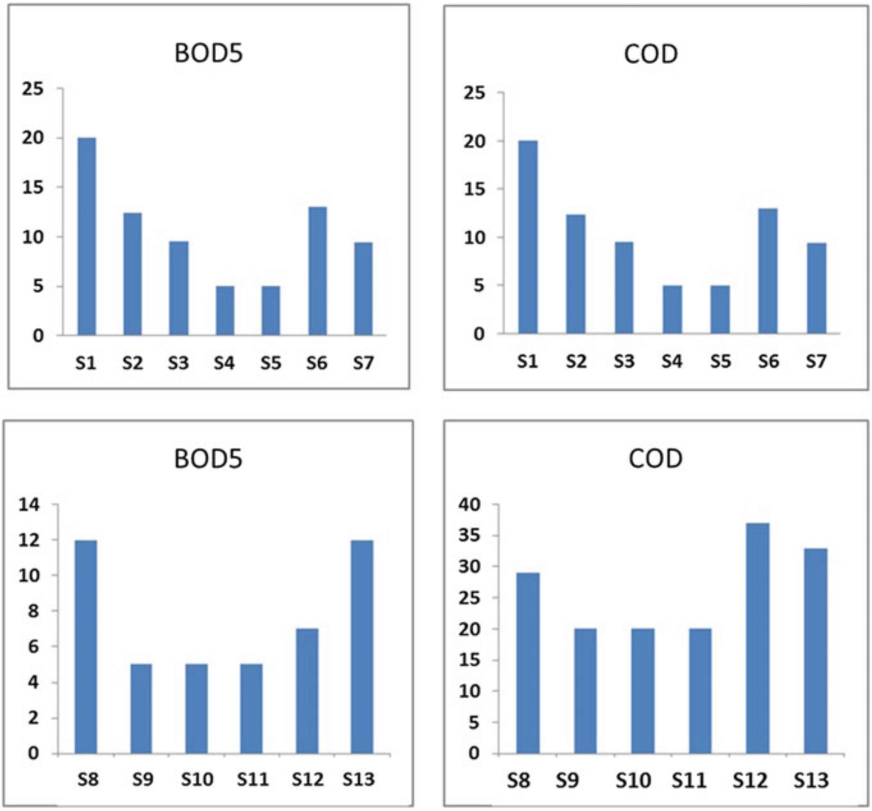

Fig. 4.3 Results of BOD and COD in water samples +in the LRB (ppm, mg/l)

3. Microbiological Properties

The identification of bacteria, potentially toxic substances, and other contaminants in water is usually performed by laboratory testing. Many analytical procedures are applied to identify the degree of water contamination. Detection and enumeration of indicator organisms is the most significant microbiological method used in water-quality testing. The coliform group of bacteria can be defined as the main indicators for water purity in domestic water, industrial water, and water for other uses. Normally, the total coliform (TC) includes fecal coliform (FC) and non-FC.

The microbiological analysis of river water at the selected sites includes TC, FC, Staphylococcus, and Salmonella as listed in Table 4.4.

FC can be separated from the total coliform group depending on their ability to grow in warmer temperatures, and they are associated only with fecal substances. Therefore, *Escherichia coliform* is the main evidence of fecal contamination (Shaban and Nassif 2007; Shaban 2011).

Table 4.4 Microbiological results of the Litani River water samples

Sites	Sample code	Staphylococcus	TC	FC	Salmonella
Al-Oliek	S1	6000	2067	2750	0
Houch El-Rafika	S2	8750	183200	180200	0
Beddnayel	S3	3095	180400	180000	0
Berdaouni-1	S4	1550	1440	400	0
Berdaouni-2	S5	1566	1400	500	500
Deir Zannoun	S6	5700	181920	180400	1000
Masabki	S7	325	800	120	120
Qelieh	S8	0	55	6000	480
Khardali	S9	450	25	1000	50
Kakaiet El-Jesser	S10	600	50	600	700
Tair Felsay	S11	300	60	1800	600
Abou Abdallh	S12	500	80	600	60
Kasmieh	S13	600	100	2700	1000
WHO (2006)		**0 in 100 ml**	**0 in 100 ml**	**0 in 250 ml**	**0 in 100 ml**

Results of the investigated water samples from the selected 13 sites show high microbial contamination. Thus, the highest reported TC and FC content were found in Houch Al-Rafika, Beddnayel, and Deir Zannoun where they exceed 180,000 bacteria/ml.

Regarding Staphylococcus content, there is remarkable increase at Al-Oliek, Houch Al-Rafika, and Deir Zannoun. In addition, Salmonella occurs significantly at the Deir Zannoun, Kakaiet El-Jesser, Tair Felsay, and Kasmieh sites (Fig. 4.4).

The role of human activity and the pollution-increasing bacterial concentration were verified in this study. Monitoring of bacterial concentration throughout 1 day shows that the concentration of bacteria in the water increases with the presence of human activities such as bathing, tourism, and dumping wastes into the river.

4.5 Conclusion

The status of water pollution in LRB can be described as negative, and solid and liquid wastes have become a common feature along the river courses (Fig. 4.5). Solutions to mitigate and reduce pollution are needed to protect water resources in the entire country of Lebanon, with special emphasis on the health of the Litani River, to secure their sustainability and conserve the public health. With global warming and climatic variability, the rainfall rate has become abruptly reduced. In addition, the increased population has resulted in a significant water shortage in Lebanon. Hence, there is an urgent need to turn to the wise use of available water resources and to consider nonconventional resources as well.

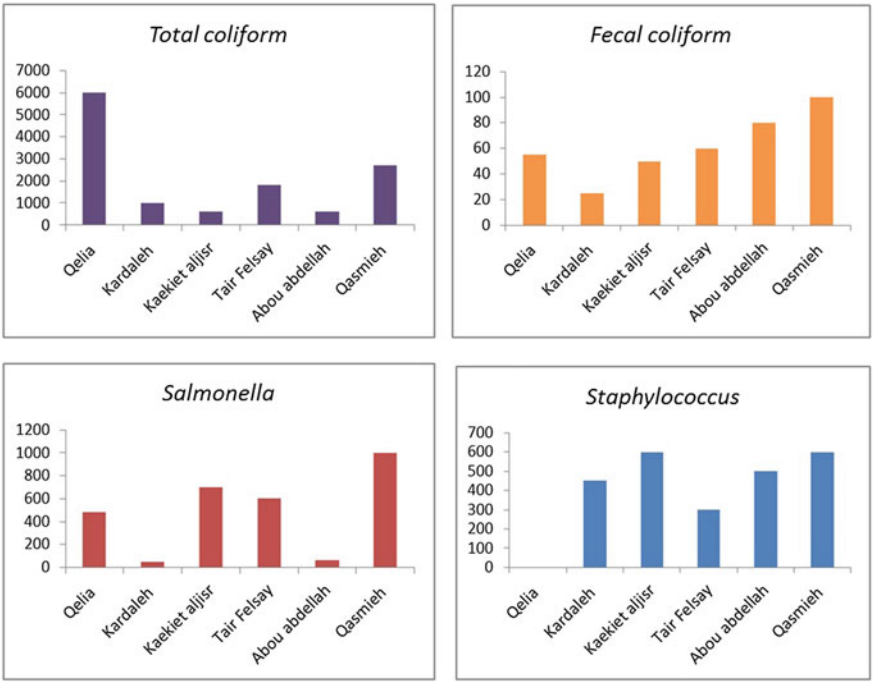

Fig. 4.4 Results of the microbiological analysis of water in the LLRB (bacteria/ml)

Water-quality control is essential issue today it has been evidenced as the key for water-quality monitoring in the Litani River. In fact, many physical parameters—such as rock types, land cover/use, morphology, and climatic conditions—also affect the amount of nutrients released.

The results of this study show that there are different reasons behind the pollution in the Litani River as a result of natural and/or anthropogenic sources and that this pollution varies between the different investigated sites. Most of pollution caused by anthropogenic impact is shown to come mainly from outfalls of municipal wastewater and agricultural activity into the Litani River.

The results of his study show that pollution levels in the investigated sites are higher than the permissible WHO norms. Thus, there is a remarkable increase in the water-contamination rate in the ULRB compared with the LLRB. This occurs because the ULRB is characterized by dominant agricultural activities and dense human settlements. In addition, uncontrolled industrial entities are widely distributed in the Bekaa Plain. This also has been exacerbated by the presence Syrian refugees who have settled along many parts of the river's flood plain.

Although the status of the LLRB is relatively better than that of the ULRB, there is also contamination within the physicochemical parameters, which can be attributed to

Fig. 4.5 Solid and liquid wastes: a common view in the Litani River

domestic wastes, municipal sewage, and agricultural run-off. The increase in Fe, Cr, and Cu content is probably due to mill discharges and domestic purposes.

This study aimed at analysing water quality along the major streams of the Litani River, the pollution of which is a result of genetic processes and the origin of pollutants with respect to domestic, agricultural sectors, and industrial purposes.

Periodical water-quality analysis is significant for integrated water-management approaches and sustainable development on which new water strategies and policies can be established.

The study introduces numeric data, which are compared with the international standards. It highlights all physical, chemical, and microbial characteristics of Litani River water. The major sources of pollutants are local anthropogenic and agricultural activities resulting in high levels of NO2-, Fe, and CaCO3.

Microbial pollution is clearly visible in all investigated sites along the river, which is due to domestic wastes and wastewater as well as tourist activities in the LLRB.

The results of this study show bacterial contamination in the surface water by TC and FC coliforms, Streptococci, Salmonella, etc. Thus, it would be interesting to follow-up on this research to detect pathogenic and dangerous bacteria—such as Legionella, Adenovirus, and Astrovirus—because their presence is correlated with coliforms and enterobacteria.

In the view of the above-mentioned results, the following actions are recommended: (1) establish wastewater-treatment systems along the Litani River, notably where levels of pollution are high; (2) oblige existing factories to install treatment plants based on their particular type of industrial waste; (3) treat solid waste to avoid water and air pollution; and (4) hold campaigns recommending the use of fertilizers and pesticides in rational amounts.

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Chapter 5
Evaluation of the Physicochemical and Environmental Status of Qaraaoun Reservoir

Ali Fadel and Kamal Slim

Abstract Qaraaoun Reservoir, the largest freshwater body in Lebanon, is a vital organ for the Bekaa region. It is used for hydropower generation, fishing, crop irrigation, and tourist activities. In this chapter, we assess the evolution of its physico-chemical and ecological status and compare it with the results of previous studies. The lake, which is considered as monomictic, stratifies in spring and summer providing different physico-chemical compositions at different depths. The trophic state of the lake has not witnessed any improvements in the last 10 years. Its phytoplankton community has low biodiversity and is dominated by toxic cyanobacterial blooms *Microcystis aeruginosa* and *Aphanizomenon ovalisporum.* Due to these toxic blooms, using its water for swimming and drinking should be avoided under the present conditions. For safe use of its water, an effective management at the level of its watershed is highly recommended to improve water quality.

5.1 Introduction

The growing populations of cities and developing industrial activities require greater quantities of water with each passing year. More than 45,000 large dams were built in >140 countries by the twentieth century. The worldwide development of reservoir storage in the twentieth century was slow until the mid-1950s when large projects began to be built on streams, and the rate increased until the 1980s. Regardless of their importance in flood control, artificial lakes offer important ecosystem services presented by power generation, agriculture irrigation, recreational

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A. Fadel (✉)
National Center for Remote Sensing, National Council for Scientific Research,
Riad El Solh, P.O. Box 11-8281, Beirut 1107 2260, Lebanon
e-mail: afadel@cnrs.edu.lb

K. Slim
Lebanese Atomic Energy Commission, National Council for Scientific Research,
Beirut, Lebanon

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activities, drinking-water resources, fish farming, and patrimonial value (Downing et al. 2006).

However, anthropogenic pressure on these freshwater ecosystems can degrade their quality (Kiefer et al. 2015). Fertilizers and untreated wastewater in the catchment basins increase the nutrient influx in lakes, thus resulting in their eutrophication, which may prevent the proper use of their water (Chorus 2005; Paerl and Paul 2012). Therefore, there is a need to monitor and assess the quality of inland water bodies as a means to understand the evolution of their ecological status to model future changes (Palmer et al. 2015) and to predict cyanobacteria occurrence as a health risk–warning system (Mishra 2012).

Regular monitoring of the environmental and ecological status of aquatic ecosystems is crucial, and it is accomplished by reviewing their physico-chemical and biodiversity status (Piha and Zampoukas 2011). In the European Union, phytoplankton biodiversity is considered a biological indicator of the environmental status of water bodies as monitored according to the Water Framework Directive (European Parliament Council 2000). In addition, the WHO has published standard values for water used for drinking and recreational activities.

Qaraaoun Reservoir, Lebanon's largest freshwater body, is one of worldwide aquatic bodies suffering from numerous water-quality problems (Fadel et al. 2014a). The reservoir is eutrophic to hypereutrophic with very low biodiversity in its phytoplankton community. Very few publications address the issue herewith due to there being little or no assessment of the evolution of its ecological state (Fadel et al. 2014a; Slim et al. 2014). In this chapter, we assess its physico-chemical and ecological status and compare it with the results of previously available studies.

5.2 Qaraaoun Reservoir: Location, Hydrology, and Uses

Qaraaoun Reservoir was constructed in 1965 (Fig. 5.1). It is located between the two Lebanese mountain ranges, in the Bekaa valley, 86 km upstream from the entrance of the Litani River into the Mediterranean Sea. The reservoir was built mainly for agricultural irrigation and power generation. However, professional fishing and sport activities are also practiced in this lake. Qaraoun has a surface area of 12.3 km^2 at its full capacity, a maximum depth of 60 m, and an 860-m crest elevation. The Qaraaoun Reservoir dam is 62 m high, 1090 m long, 162 m wide at the bottom, and 6 m wide at the top. The reservoir capacity is 230.10^6 m^3 (Fadel et al. 2017). The main input of Qaraaoun Reservoir is the Litani River, whose average discharge rate was 9.09 m^3/s for the period between 2009 and 2011 (Fadel et al. 2014a). Another input resource are the springs that discharge at the bottom of the reservoir. There have been no recent studies about their contribution in the input to the Qaraaoun Reservoir. However, in the summer of 1952, the flow rate of a spring that discharged into the dam site was 0.69 m^3/s (United Nations Development Program 1970). About 40.10^6 m^3 remains in storage over the dry season.

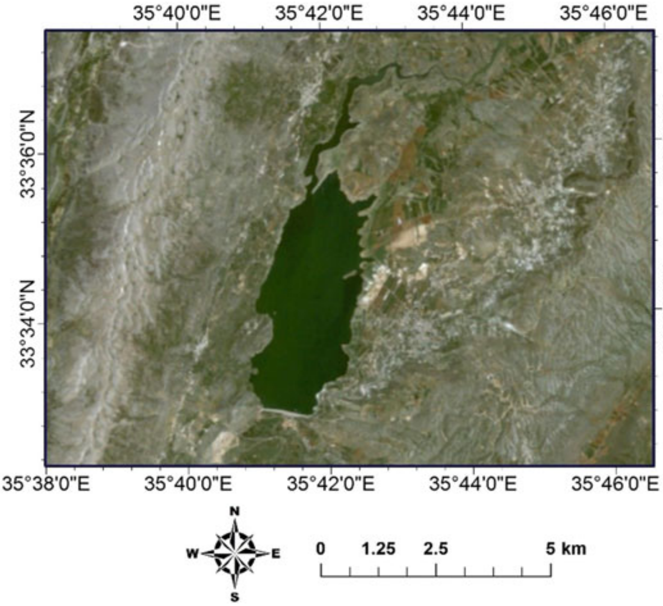

Fig. 5.1 Qaraaoun reservoir, the largest freshwater body in Lebanon

Qaraaoun Reservoir has three main outputs: (1) a bell-mouth spillway located near the dam and used to evacuate the overflow into the Litani River to prevent water overtopping and dam damage, (2) two evacuation towers, and (3) tunnels located at 810 m above sea level and used for power generation with a maximum flow of 22 m^3/s.

5.3 Stratification and Mixing in the Qaraaoun Reservoir

Changes in water temperature affect the ecosystem's functions of lakes, which result in changes in their biogeochemical compositions (Reynolds 2006). Surface-water temperature in the Qaraaoun Reservoir has high seasonal variations. It reaches a maximum of 27 °C in July and can go below 9 °C in December (Fadel 2014). The reservoir is a monomictic lake that mixes from top to bottom during one mixing period each year, i.e., the winter season. Each year, thermal stratification is established in this reservoir in early spring (Fadel et al. 2015) with strong persistent stratification reaching a difference of >10 °C between the surface and the bottom in June and July (Fig. 5.2). Stratification starts to weaken at the end of July, mostly due to decreased water level and solar irradiation.

Qaraaoun Reservoir can be at its full capacity in mid-May of each year with a -m average depth and a 60-m maximum depth. However, due to continuous

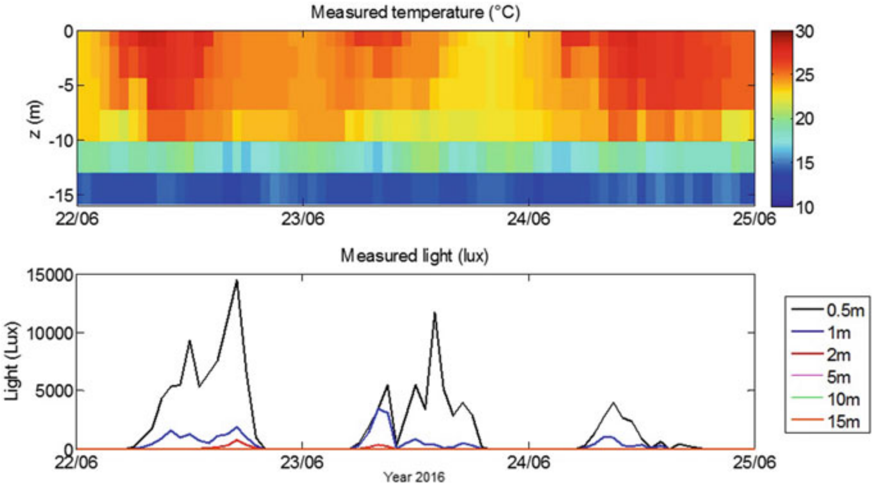

Fig. 5.2 Hourly temperatures and light intensity at 1-, 4-, 7-, 10-, 13-, and 16-m depths in the Qaraaoun Reservoir during June 2016

withdrawal, the water level can decrease as much as 22 m by the end of November before being filled up again between December and May. This continuous decrease in its water level, from the beginning of May until the end of November, is due to the withdrawal used to produce hydro-power resulting in a decrease of the reservoir volume to 25% of the total capacity.

Such a decline in water level can affect the chemical, physical, and biological characteristics of reservoirs by mixing boosting (Valdespino-Castillo et al. 2014). Extreme decline in the reservoir's water level affect the thermal structure of the water column. In the Qaraaoun Reservoir, when the water level decreases >15 m after continuous withdrawal, thermal stratification becomes weaker, and less energy will be required to mix the water column. In Lake Arancio, which has a 29-m maximum depth, a strong wind can result in its desertification after the water level decreases by 15 m (Naselli-Flores 2003). The amount of energy needed to de-stratify the water column will be higher as the water level increases (Kling 1988). In Lake Elsinore, the increase in maximum depth from 5 m to 10.5 m has a remarkable effect on the stability of its water column, which increases from 18 to >60 J/m^2 (Lawson and Anderson 2007).

The presence and abundance of light in lakes controls many biological processes. For primary producers in water bodies, light is the primary source of energy for photosynthesis. The levels of light under the water is influenced by the time of the day, the season, the depth in the water body, the transparency of the water, the nebulosity, and the altitude of the lake. Figure 5.2 presents hourly data from light sensors placed at different depths. In the first two of the three shown days, the light was 2 m deep, but not 5 m, thus indicating a relatively low euphotic zone in the Qaraaoun Reservoir.

5.4 Overview of Its Physico-chemical Characteristics

Water transparency is often low in the Qaraaoun Reservoir ranging between 0.5 and 2.5 m with little seasonal variation (Fadel 2014). Specific conductivity ranges between 405 and 490 µS/cm (Fadel et al. 2015). The pH of the reservoir during the past 10 years has been high ranging between 8 and 8.5. Total dissolved solids ranges between 200 and 400 mg/l (Saadeh et al. 2012).

Turbidity is mostly affected by suspended phytoplankton biomass (Fadel et al. 2016). Turbidity measured during 2015 ranged between 10 and 176 NTU. It was highly correlated with chlorophyll-a measurements with $R^2 = 0.94$ for a wide range of chlorophyll-a concentrations, 36–423 mg m^{-3}. The Qaraaoun Reservoir is a monomictic water body that strongly stratifies between May and August as shown in Fig. 5.2. This prevents the resuspension of bottom sediment and the physical-chemical exchanges between the different layers of the water columns. No mixing is induced by the river inflow into the reservoir because the inflow rate is negligible between May and August each year due to lack of precipitation (Assaf and Saadeh 2008).

Dissolved oxygen often ranges between 4 and 14 mg/l at the surface. Hypoxia occurs at a depth >15 m and is thought to be established after thermal stratification with a sharp decrease in oxygen concentration between 10 and 15 m, thus presenting the oxycline depth during summer season. Subsurface chlorophyll-a concentration measured in the period between 2011 and 2016 reached as high as 450 µg l^{-1} during July 2015 (Fadel 2014; Fadel et al. 2016).

5.5 Evolution of the Trophic State

Eutrophication is a serious ecological problem in the Qaraaoun Reservoir. This phenomenon results from the nutrient enrichment of water bodies, mainly by phosphorus and nitrogen, which are essential components to increase the primary productivity of the ecosystem. The phosphorus and nitrogen concentrations are always lower during the dry season than the wet season (Fadel et al. 2014a). Lake overturns in wet seasons lead to the release of nutrients from sediments through the water column. The nutrient concentration can decrease to undetectable levels at the subsurface in the dry season due to consumption by the primary producers, i.e., the phytoplankton.

The Carlson Trophic State Index (CTSI) (Carlson 1977), an index used by the Environmental Protection Agency (EPA) as well as worldwide for the purpose of classifying and ranking lakes, most often from the standpoint of assessing water quality, has been applied to the Qaraaoun Reservoir during the last few years.

In 2013 and 2015, the CTSI ranged between 66 and 84. In 2013, the CTSI was <70, thus classifying the reservoir as eutrophic. The CTSI was much higher in 2015, >70, thus classifying the reservoir as hyper-eutrophic. Previous studies performed on the reservoir in 2004, 2005, and 2010 classified the reservoir as eutrophic to hypereutrophic. Results of 2013 and 2015 show that the reservoir's trophic state has not improved during the last 10 years (Fadel et al. 2014a, 2016).

Deterioration of the Qaraaoun Reservoir's water quality is attributed to many sources of contamination such as agricultural waste runoff, untreated municipal and industrial wastewaters, and liquid and solid wastes being dumped into the Litani River. According to a study performed by Stephenson et al. (1998) in September 1997, sewage and industrial waste produced by factories, such as paper and sugar beet factories, were found to produce toxic organic chemical compounds, e.g., dichlorobenzene, which is considered a sewage marker and has been shown to be toxic to aquatic invertebrates and fish by inhibiting their growth (Mortimer and Connell 1995). These sources of contamination in the Litani River and its tributaries are the principle causes of turbid river water and high nutrient discharges leading to algal blooms in the Qaraaoun Reservoir.

5.6 Heavy Metals and Pesticides

Heavy metals are not degradable, and they get deposited in water as sediment and therefore exist in aquatic animals (Calace et al. 2002). Hence, their occurrence in water bodies receives particular concern considering their strong toxicity even at low concentrations (Duruibe et al. 2007; Quinn et al. 2003; Raikwar et al. 2008). They can originate naturally from leaching off or as deposits, sediments, or products extruded by volcanoes. However, anthropogenic activities increase heavy metals in aquatic ecosystems. The bioaccumulation and biomagnification of metals in aquatic animals, mainly in fish, make them good indicators of the contamination of aquatic ecosystems in heavy metals (Gupta et al. 2009; Malik et al. 2010).

Comparison between heavy-metal measurements performed in 1995 and 2008 by Jurdi et al. (2002) and Korfali and Jurdi (2010) showed no considerable variation in the concentration of Ca^{2+}, Mg^{2+}, Na^{-}, and Cu^{2+}. However, an obvious decrease in Zn^{2+} was observed in 2008 reaching half of its concentration in 1995. Moreover, Cr^{3+} concentration decreased to 0.06 μmol/l. In addition, there was an enormous increase in the concentrations of Fe^{3+}. The increase in industrial discharges (tanning, dyeing, mineral processing, and electroplating) can explain the great increase in Fe^{3+} concentration.

Fishing in freshwater is limited in Lebanon. However, fishing in Qaraoun Reservoir produces notable quantities of fish compared with sporadic fishing in rivers such as the Litani and Ibrahim. About 30 fishermen practice net fishing with about 15 traditional small boats in the Qaraaoun Reservoir, catching about 30 metric tons/ year, mainly carp (*Cyprinus carpio*) and common trout. In 2005, the LRA conducted a quantification of heavy metals in seven fish samples (Litani Basin Management Advisory Services 2005). The results showed that chromium levels in the sampled fish are significantly below the Food and Drug Administration (FDA) levels. However, cadmium and lead levels exceeded the FDA guidelines

(Fadel et al. 2014a). These high concentrations of heavy metals in some fish samples may be indicative of the bioaccumulation of heavy metals in the low-contaminated water of the Qaraaoun Reservoir (Ebrahimpour et al. 2011; Vinikour et al. 1980).

Pesticides are widely used in agricultural practices by farmers in the Bekaa region. They are inherently toxic to phytoplankton, zooplankton, and fish. According to the Stockholm convention, the most important pesticides to be considered for their adverse effects on the environment and on human beings are aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, and toxophene. In the Qaraaoun Reservoir, detected pesticides with the highest concentration include fenpropathrin (220.1 ng L^{-1}), bifenthrin (33.7 ng L^{-1}), and chlorpropham (34.6 ng L^{-1}). Lindane, endosulfanesulfate, chlorpyrifos, diazinon, alachlor, bromopropylate, procymidone, pendimenthalin, and tetradifon were also detected during the period between March and May 2011 with an individual concentration reaching 10 ng L^{-1} (Kouzayha 2011).

5.7 Phytoplankton Community of the Qaraaoun Reservoir

Qaraaoun Reservoir has been subject to major changes in its phytoplankton community during the last 20 years. Before the year 2000, diatoms dominated the reservoir and comprised 80% of the total phytoplankton community (Slim 1996). Qaraaoun Reservoir has a high phytoplankton biodiversity. More than 90 species were identified between 2000 and 2001, among which about 60 species of planktonic diatoms were dominated by *Aulacoseira granulata* and dinoflagellates by *Ceratium hirundinella*. Between 2002 and 2003, *C. hirundinella* disappeared, and Filamentous green algae (*Cladophora glomerata*, *Spirogyra lambertiana*, *Oedogonium* sp., and *Ulothrix zonata*) dominated the reservoir (Saad et al. 2005). A complete list of the main phytoplankton species identified between early the 1990s and 2016 is presented in Table 5.1.

Toxic cyanobacterial blooms of two major species (*A. ovalisporum* and *M. aeruginosa*) were first reported in 2009. Since then, these two cyanobacterial species, together with other phytoplankton species, have been dominating the lake with a predictable and similar blooming pattern each year (Figs. 5.3 and 5.4). *A. ovalisporum* is mostly seen at the beginning of spring and autumn, whereas *M. aeruginosa* is seen in summer. *A. ovalisporum* optimal temperature is lower than that of *M. aeruginosa*, thus allowing it to dominate during spring and autumn.

In freshwater bodies around the world, *M. aeruginosa* grows best at a temperature between 28 and 32 °C and has a minimal growth temperature of 20 °C (Imai et al. 2009; Robarts and Zohary 1987). Although *A. ovalisporum* is a nitrogen-fixing bacteria, capable of providing its own nitrogen sources by fixing the atmospheric nitrogen, it is outcompeted by *M. aeruginosa* in the Qaraaoun Reservoir whenever water temperature reaches >25 °C.

Table 5.1 Main identified phytoplankton species* during field campaigns performed between the early 1990s and 2017

Cyanobacteria	Chlorophyta	Diatoms
Anabaena spiroides	*Ankistrodesmus falcatus*	*Achnanthes exigua*
An. circinalis	*Botryococcus braunii*	*Ac. minutissima*
Aphanizomenon ovalisporum	*Cladophora glomerata*	*Amphora ovalis*
Dactylococcopsis irregularis	*Closterium acutum*	*A. veneta*
Da. rhaphidiodes	*Cl. ehrenbergii*	*Aulacoseira granulata*
Lyngbya kutzingii	*Coelastrum microporum*	*Caloneis silicula*
Merismopedia glauca	*Cosmarium formosulum*	*Cocconeis placentula*
Me. punctata	*Dictyosphaerium pulchellum*	*Cyclotella glomerata*
Microcoleus vaginatus	*Desmodesmus communis*	*C. meneghiniana*
Microcystis marginata	*Haematococcus pluvialis*	*C. ocellata*
Mi. robusta	*Kirchneriella obesa*	*Cymatopleura elliptica*
Mi. aeruginosa	*Oedogonium spp.*	*C. solea*
Mi. ichthyoblabe	*Pediastrum boryanum*	*Cymbella affinis*
Mi. viridis	*Pe. duplex*	*C. tumida*
Mi. botrys	*Scenedesmus crassus*	*C. ventricosa Kütz*
Oscillatoria agardhii	*Sc. quadricauda*	*Diatoma elongatum*
Os. amphibia	*Spirogyra lambertiana*	*D. vulgaris*
Os. articulata	*Staurastrum brachioprominens*	*Diploneis puella*
Os. irrigua	*St. manfeldtii*	*Eunotia pectinalis*
Os. raciborskii	*Tetraedron minimum*	*E. tenella*
Os. tenuis	*Ulothrix zonata*	*Fragilaria brevistriata*
Phormidium retzii	*Volvox aureus*	*F. capucina*
Pilgeria brasiliensis		*F. famelica*
Pleurocapsa minor		*F. ulna*
Pseudoanabaena catenata		*Frustulia vulgaris*
Radiocystis geminata		*Gomphonema constrictum*
Spirulina platensis		*G. dichotomum*
Sp. princeps		*G. lanceolatum*
		G. parvulum
		Gyrosigma acuminatum
		Hantzschia amphioxus
		Melosira varians
		Meridion circulare
		Navicula cincta
		Navicula cryptocephala
		Navicula cuspidata
		Navicula menisculus
		Navicula pupula
		Navicula rhynchocephala
		Nitzschia amphibia
		Nitzschia apiculata.
		Nitzschia gracilis
		Nitzschia intermedia
		Nitzschia linearis
		Nitzschia palea
		Nitzschia recta
		Nitzschia thermalis
		Surirella biseriata
		Surirella ovata
		Thalassiosira fluviatilis

*In addition to Dinophyta species *Ceratium hirundinella*

Fig. 5.3 Main blooming phytoplankton species between 2011 and 2016. Chlorophyta species include *Volvox aureus* (V.A.), *Coelastrum microporum* (C.M.), *Botryococcus braunii* (B.B.), *Staurastrum manfeldtii* (S.M.). *Dinophyta* species include *Ceratium hirundinella* (C.H.). *Cyanobacteria* species: *Aphanizomenon ovalisporum* (A.O.) and *Microcystis aeruginosa* (M.A.). Diatoms species include *Aulacoseira granulata* (A.G.) and *Melosira varians* (M.V.)

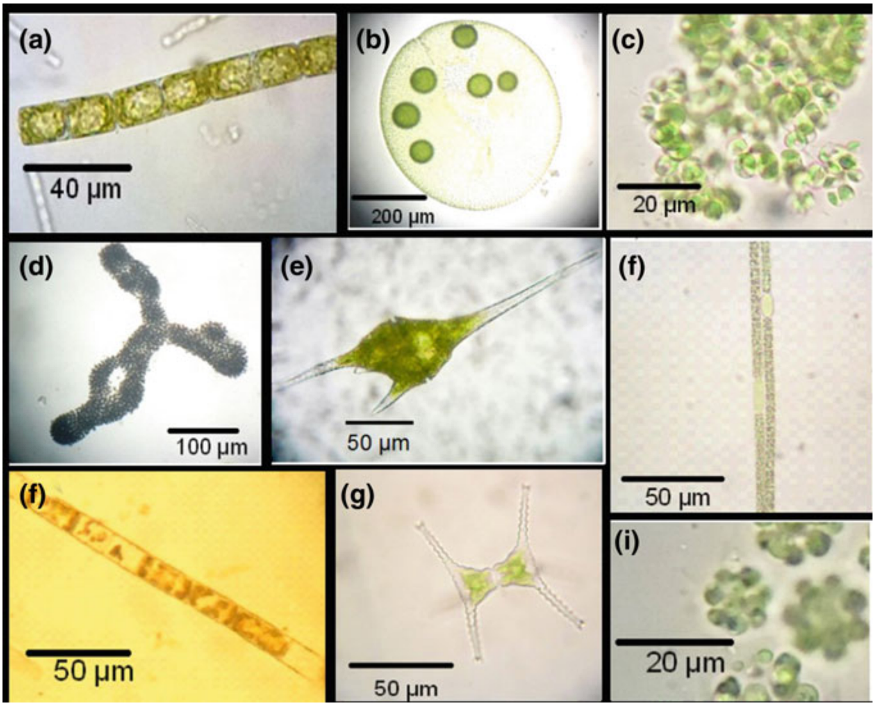

Fig. 5.4 Main blooming species in Lake Qaraoun: **a** *Melosira varians*, **b** *Volvox aureus*, **c** *Botryococcus braunii*, **d** *Microcystis aeruginosa*, **e** *Ceratium hirundinella*, **f** *Aphanizomenon ovalisporum*, **g** *Aulacoseira granulata*, **h** *Staurastrum manfeldtii*, and **i** *Coelastrum microporum*

Species diversity is greatly reduced during the blooms of *M. aeruginosa* and *A. ovalisporum.* When they bloom in the Qaraaoun Reservoir, they constitute >95% of the total phytoplankton biomass with the minor occurrence of two or three species.

Green algae species occur in the Qaraaoun Reservoir between spring and early summer. *Volvox aureus*, *Coelastrum microporum*, and *Botryococcus braunii* usually coexist with other phytoplankton species during spring, thus contributing to greater biodiversity during the year. However, another green algae species, known as *Staurastrum manfeldtii*, is usually identified in high biomass during early summer, which may co-exist with the *M. aeruginosa* that takes over in August and September. Diatom species *A. granulata* and *Melosira varians* are usually identified in low concentrations during the year, with *A. granulata* occurring in April and November and *M. varians* between March and April at a lower water temperature and weak thermal stratification.

Thus far, only dinophyta species *C. hirundinella* has been identified in the Qaraaoun Reservoir. It dominates in late autumn during weak thermal stratification at a low water temperature and light intensity. Increase in nutrient concentration through inflows and destratification favored by low water level is thought to re-suspend *Ceratium* cysts from the sediment and promote their the development as occurs in the Billings Reservoir (Matsumura-Tundisi et al. 2010).

Chlorophyll-a is a pigment found in all phytoplankton species and is used as an indicator of their abundance. A high spatial variation of chlorophyll pigment was recorded during a bloom of buoyant cyanobaterium, *A. ovalisporum*, on 10 July 2015 with concentrations ranging between 95 and 440 μg/l (Fig. 5.5). Such phenomena of high spatial variation can be attributed to horizontal displacement or different nutrient distribution. Humphries and Lyne (1988) found that high rising velocities of *M. aeruginosa* could concentrate them near the surface and favor scum formation, thereby incurring losses from wind-driven advection to the edges. Wind speed and direction were found to be the main reason affecting the spatial distribution of phytoplankton, especially *Microcystis*, in lake Taihu (Chen et al. 2003). Floating cyanobacteria were passively displaced by surface currents to the southern region of the reservoir as well, thus accumulating near the dam (Moreno-Ostos et al. 2006). This signifies that the use of a single station to monitor in situ chlorophyll-a at the Qaraaoun Reservoir can be insufficient during some bloom events because it may overestimate or underestimate chlorophyll-a concentrations compared with the amount of chlorophyll-a averaged over the reservoir area.

5.8 Zooplankton of the Qaraaoun Reservoir

Phytoplankton represent an important feeding source for many herbivores that inhabit water bodies such as zooplankton, zebra mussels, and planktivorous fish. Zooplankton dominated in the Qaraaoun Reservoir when the cyanobacterial

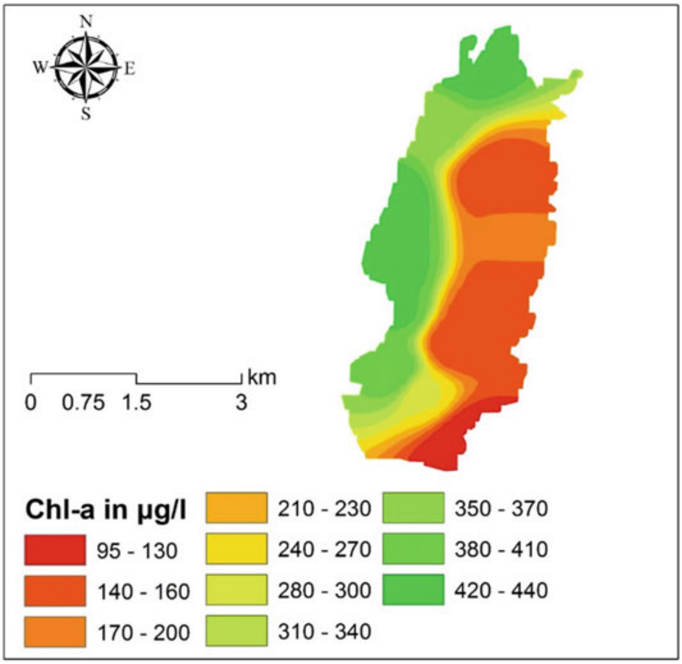

Fig. 5.5 Spatial variation of chlorophyll-a concentration in Qaraaoun reservoir on 10 July 2015

biomass was low. Four zooplankton species were reported in the reservoir during spring 2016 (Fig. 5.6).

Nine zooplankton species were found in the lake in 2012 and 2013: two rotifers (*Asplanchna periodonta* and *Keratella cochlearis*), three cladocerans (*Chydorus sphaericus*, *Daphnia magna* and *Moina rectirostris*), and four copepods (*Eudiaptomus drichii*, *Mesocyclops ogunnus, Mr. leuckarti,* and *cyclopoid nauplii*). Grazing by zooplankton can cause a loss in the small-sized phytoplankton groups (Wang et al. 2010; Zhang et al. 2009). Large-sized *Daphina* can consume small-sized toxic cyanobacteria colonies with a diameter generally <50 µm, but they have difficulties ingesting large-sized colonies. Rohrlack et al. (1999) found in the laboratory that colony-forming *M. aeruginosa* produce mucilage that has an inhibitory effect on the swallowing and consequently, ingestion rate of these cyanobacteria by *Daphnia galeata*. The ingestion rate of a phytoplankton community depends on the duration of the application of *Daphnia* and the presence of fish that affect the process of grazing (Sarnelle 2007). It is a complex process that is dependent on the colony size and presence of fish. More frequent monitoring is recommended in the coming years to understand the fluctuations of the zooplankton community and their interaction with the cyanobacterial community in the Qaraaoun Reservoir.

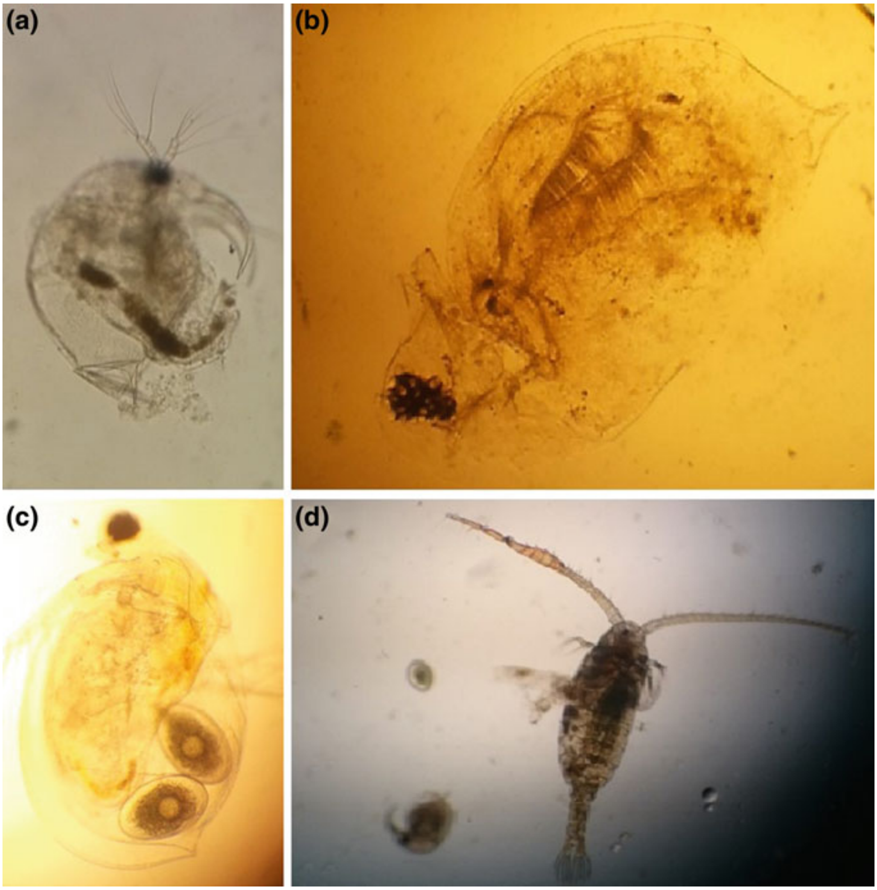

Fig. 5.6 **a** *Bosmina longirostris*, **b** *Diaphanosoma brachyurum*, **c** *Ceriodaphnia reticulate*, **d** *Eudiaptomus driesch* identified in Qaraaoun Reservoir in Spring 2016

5.9 Suitability of Water for Different Uses

Several negative economic impacts can results in the deterioration of the water quality of lakes. This may include the reduction and prevention of recreational and touristic activities, clogging of irrigation pumps, and breakdown in power–generation tools (Smith 2003).

Meanwhile, the Qaraaoun Lake is currently used for hydropower generation and limited recreational activities. It not suitable for several other uses under its present conditions. Drinking or swimming are not recommended because swimmers may experience abdominal pains, nausea, diarrhea, and skin irritations due to skin contact or ingestion of water containing toxic cyanobacteria and/or their toxins (Fadel et al. 2014b). Studies show that damage to liver and nerves has been detected after long-term exposure such as drinking potable water with toxic algal blooms. Although there is no confirmation of human death from those toxins, several studies have reported the death of animals and water inhabitants after being exposed to toxic cyanobacteria.

Irrigation and fishing activities can also be at high risk during and after toxic cyanobacterial blooms. Transfer of microcystins and anatoxin-a to edible fish and diverse tissue distribution of MC variants were reported by Pawlik-Skowrońska et al. (2013). However, a recent study by Hardy et al. (2015) found that levels of cyanotoxins were greater in fish liver than in tissues and muscles, whereas nearly no accumulation of MCs was found in fish fillets, thus supporting the safe consumption of $\leq$two 8-oz fish fillet meals/wk from water bodies with toxic blooming cyanobacteria.

The phytotoxicity of Cylindrospermopsin toxin, produced by *A. ovalisporum*, was investigated by applying toxin-containing water from the Qaraaoun Reservoir to seeds and seedlings of tomato (*Lycopersicon esculatum L.*) and cucumber (*Cucumis sativus L.*). Results showed that seed germination of cucumber and tomato was decreased after exposure to greater concentrations of Cylindrospermopsin. A significant reduction in the length of stems and roots, as well as the number and size of leaves, appeared on the seedlings exposed to Cylindrospermopsin toxin. In addition, other symptoms, such as chlorosis and leaf necrosis, after a reduction in the chlorophyll content was also noticed (Temsah et al. 2016).

5.10 Conclusions and Perspectives

In this chapter, we assessed the physico-chemical characteristics and ecological status of the Qaraaoun Reservoir. The lake, considered monomictic, stratifies during spring and summer, thus providing different physico-chemical composition throughout the water column. Its trophic state has not improved during the last few years classifying it as hyper-eutrophic lake. Several types of pesticides are present in the lake at both high and low concentrations. The phytoplankton community in the lake has changed during the last few years with reduced biodiversity and dominance of toxic cyanobacterial blooms in addition to other phytoplankton species. The zooplankton community remains understudied. Its water can be used for hydropower generation and limited recreational activities. However, swimming and drinking should be avoided.

Effective management of water quality in the Qaraaoun Reservoir is highly recommended to improve it. This may be started by treating wastewater discharges from industries and municipalities in the reservoir catchment area to control the levels of enriching nutrients (mainly phosphates and nitrates) and to prevent eutrophication. Also needed for effective management are raising awareness among LRB inhabitants; controlling and treating domestic sewage, municipal, and industrial solid wastes that flow into the river; and enforcing the on-site treatment of industrial wastewater effluents discharged into the Litani River and its tributaries.

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Chapter 6
Groundwater Quality in the Upper Litani River Basin

Nabil Amacha and Safaa Baydoun

Abstract Groundwater in the Upper Litani River Basin (ULRB) has in recent years become highly vulnerable to contamination, thus impacting socioeconomic development and community resilience in the basin. Drivers—such as anthropogenic pressures, high infiltration of karstic aquifer features, and climatic changes—are the causes of extensive stress on this important resource. Although unsustainable agricultural practices still have the most widespread impact on groundwater quality, wastewater and solid waste (SW) disposal from *urbanized agglomerations* and industrial enterprises have increasingly become serious sources of pollution. In the absence of comprehensive long-term monitoring programs, the findings of several projects and studies have recorded high nitrate, total dissolved solids, and *fecal coliform* levels exceeding standard limits for drinking water and irrigation purposes in different zones across the basin. Although the concentrations of some heavy metals may be still too low to generate acute adverse health impacts, their effects may become serious in the near future given the sudden increase in population due the surge of Syrian refugees into the basin and the changing climatic conditions. Specifically, the nitrate level, which exceeds the suitability limits for irrigation, currently stands as a major concern and may cause economic and productivity losses, especially with low levels of farmer extension services and poor agricultural practices. Supported by international-development programs, noteworthy national efforts have been initiated to enhance basin management. However, political conflicts, unclear institutional responsibilities, and economic challenges may impede effective implementation. This review calls for a long-term monitoring of groundwater quality and addresses the need to consider groundwater quality as an integral component for the management of water resources of the basin.

N. Amacha (✉)
Faculty of Sciences, Lebanese University, Beirut, Lebanon
e-mail: nabilamacha@hotmail.com

S. Baydoun
Research Center for Environment and Development,
Beirut Arab University, Bekaa, Lebanon

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6.1 Introduction

Groundwater in the Upper Litani River Basin (ULRB) represents a significant component of the hydrological cycle of the Litani River watershed and continues to be the primary source of water for agriculture, domestic, and industrial uses. This important resource is currently facing enormous natural and anthropogenic pressures adversely affecting its valuable consistent good quality (LRBMS 2010; SWIM 2013). The issues of groundwater quality in the ULRB have recently become a growing national concern due to the sudden increase in population, lack of well-planned urbanization, inadequate wastewater and solid-waste services, as well as the overuse of agrochemicals. Although the overall extent of the problem is not well-monitored, several studies and many individual contaminated wells have shown considerable levels of contamination across the different zones of the basin (BAMAS 2005; Darwich et al. 2011; LRBMS 2010; Baydoun et al. 2015).

Since the last decade, groundwater quality in the ULRB has become severely crucial for economic growth and livelihood development due to water scarcity and severe water-quality deterioration of the Litani River under the extended drought conditions in the region. A new NASA study finds that the recent drought that began in 1998 in the Easter Mediterranean Levant region is likely the worst drought to have occurred during the past nine centuries (NASA 2016). The strategic importance of good groundwater quality for water and food security in Lebanon, particularly in rural regions, such as the ULRB, will probably intensify under the changing climatic conditions. Despite the major uncertainties, population growth in Lebanon is likely to increase the water demand while shrinking the water supplies. Temperatures are projected to increase around 1–2 °C by 2040 and 3.5–5 °C by 2090 accompanied by 10–20% decrease in rainfall by 2040 and 25–45% by 2090. Significantly less wet and substantially warmer conditions will result in intensified temperature and extreme precipitation followed by more frequent and extended drought periods, thereby jeopardizing the groundwater quality (MOE/UNDP/GEF 2011, 2015; Gurdak et al. 2012). In 2008, Assaf and Saadeh developed a simulation model for water-quality evaluation and pollution management. The model showed that discharging untreated sewage in the Litani River Basin (LRB) will cause wide-scale pollution that would escalate to an alarmingly hazardous state during the dry season, and drought spells are expected to increase in frequency and duration under the climate-change conditions (Assaf and Saadeh 2008).

Representing the major agricultural land in the country, groundwater in the ULRB falls under a moderate to high vulnerability category due to the high infiltration of karstic aquifers forming the major hydrological units of the resource (Metni et al. 2004; Darwich et al. 2008; LRBMS 2012). The seasonal fluctuation of groundwater levels in the ULRB is an additional factor promoting the spreading contamination (Metni et al. 2004). When the water tables rise during the wet season, they may come in contact within the previous vadose zone with soil horizons that were able to retain significant contamination levels. The submerged contamination may now spread out to reach water tables or transport to the deeper saturated zone during the declining water levels (Metni et al. 2004; Darwich et al. 2008).

The environmental degradation of the ULRB has in recent decades become one of the greatest threats to the Lebanese ecosystem's impeding economic growth and sustainable development at both the basin scale and the national level. In 2012, the cost of water-resources degradation in the ULRB was estimated at US$227 million, which is equivalent, on average, to 2.2% of the GDP in the ULRB and 0.5% of the GDP at the current national GDP of Lebanon. Water degradation represented 77% of the overall cost (US$175.7 million), 49% of which was quality-related (US $86 million), thus confirming the heavy pollution and poor water quality associated with the lack of adequate wastewater and solid-waste services in the basin (SWIM 2013). Degradation cost associated with waterborne diseases reached $49.33 million with hepatitis A being prevalent in the basin, contributing to 30.25% of the national prevalence *based* on accumulated *reportable cases* to the Epidemiologic Surveillance System of the Ministry of Public Health (SWIM 2013; MOPH 2017). With the Syrian conflict now entering its 8th year, the unexpected increase in the Lebanese population, as much as 37%, has contributed extra pressure on the natural resources of the ULRB. According to the UN, nearly half a million registered refugees are living in Bekaa with thousands more illegally residing or awaiting registration, thus adding pressure on the already fragile water resources, public services, and wastewater infrastructure (MOE/EU/UNDP 2014; UNHCR 2016).

Despite the overall political instability, frequent *terrorist attacks,* and sluggish economic performance, the Lebanese government, assisted by international development programs, has been able to initiate a series of reforms in the water and wastewater sectors during the last 5 years. In this context, the Ministry of Energy and Water (MOEW) has completed a draft of the Water Code—with the assistance of the Agence Française de Développement—which is still awaiting governmental approval. In 2012, the MOEW National Water Sector Strategy 2010–2020 (NWSS) —aiming at ensuring continuous and optimal water supply, irrigation, and sanitation services while committing to environmental, economic, and social sustainability—was adopted by the Council of Ministers (MOEW 2012). The NWSS proposes a series of investments and measures for improving wastewater management, promoting and improving water-quality management, and protecting recharge zones. In 2011, the Ministry of the Environment (MOE) completed the Business Plan for Combating Pollution of the Qaraaoun Lake (MOE/UNDP/ELARD 2011). Of the US$255 million programs identified in the plan, the first tranche, approved for financing by a loan from the World Bank (US$55 million), focuses on reducing municipal wastewater pollution (WB 2016). The Central Bank of Lebanon and MOE, supported by the World Bank and the Italian Cooperation Agency, initiated the Lebanon Environmental Pollution Abatement Program (LEPAP) (MOE and UNDP 2017) in 2014 to tackle industrial pollution and encourage green investments through a combination of regulations and incentives.

This chapter aims to review the groundwater quality and related challenges in the ULRB. It will contribute to the development of a clear, aggregate picture and build awareness toward a more effective integrated-management strategy of groundwater in the ULRB while maximizing the economic and social benefits of the basin.

6.2 Hydro-Geographical Setting and Groundwater of the ULRB

The Litani River is the longest and largest river in Lebanon. The river rises from the Al-Oleik spring in the north east of the Bekaa Valley and flows entirely within the boundaries of the Lebanese territory for nearly 170 km in a southwest direction to meet the Mediterranean Sea at the south of Tyre. With an average flow of about 770 Mm^3/y, the river accounts for about 30% of the total water flow in all Lebanese rivers. The LRB covers about 2000 km^2, thus supporting the livelihood of 20% of the Lebanese territory. In 1950s, the Qaraaoun Reservoir hydro-electrical system was constructed with a reservoir of approximately 224 Mm^3 storage capacity purposed for irrigation and hydropower generation. Based on geomorphological features, the LRB may be divided into the upper basin, which covers about 1500 km^2 of the Bekaa valley (1000 m elevation) (Fig. 6.1) and the lower basin, which occupies the remaining 500 km^2. The Litani River has 16 tributaries with the Berdawni, Chtoura, and Ghzayel rivers being the most important ones (LRBMS 2011).

Extending between the city of Baalbeck and the surrounding villages in North Bekaa to the Qaraaoun Lake and its surrounding villages in West Bekaa, the aquifer systems of the ULRB (Fig. 6.1) comprise four main hydrogeological units (UNDP 1970), which are presented from younger to older as follows:

- The Quaternary−Neogene Aquifer is composed of two formations: the Quaternary deposits and the Miocene formation. It is an unconsolidated aquifer consisting of alluvial deposits, conglomerates, sand, silt, and clay. It has a thickness range from 0 to >700 m. It is found in the central part of the Bekaa plain. Groundwater flow in this unconsolidated aquifer is relatively low.
- The Eocene Aquifer has a thickness of 800–900 m and a high infiltration rate with preferential flow in karstic channels and fractures. It outcrops at the boundaries of the Bekaa plain within the highland areas on the eastern and western sides of the plain.
- The Cenomanian–Turonian Aquifer is considered as the second major aquifer in the ULRB, reaching a thickness of 900 m, and has high infiltration rates in recharge areas. It outcrops in the elevated areas of the eastern slopes in the northern part of Mount Lebanon and the western slopes of the Anti-Lebanon Mountains.

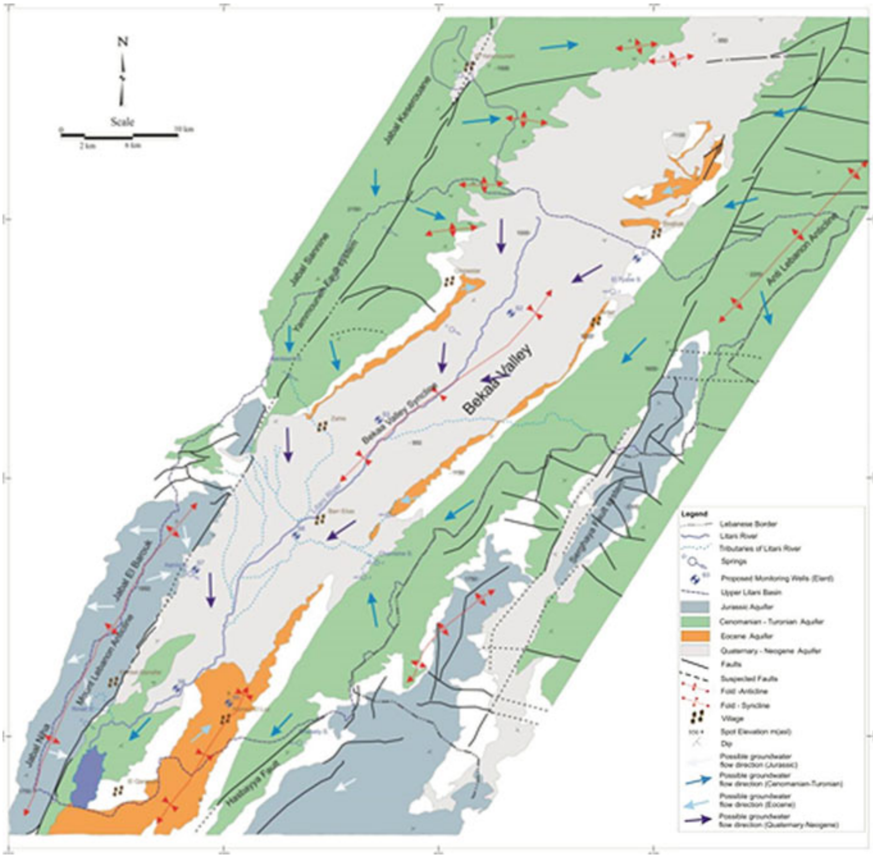

Fig. 6.1 Simplified schematic hydrogeological map of the ULRB. *Source* LRBMS (2012)

– Jurassic Aquifer is considered the first major karstic aquifer in the ULRB. It has a thickness of 1000 m and high infiltration rates in recharge areas with groundwater flowing preferentially in karstic channels and fractures.

According to the USAID program Litani River Management Support System (LRBMS), the total runoff in the river, estimated in 2010, was 300 Mm^3/y, and groundwater recharge was approximated at 210 Mm^3/y. Recent competing demands reached 210 Mm^3/y in 2010. The interplay between hydrogeological environments, climate change, and increased demands during recent years has resulted in a drastic increase in the number of groundwater wells in the basin. Thousands of government and privately owned wells, distributed all over the basin, provide about an estimated 150 Mm^3/y of water corresponding to 71.4% of all the furnished demands for domestic and industrial use and for irrigation in the basin (LRBMS 2011). Even before the Syrian conflict in 2011, human demands on water resources drastically increased in the past few decades resulting in uncontrolled water diversions of the Litani River and extensive groundwater pumping in the basin. Groundwater storage now shows large annual decreases estimated at 70 Mm^3 between 1970 and 2010 and is estimated to be 90 Mm^3 in 2030 without taking into consideration the large increase (LRBMS 2011; Amacha et al. 2015).

This drawdown is expected to continue in the future resulting in the drilling of more new wells and deepening the existing wells. It is certain that the current and future demands will exceed availability. Despite of this fact, plans to divert water from the Qaraaoun Reservoir for domestic use in Beirut (Bisri—Awali project) and to irrigate large areas in the south (Canal 800 project) are now underway.

6.3 Pollution Pressures in the ULRB

The geological history and climatic elements reflected in the variation of surface cover, soil types, and hydrology have allowed a variety of human activities in the ULRB including agriculture, industries, trade, and services. The LRB is home to many villages and small towns, most of which are concentrated in the ULRB (i.e., Baalbeck, Zahleh, Anjar, Bar Elias, Joub Jenine, and Qabb Elias). The population in the ULRB was estimated to exceed 1.1 million in 2012 with 77% rural population and 23% urban population (SWIM 2013). Now that a significant portion of Syrian refugees reside in the Upper Basin, the current population may exceed 1.6 million (MoE/EU/UNDP 2014). The LRB ranks high in poverty prevalence: 25% of the population is characterized as poor or very poor. The employment rate is <40% with agriculture contributing to 20% of incomes (SWIM 2013). According to LRBMS, land use consists of 50% natural lands, notably on the hillsides of Mount Lebanon and Anti-Lebanon; 40% of the agricultural lands is situated mostly in the Bekaa region; and 10% comprises the urban and peri-urban areas, industrial areas, quarries, roads/highways, and other constructed structures (LRBMS 2012).

In assessing the types and extent of pollution pressure, the Business Plan for Combating Pollution of the Qaraaoun Lake by MOE (2011) generated a database with visualized scenarios and thematic maps prioritizing hot spots with the highest risk for management plans and actions (Fig. 6.2). With some variations, moderate to heavy pollution pressures are noted to span across the different zones identified in the plan. The highest risk is generally associated with municipal and industrial wastewater in and around the large cities of Zahle and Baalbek, which generate a large number of substances of widely variable origin and diverse contamination processes. Evaluating the urban expansion in Lebanon between 1963 and 2005 using topographic maps and satellite images, Faour (2015) illustrated that the main cities of Zahle and Baalbek of the ULRB were among the cities in the country witnessing rapid urbanization rates (2.85 and 3.87%, respectively). Although there is always a margin of overlap, the major sources of pollution of the ULRB are discussed in the sections below.

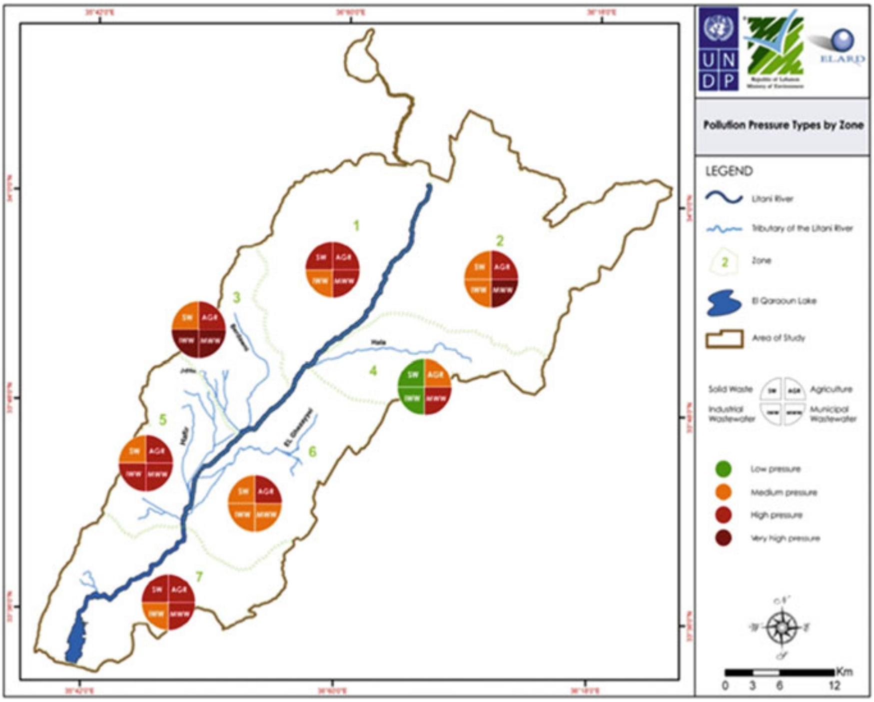

Fig. 6.2 Pollution pressures in ULRB. *Source* MOE/UNDP/ELARD (2011)

6.3.1 Municipal Wastewater

An estimated amount of 45.4 Mm^3 of untreated municipal wastewater (MWW) is discharged into the ULRB with a biological oxygen demand (BOD) load of 16,600 tons/y (MOE/UNDP/ELARD 2011). This volume has most certainly grown much larger due to the Syrian conflict with the ULRB being one of the sites of highest pollution impact on both surface and groundwater, which has been estimated at 13,840 tons/y of BOD (MOE/EU/UNDP 2014).

According to the Strategic Environmental Assessment of the New Water Sector Strategy for Lebanon (gef/WB/Plan Bleu 2015) and the Council for Construction and Development (CDR 2014), there are currently seven operating wastewater treatment plants in ULRB (i.e., Yammouneh, Baalbeck, Aitanit, Forzol, Ablah, Joub Janine, and Saghbine) with a total installed capacity of 39,500 m^3/d. Because these plants face major constraints of incomplete networks, inadequate technical capacity, and management, it is estimated that the operating capacity of these plants today is only about 19.9% and only 3.9% of total MWW of the basin is treated.

Municipal wastewater systems can be a source of a wide range of contaminants including nitrate and organic compounds from human waste as well as inorganic compounds used in household products such as detergents and disinfectants, solvents, gasoline, and diesel fuel. It can also contain microbial contamination, which may be the most common source for the health risk of small rural communities in the ULRB using septic tanks when groundwater contaminated with bacteria, viruses, and protozoa is used for drinking water (United States Environmental Protection Agency [USEPA] 2002; USGS 2017).

6.3.2 Industrial Wastewater

Industrial wastewater generated from about 294 industrial medium- and small-scale establishments in the ULRB was estimated at about 4 Mm^3 in 2011. Half of these industrial establishments are situated in the industrial zones of Zahleh and Taanayel. They include agro-business, plastics manufacturing, detergents, paper manufacturing, as well as dyeing and tanning and battery manufacturing. This waste contains a wide spectrum of biodegradable organic pollutants and non-biodegradable inorganic pollutants such as hydrocarbons, phenols and detergents, and several nitrogen and phosphate chemicals (MOE/UNDP/ECODIT 2011). With the lack of efficient wastewater management programs and incentives, industries not only in the ULRB but also across the country discharge their wastewaters, mostly untreated, into the sewer network or directly into the water bodies. The severity of the impact of industrial wastewater depends on the toxicity of pollutants considering pollutant loading and vulnerability (British Geological Survey 2008). Not only does industrial wastewater inflict considerable impact on groundwater quality, it can also affect other ecosystems and cause adverse effects on human and animal health. There is no doubt that effective treatment and reuse of treated industrial and domestic wastewater can substantially contribute to community development and the economic growth of the basin. This can only be achieved by effective management and concerted institutional efforts with more political will and security stability (UN-Water 2017).

6.3.3 Municipal and Industrial SW

According to the Country Report on Solid Waste Management (SWEEP-NET 2014), a total of 750 tons/d of SW (equivalent to 13% of the national total) was generated in 2013 in Bekaa, and the amount of SW at the country level reached 2.04 million tons/y. The report also shows that around 188,000 tons/y of industrial SW (ISW) was generated, of which 3,338 tons/y only was hazardous waste as referred to in the Basel convention. In the absence of well-defined legislations and stringent means of control, most of this ISW continues to be mixed with the municipal SW and follows the same collection procedures. Considering the current conditions prevailing in Lebanon and based on an average increase rate of 1.65%/y, it was estimated that SW generation will increase to 2.8 million tons/y by 2035 not taking into consideration the effect of the Syrian refugees. Zahle is the only city in the ULRB that has one operational sanitary landfill with a capacity to dispose 200 tons SW/d from 18 neighboring municipalities. In Baalbeck, another sanitary landfill with at least a 200,000 M^3 capacity is now under construction, which is expected to be in operation soon (UNDP 2017). This will hopefully help in reducing the amount of SW currently dumped into open landfills or directly into water bodies of the basin. This dumped SW represents a potential persistent environmental hazard to groundwater, which may last for years as leachate containing metals and various chemicals percolating through the soil to vulnerable aquifers, especially because SW in Lebanon has high moisture content, often exceeding 60% (SWEEP-NET 2014). With the emerging crises in SW management since 2015 and the absence of a management strategy for the country (Hilal et al. 2015; SWEEP-NET 2014)—coupled with the sudden population growth and increased urbanization pressure—SW remains a contamination risk in groundwater of the ULRB, which will adversely impact both public health and community resilience.

6.3.4 Agricultural Land-Use and Cultivation Practices

Pollution of vulnerable aquifers in the ULRB can be caused by agricultural activities, the influence of which may be significant because of the large areas of aquifer being affected. The danger of intensive cultivation practices lies in their ability to leach minerals and agrochemicals, or any of their transformation or degradation byproducts, down to water tables. Bekaa Valley represents about 42% of the total agricultural area and almost 50% of the irrigated Lebanese land. It is also home to 30% of the agro-food establishments, which were estimated in 2011 to generate 26.3% of the industrial sector's value (Asmar 2011; IDAL 2015). Despite the sluggish economic performance in recent years, the contribution of the agricultural sector to the GDP witnessed a small increase from 3.85% in 2010 to 4.04% in 2011. Although arguments differ regarding the key factors through which agricultural development is increased, it is generally agreed upon that fertilizer inputs paly a substantial role. Increasing agricultural productivity requires large inputs of fertilizers to replenish soil fertility and produce targeted yields (Syed and Miyazako 2013; Muir 2014). In 1999, Lebanon imported 1,530 tons of pesticides and almost 32,000 tons of fertilizers. Although Lebanon no longer imports a whole range of persistent pesticides, Lebanese soils are still potentially contaminated from the existing chemicals and residues because many pesticides that were commonly used are long persistent (MOE/LEDO 2001). Although current pesticides do not contain such chemicals, misuse may potentially pollute the soil and groundwater. Intensive fertilization and excess irrigation, commonly practiced by farmers in the region, multiply the risks of nitrate leaching beyond the root zone (Darwich et al. 2012). Fertilizer applications have been estimated to be 1.5–3 times the needed doses, and pesticide applications are twice the required doses, far exceeding plant growth and development demands and the good-yield target (MOE/UNDP/ELARD 2011; Darwich et al. 2012).

Livestock industry is also a valuable segment of the Lebanese economy and the socioeconomic structure of the ULRB. In 2003, dairy cattle, sheep, and goat milk production represented 7.2% of the total value of agricultural production. Since then, the sector has been witnessing major growth (Asmar 2011; MOA 2014). Despite limited studies, indications from different countries across the world revealed that leaching of nutrients (primarily nitrogen) and other constituents can reach groundwater at levels that may pose a high risk to environment and public health (World Health Organization [WHO] 2012; Harter et al. 2014). Although much of the livestock waste is used as a viable fertilization material, proper storage and development of a livestock waste—management system are important in minimizing the risk.

6.4 Groundwater Quality of the ULRB

Today, groundwater pollution in the ULRB has turned into a growing national concern and public health risk. This problem is exacerbated by climate change impact because extended dry periods and higher temperatures are likely to increase bacterial activity and pollution levels. Assessment of groundwater quality in the ULRB has received the attention of some research studies and short-term monitoring efforts. Findings of the Arab German Technical Cooperation Project, Management, Protection and Sustainable Use of Groundwater and Soil Resources in Arab Region (BGR/ACSAD/CNRS-CRS 1997–003), USAID funded Basin Management Advisory Services Project (BAMAS 2005–2007) and the Litani River Basin Management Support Program (ULRBMS 2009–2012) as well as several studies either focusing on a specific zone (Darwich et al. 2008, 2011) or spanning across the basin (Baydoun et al. 2015) provide a scientific basis for understanding groundwater quality in ULRB. These findings along with future generated evidance can support the decision-making process related to water-resources and land-use management aiming at a more sustainable and desirable future of groundwater resources in the basine. High levels of nitrate, fecal coliform, and *total dissolved solids* (TDS) make the water in some of the severely polluted wells unsuitable for human consumption and irrigation.

6.4.1 Nitrate

Moderate contamination of NO_3^- appears to be widespread in wells as assessed in several studies on the basin (Table 6.1) (BGR/ACSAD/CNRS-CRS 1997–2003; BAMAS 2005; LRBMS 2010; Baydoun et al. 2015). Concentration levels >50 mg/l are prevalent in most of the assessed wells rendering them unsuitable for drinking (Table 6.2) or irrigation purposes (Table 6.3). Analysis of the NO_3^- origin indicates a diffuse pollution originating from the excessive use of fertilizers in agricultural

Table 6.1 Groundwater quality profile of the Upper Litani Basin

Parameter	BAMAS (2005)*			LRBMS (2010)**			Baydoun et al. (2015)***		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum
TDS (mg/L)	NA	NA	NA	170.00	385.00	863.00	163.00	369.07	847.33
Nitrate (mg/L)	13.26	212.16	755.82	0.88	29.61	181.22	0.65	64.12	279.33
Sulfate (mg/L)	7.00	31.42	205.00	1.50	15.92	60.0	NA	NA	NA
Phosphate (mg/L)	0.00	0.30	12.00	0.10	1.20	6.43	NA	NA	NA
Fecal coliform (CFU/100 mL)	0.00	42.8	0.00	0.00	39.2	400.00	0.00	11.45	210.00

N/A = not applicable

*Results of 25 wells. **Results of 25 wells. ***Results of 20 wells

Drinking-water guidelines (Libnor 2017; USEPA 2017a, b): TDS 500 mg/L; Nitrate 50 mg/L; Sulfate 250 mg/L; Phosphate 1.35 mg/L; fecal coliform 0 CFU/100 mL

Table 6.2 Percentage (%)* of wells exceeding recommended national and international standard levels for drinking water

Parameter	BGR (1997–2003)	BAMAS (2005)	LRBMS (2010)	Baydoun et al. (2015)
TDS (mg/L)	56.6**	NA	4.0	30.0
Nitrate (mg/L)	80.0***	70.0	20.0	40.0
Sulfate (mg/L)	NA	35.0	0.0	NA
Phosphate (mg/L)	NA	3.0	0.0	NA
Fecal coliform (CFU/100 mL)	NA	35.0	16.0	25.0

*No. of wells assessed: 30 wells in BGR (1997−2003), 25 wells in BAMAS (2005), 25 wells in LRBMS (2010), and 20 wells in Baydoun et al. (2015). **Considered as TDS > 400 mg/L. ***Considered as NO_3^- > 40 mg/L

Table 6.3 Suitability of wells (%) for irrigation on FAO standards (300)*

Parameter	BGR 1997–2003			LRBMS 2010			Baydoun et al. 2015		
	None	Slight to moderate	Severe	None	Slight to moderate	Severe	None	Slight to moderate	Severe
TDS (mg/L)	43.4^{α}	56.6^{β}	0.0^{δ}	76.0	24.0	0.0	25.0	75.0	0.0
Nitrate (mg/L)	20.0^{λ}	46.6^{θ}	33.4^{γ}	87.0	13.0	0.0	10.0	65.0	25
Sulfate (mg/L)	NA	NA	NA	100	0.0	0.0	NA	NA	NA
Fecal coliform	NA	NA	NA	100	0.0	0.0	100.0	0.0	0.0

$^{\alpha}$TDS = < 400 mg/; $^{\beta}$TDS = 400−1300 mg/L; $^{\delta}$TDS > 2000 mg/L; $^{\lambda}NO_3^-$ < 40 mg/L; $^{\theta}NO_3^-$ = 40−200 mg/L; $^{\gamma}NO_3-$ > 200 mg/L

*FAO guidelines criteria for irrigation (FAO 2003): TDS < 450 mg/L = none; 450−2000 mg/L = slight to moderate; and >2000 mg/L = severe. NO_3^- N < 5 mg/L = none; 5−30 mg/L = slight to moderate; and >30 mg/L = severe. For NO_3^- multiply by 4.42. SO_4^{2-} < 400 mg/L = suitable. Fecal coliform <2000 CFU/100 mL = suitable

lands (e.g., Terbol in Central Bekaa) (Darwich et al. 2011), whereas contamination in other wells (e.g., Bar Elias, Saadnayel) was linked to the applications of fertilizers and the infiltration of open dumping sites (Baydoun et al. 2015). Although variations in contamination risk are evident in the various reported studies, it is important to emphasize that given the dynamic nature of groundwater in the ULRB, even mild levels NO_3^- may indicate appreciable contamination.

The availability of microelements and macroelements in the soil, particularly the mass ratios between elements, is also key in determining the extent of nitrogen leaching (Szczepaniak et al. 2013; Lawniczak et al. 2016). Reduction of fertilization level or one of the elements may not reduce nitrogen leaching because of the unfavorable ratio of nutrients in the soil. It is also suggested that deficiency of phosphorus or potassium limits the uptake of nitrogen by plants, even when the nitrogen level is sufficient, thus increasing the likelihood of nitrogen leaching (Lawniczak et al. 2009). Actually, this issue is considered a major global concern because a large share of the world's agricultural land suffers from potassium deficiency (Römheld and Kirkby 2010). Inadequate knowledge among farmers on good cultivation and agronomic practices, primarily fertilization application and requirements of the soil, plays a key role in aggravating the problem hampering management efforts.

To date, the magnitude of the risk of groundwater to public health has not yet been assessed in Lebanon. However, potentially significant health risk is believed to be associated with the consumption of nitrate-rich groundwater where groundwater is the main source of drinking. Excess nitrates in drinking water could *cause methemoglobinemia* or "blue baby disease" in infants of younger than 6 months of age. Other conditions—including diseases of the central nervous system, birth defects, certain cancers, diabetes mellitus, and hypertension among others—have also been linked to the consumption of high nitrates in drinking water (Keeton 2017). Progress has been made in assessing and monitoring studies with long-term monitoring programs, institutional policies, and regulatory measures to limit the use of fertilizers, which represent important tools for the development of effective and economic management of NO_3^- (FAO 2003; Darwich et al. 2011).

6.4.1.1 Total Dissolved Solids

Low to moderate TDS levels appeared to be present in the different assessed wells during the periods of the two monitoring studies with a 5-year interval reaching an overall means of 284 mg/l (LRBMS 2010) and around 369.07 mg/l (Baydoun et al. 2015). Both levels fall within the acceptable limit for drinking water according to the Lebanese (Libnor 2017) and USEPA standards (USEPA 2017b) as well as those of the WHO (2011) (Tables 4.1 and 4.2). For irrigation purposes, all assessed wells expressed a slight to moderate degree of suitability according to the FAO criteria (450–2000 mg/l) (FAO 2003) (Table 4.3). With the exception of manganese, which exhibited a high mean value at 0.07 mg/l—exceeding the guideline level of 0.05 mg/l—all other macroelements and microelements were within the recommended Lebanese standards and USEPA and WHO guidelines. The TDS levels recorded may originate from natural sources and, possibly, some leaching from domestic and industrial wastewater or SW open dumping sites as well as agricultural runoffs and livestock waste. TDS concentrations in natural groundwater usually <500 mg/l and water with >500 mg/l reflect potential contamination risk. This requires special management practices to maintain agricultural productivity and sustain soil fertility (FAO 2003). Long-term monitoring programs press on the growing importance of groundwater given the increased anthropogenic pressures and climate-change conditions.

6.4.2 Metals

In assessing the level of breadth of trace metals (nickel [Ni], chromium [Cr], cadmium [Cd], zinc [Zn], lead [Pb], aluminum, etc.) in a few wells in the ULRB, the ULRBMS Water Quality Survey-Dry Season in 2010 demonstrated that the levels of all assessed metals were within the USEPA and WHO standards for drinking water (USEPA 2017a, b; WHO 2008). Although the recorded levels currently may be too low to generate any acute adverse impact, the effects of long-term increased contamination might well-represent serious health problems in the future, especially when simultaneous exposure to multiple metals occurs. In excessive concentrations, metals can have negative health effects (Zhang et al. 2016; Belkhiri et al. 2017). Keeping in view the hazardous nature of trace metals, further investigations are imperative to assess and constantly monitor their levels in the groundwater of ULRB.

An earlier study carried out within the framework of the project Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region (BGR/ACSAD/CNRS-CRS 1997–2003) revealed that the deep groundwater in the basin contained lower concentrations of some metals (Ni, Cr, Zn, Pb). Although concentrations during the study period were within the permissible levels for both drinking and agricultural use, shallow, perched wells appeared to be more vulnerable than the deeper wells with regard to the assessed metals (FAO 2003; WHO 2011).

6.4.3 Fecal Coliform

The presence of high levels of fecal coliform (e.g., *Escherichia coli*), in most examind wells reaching 400 CFU/100 ml, presents a high public health risk in the basin (Table 6.1). This microbial contamination has been mostly associated with domestic sewage leaking from network pipes or septic tanks, SW dumping sites, and agricultural waste. In practice, the presence of fecal coliform bacteria is taken as an indicator of fecal contamination, thereby indicating the potential presence of associated pathogenic microorganisms. It is, nevertheless, believed that the bacteriological contamination of shallow wells and boreholes is widespread, whereas the migration of pathogens into deep wells is generally less likely. Furthermore, karstic aquifers are believed to be highly vulnerable to pathogenic contamination (Zheng et al. 2013). Nevertheless, this vulnerability cannot be exclusively linked to aquifer types and soil properties but also to other factors such as those derived from human activities (Llopis-Gonzalez et al. 2014). Karstic aquifers of the ULRB are highly likely to allow the rapid movement of pathogens from agricultural fields where untreated domestic wastewater is used for irrigation or manure is applied (Jamieson et al. 2002; Unc and Goss 2004).

From the perspective of the human use and consumption of groundwater, microbiological contamination has profound and severe implications for public health in areas where groundwater is often used for drinking water. Disinfection techniques, such as filtration and chlorination, are usually used to counteract this potential problem in public wells. However, the majority of private groundwater supplies do not undergo any treatment before use. Contaminated groundwater may sometimes lead to epidemics and can contribute to high morbidity and mortality rates from diarrheal diseases.

Unfortunately, some farmers are forced to use water containing high fecal coliform levels for the irrigation of various economic crops due to water scarcity and unavailability of alternative water sources, especially in the dry seasons of summer and fall (August through November). The poorly constructed sewage treatment works and raw sludge discharge in streams and natural lands can lead to groundwater contamination. However, the role of contaminated groundwater to the incidence of waterborne diseases in the ULRB cannot be easily estimated; reports from other countries across the world may offer good insight on the magnitude of the situation. Groundwater pathogen contamination has led to numerous disease outbreaks in the United States with 46 outbreaks, at least, occurring between 1992 and 1999 resulting in 2739 cases of illness and several deaths (John and Rose 2005).

Similarly, identifying sources of groundwater-pathogen outbreaks has also received significant attention in France (Grisey et al. 2010). In Lebanon, the recent assessment of the prevalence of diarrhea, as well as mortality due to diarrhea, in the Litani Basin due to poor water quality was estimated at 0.3 cases of deaths in 13 newborns/1000 inhabitants in 2012. The prevalence of diarrhea was 2.3 cases/children younger than 5 years of age and 0.45 cases/children older than 5 years or more of age (SWIM, 2013). The national epidemiological surveillance program of the Ministry of Public Health (MOPH) has in recent years registered a significant increase in trends in modifiable water and food borne diseases (MOPH 2017). Considering the limitation of the existing knowledge, long-term monitoring programs are necessary to assess the extent of the problem, develop management strategies to address the public health epidemic, and plan for the implementation of prevention, sanitation, and awareness components relevant to water and food quality (Pandey et al. 2012).

6.5 Conclusion

This review offers a distinctive insight on the vulnerability of the groundwater quality in the ULRB caused by the influence of karstic geological formations and anthropogenic activities. Unsustainable agricultural practices majorly impact groundwater quality. However, the risk of wastewater and SW from *urbanized agglomerations* and industrial enterprises is rapidly becoming very serious given the sudden increase in population due to the Syrian conflict and inflow of refugees into the country.

Although the concentrations of trace metals (e.g., Ni, Cr, Cd, Zn, Pb) may be currently too low or moderate to generate any acute adverse impact, the effects of long-term increased contamination might well represent serious health problems in the future especially when simultaneous exposure to multiple metals occurs. This review calls for further assessment studies and long-term monitoring of groundwater quality as well as addresses the need to consider groundwater quality as an integral component of the management of the water resources of the basin.

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Chapter 7
Improving Water-Use Efficiency and Productivity in the Litani River Basin

Ihab Jomaa and Amin Shaban

Abstract The Litani River Basin (LRB), with special emphasis on the upper part of the basin, occupies the largest area of arable land in Lebanon where agriculture is dominant. However, like many Lebanese regions, the upper part of the LRB suffers from water deficiency, and at the same time, the need for irrigation water is quite pronounced. The irrigation and the related aspects of water consumption in the area of concern follows many traditional and advanced techniques where a large part of the irrigated water is not used efficiently. This, in turn, affects water productivity, which affects crop yield. In this area of study, many institutes are concerned with improving the water-use efficiency and productivity, most notably in the irrigation systems. The Lebanese Agriculture Research Center (LARI) has applied several advanced techniques and applications in this respect. Therefore, results on water use and productivity are improving by using the new techniques provided by LARI to alert framers about meteorological forecasts and extending periodical instructions and awareness. This chapter reveals examples of these techniques and proposes new applications to be used in the LRB for better water use and crop yield.

7.1 Introduction

Water is a valuable commodity, and its availability has been a matter of debate, most notably given the increasing challenges regarding the physical system of the Earth and the changing human behavior toward water resources. Lebanon, as a semi-arid region, is a typical example where more than two thirds of its water goes

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I. Jomaa (✉)
Department of Irrigation and AgroMeteorology,
Lebanese Agriculture Research Institute, Tal Amara, Lebanon
e-mail: ijomaa@lari.gov.lb

A. Shaban
National Council for Scientific Research, Beirut, Lebanon

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into irrigation processes, certainly in the Bekaa Plain, the most fertile geographic region in Lebanon with thick soil deposits. However, many constraints have recently occurred, which have affected the agricultural sector in Lebanon. The Litani River Basin (LRB)—particularly the upper part of the catchment where several aspects of crops and vegetables are cultivated that account for the largest number of needs for the entire country of Lebanon—is a typical example.

Even though the Litani River spans along the Bekaa Plain, many challenges have put a huge stress on all kinds of water resources. The water shortage has been increasing on a yearly basis with the water quality being increasingly deteriorated. Crop productions have been facing low or no benefited market chain. Political and security situations in Lebanon might negatively affect the distribution of products. Importation calendars of agricultural products do not match the internal country production. Importation of agricultural products might enter the country through smuggling routes. Expensive fertilizers and pesticides have also been increasing the production cost. Fuel and energy costs adversely affect water pumping and other related agricultural practices. The groundwater piezomeric level has decreased rapidly under the agriculture intensification (Jomaa et al. 2015; Jomaa and Jualbert 2017). Small fragmented lands are preventing investment in the agricultural sector. Rapid urban encroachment is invading fertile agricultural lands.

There is an increased water demand for different purposes, which is attributed to the population growth, increased demand of domestic and agricultural uses, and existence of water use that is not accounted for, e.g., the use of water for commercial reasons, and this has been exacerbated by the climatic variability. Surface water and groundwater-quality deterioration occurs in response to chemical and organic contamination in the water. Moreover, sewage water—which is the main source of irrigation in the Bekaa Plain—is left to flow freely into the Litani River.

Agriculture is the largest user of water worldwide. Middle East and North Africa (MENA) region, the ratio is about 85 % of fresh water for irrigation (Meyer 2008; GRID and UNEP 2008; Evans et al. 2013). Irrigated agriculture extends over 270 million hectares and is increasing at a rate of 1.3%/y (Postel 1999; Morison et al. 2008). Water consumption for agriculture is directly related to irrigation efficiency, which has not been not well investigated in many regions worldwide.

Only small amounts of the water applied for irrigation reaches the plants' root zone, and the rest of the water is lost. Efficient use of water in agriculture is a target for research institutions and management organizations. WUE in agriculture has been extensively researched over the years. Increasing WUE provides benefits that go far beyond decreased water use (AFED 2014). The increasing water productivity and efficiency of irrigation can possibly be attained through the selection of suitable irrigation systems with proper irrigation scheduling, use of effective irrigation techniques, selection of appropriate crop varieties, and employment of alternative sources of water for irrigation.

7.2 Improving Irrigation Efficiency and Crop Productivity

Because water shortage is a major challenge in agriculture, especially in the arid and semi-arid regions such as the LRB and Bekaa, farmers should create alternative management approaches for irrigation to grow crops along with increased water productivity and efficiency. This represents the core decision in irrigation-management plans at all agricultural levels. Irrigation management mainly implies the following:

(1) Quantifying crop water requirements.
(2) Regulating the irrigation scheduling and WUE.
(3) Selecting the most suitable irrigation system.

7.2.1 Crop Water Requirements

Crop water requirement is a fundamental issue to balance water availability and the optimization of productivity. Proper irrigation technique is an integral part of water-conservation and -efficiency optimization. Hence, crop productivity was found to be related asymptotically to the number of water applications (Fig. 7.1) (De Pascale et al. 2006). Potential crop yields are not attained by applying the full crop evapotranspiration (ET). Under deficit irrigation, crop productivity could be optimized.

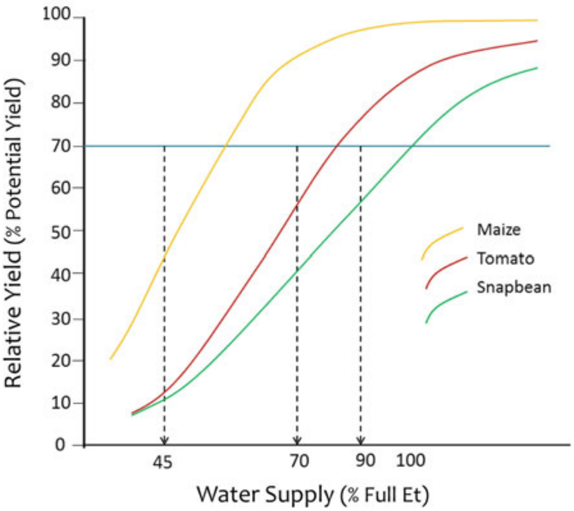

Fig. 7.1 General dose–response curves of crop yield to irrigation (De Pascale et al. 2006)

Table 7.1 Proposed approaches for increasing productivity and conserving water for irrigation in the LRB

Proposed improved approach	Impact[a]	Applicability in Bekaa valley[b]
Applying rain/water harvesting on different scales (e.g., small channels, mountain lakes, earth dams, etc.)	XXX	✓✓
Decrease conveyance losses by lining channels or, preferably, by using closed conduits	XXX	✓✓
Applying water-recharge techniques	XXX	
Increasing IUE and using the concept of deficit irrigation	XXX	
Improving irrigation scheduling and disseminate it through farmers	XXX	
Improve agricultural practices, e.g., decreasing evaporation (FAO 1997)	XXX	✓
Monitoring groundwater piezometric level and surface water discharges	XXX	
Installing wastewater-treatment plants to increase irrigation-water availability	XXX	
Applying the use of agrometeorology for enhancing irrigation scheduling and crop productivity	XX	✓✓

[a] Impact XXX = very beneficial; XX = beneficial

[b] Applicability in Bekaa valley: ✓✓ = moderately applied; ✓ = rarely applied

7.2.2 *Water-Use Efficiency (WUE)*

In regions where water is scarce and insufficient for irrigation purposes, it is necessary to increase crop productivity per unit of water applied, which is generally termed "water-use efficiency" (WUE) or productivity. In the LRB, especially in the Bekaa region, many approaches have been proposed for increasing WUE, productivity, and conservation as listed in Table 7.1.

In this respect, factors affecting irrigation scheduling are governed by climatic parameters, crops, and agricultural practices (Fig. 7.2). These factors may differ from one region to another in accordance with their physical setting.

Irrigation scheduling in the Bekaa Plain, which occupies a part of the LRB, can successfully follow the methods and tools collected and adopted from different sources (Table 7.2) (Folhes et al. 2009; McCready et al. 2009; Cardenas Lailhacar and Dukes 2010; Padhi et al. 2012; Nolz et al. 2013; Alhammadi and Al-Shrouf 2013; and AFED 2014).

7.2.3 *Proposed Irrigation Systems in the LRB*

Discussion and studies remain accounted for in the scientific society about the used irrigation systems and their efficiency (Iqbal et al. 2014). Drip irrigation is considered

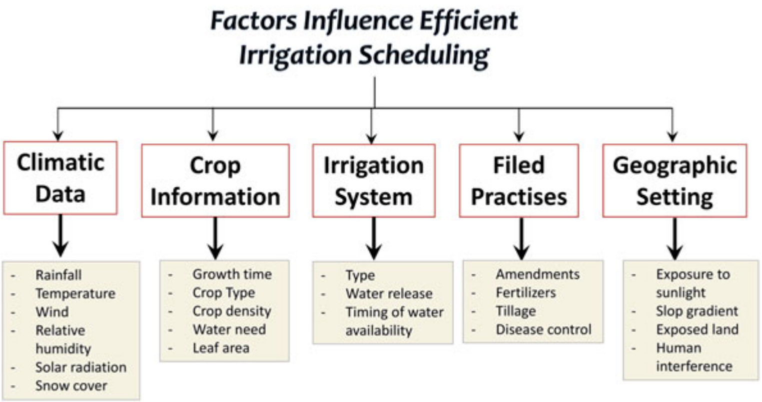

Fig. 7.2 Major factors influence irrigation scheduling

Table 7.2 Major methods used for optimized irrigation scheduling[a]

Scheduling methods	Method specifications
Visual observation	• Crop is at a specific growth stage • Crop is experiencing water stress • Water is available to irrigate • Soil-moisture check by hand investigation
Soil-moisture measures	• Soil moisture sensors indicate water availability in the root zone, e.g., gypsum blocks, granular matrix probes, tensiometers, capacitance probes, gravimetric methods, etc. • Sensors indicating the water status of the crop
Smart irrigation	Maintain soil water budget of the root zone • Daily measurement of the actual ET using lysimeters • Daily reference ET based on weather data • Crop coefficients for actual ET • Measure rainfall • Forecast daily water use • Compare computed with measured soil moisture
	Automatic irrigations (smart irrigation system) • Measured soil moisture level in root zone • Plant water potential • Computed soil-water depletions • Programmed time
Infrared thermometer	• Canopy temperature > air temperature: indicates stress irrigation is scheduled • Canopy temperature < air temperature: indicate plants have sufficient amount of water
Remote sensing	• Reflectance of solar radiation by plants with a sufficient amount of water is different from that of stressed plants • Infrared bands/satellite images

[a] Adapted from various sources

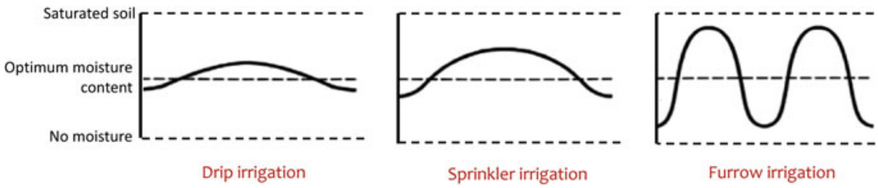

Fig. 7.3 Comparison of different irrigation systems (TWDP 2002)

one of the most efficient irrigation systems because it can achieve yield gains 100% and water savings $\leq$ 40–80% (Burney et al. 2009). In 2008, it was found that surface irrigation was predominantly used in <90% of irrigated agricultural lands in most parts of the MENA region (Frenken 2008). Different irrigation systems perform differently in wetting the soil at the root zone. Relative moisture varies most in furrow irrigation and least in drip-irrigation systems (Fig. 7.3).

Irrigation is used inefficiently in the LRB. Thus, farmers tend to over-irrigate even when using efficient irrigation systems such as drip irrigation. The water shortage forces farmers to choose the best irrigation systems. In areas where surface-water sources exist, farmers use furrow irrigation on a schedule relative to the availability of water in the nearby open channel. Thus, furrow irrigation assures water for crops once a week, or once every 2 weeks, depending on the main schedule in the network of open water channels. Furrow irrigation could be more efficient than drip irrigation because irrigation must be applied daily. Famers might not available every day for irrigation application. In contrast, the amount of water applied each day, or every other day, will reach the same or around the same amount applied by furrow-irrigation systems. Therefore, each locality tends to have specific arrangements between suitable irrigation system and knowledge dissemination.

7.3 Improving IE Through Early Warning System

Early warning systems (EWS) has been used worldwide in several disciplines where it represents a tool for event prediction that can alert users for better preparedness and precaution approaches. It is often a system for natural hazards with warnings on different levels and aspects. Properly used, EWS could substantially reduce the impact of many events and secure human and environmental safety. However, EWS—including methods for water exploitation, optimized crop seeding, and meeting demands for irrigation—has been recently used as a successful tool in agricultural programs.

As an optimal alerting system, the application of EWS can be viewed from two fundamental aspects. These are as follows:

1. Event-timing prediction: Some events can be predicted/or assessed within a specific time interval. This can be on a monthly or even annual basis, such as drought and desertification, whereas other events can only be predicted within

short time periods, a few days or even few hours, such as torrential rains or floods. Thus, the precautions required for each types of event are different.

2. Event magnitude: Natural events have several magnitudes of impact. This involves the geographic extent or the degree of damage. Thus, some events cover large areas, but not necessarily with high degrees of influence, such as temperate weather. Some events may occur within limited geography, but with high impact, such as mass movements. Other events, such as earthquakes, may include both area and magnitude, and thus they exist within large areal extent and cause severe damage.

7.3.1 Tools of EWS

EWS have several tools that can be used depending on the availability of data, financial resources, expertise, and the aspects of the existing events. However, the majority of EWS implies three major components: data and information retrieval, data storage and analysis, and data dissemination (Fig. 7.4).

1. Data retrieval: Several detecting systems can be used to acquire and monitor geospatial and observational information. These systems are mainly represented by "sensors." The latter have a miscellany of aspects (Fig. 7.4). There include fixed sensors, such as in situ measuring stations, rainfall gauges, flow meters, water-level meters, etc.
   - Mobile sensors, such as mobile monitoring cameras and radar, which are almost mounted on cars.
   - Airborne sensors—such as cameras (visible and thermal) on airplanes and unmanned planes (drones)—Lidar, and other detecting air-board systems.
   - Space-borne sensors such as satellite images with different spectral and temporal specifications.

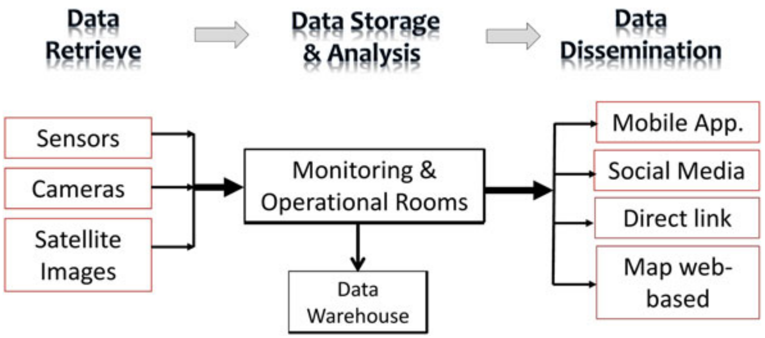

Fig. 7.4 Schematic figure for the early warning system

2. Data storage and analysis: The previously mentioned sensors are conducted with central monitoring and operational sites and rooms, which are often connected with the data-warehouse system for data storage (Fig. 7.4).
   - Miscellaneous software is used. This includes storing data, which are automated and are manually processed to enable identifying the existing processes, then predicating further configurations of events. These rooms should be well-equipped, and expertise must be hired.
3. Data dissemination: The elaborated data and information on the operational rooms and other monitoring systems will be eventually distributed to the public as well as to the concerned governmental sectors as alerting steps. The timing of data dissemination is significant, which depends on the type of the predicated event.
   - Many approaches for data dissemination exist that can be represented as map Web-based or via mobile-phone applications, social media, or direct communication along with many other aspects.

7.3.2 EWS and Remote Sensing in Agriculture

EWS can identify several processes influencing the agricultural sector. This includes meteorological and terrestrial events with a special emphasis on drought, flood, sand storms, rain, snowstorms, temperate weather, erosion, mass movement, intense heat, frost, and many other aspects of negative processes.

Recently, EWS has become well pronounced by using remotely sensed data in combination with advanced ground measures and site investigation. Therefore, meteorological satellites (e.g., AVHRR, NOAA, TRMM, etc.) and observatory satellites (e.g., Landsat, Aster, Spot, Sentinel, etc.) are being commonly used; radar sensors (e.g., Radarsat-1, SAR, etc.) are also increasingly used. Thus, remotely sensed data are often subjected to calibration with ground measures to attain the most reliable results, and then models can be established.

Usually, the principles behind EWS in agriculture follows establishing forecast indices such as agriculture stress index, vegetation condition index, vegetation health index, NDVI anomaly, and estimated precipitation, etc. Several measures can be obtained by remote sensing to investigate many agricultural purposes and related components. Many of these measures can be applied in the LRB, especially for the following:

1. Soil salinity and moisture
2. Land-cover/-use change
3. Water erosion and surficial processes
4. Plant diseases
5. Forest fire
6. Crop yield and biomass estimation

7. Evapotranspiration
8. Water use efficiency
9. Saltwater intrusion
10. Land suitability.

7.3.3 *EWS for Efficient Irrigation*

EWS can be used well in agriculture, particularly for improving irrigation efficiency. Recently it has been applied to managing water use in irrigation systems through identifying the incoming meteorological conditions as well as in response to the ability of soil and terrain surface to capture water, i.e., the irrigated amount of water. In addition, it helps for the preparedness, i.e., precautionary implements.

Table 7.3 lists the major aspects of EWS that can be applied to optimize irrigation systems in the LRB. This is based on the existing meteorological conditions in the catchment as well as most of soil characteristics, water supply, and general physiographic setting.

7.4 Water Harvesting in the LRB

Similarly, in the entire country Lebanon, due to the intermittency in water supply and availability in the LRB, water is not always accessible. However, water sometimes exists in amounts that exceed the needs and vice versa. This is since Lebanon,

Table 7.3 Forecasted events recognized by EWS for irrigation efficiency in the LRB

Forecasted event	Element of recognition[a]	Optimized implementation
Crop water requirement (ETc)	• Automated weather stations	• Irrigation scheduling
Torrential rain	• Radar sensors • Rain gauges	• Irrigation postponing
Dust storm/ blowing wind	• Optical sensors (e.g., Modis)	• Water to improve soil wetness
Temperate weather	• Standardized precipitation-evapotranspiration index	• Excessive water required
Drought period	• NDVI anomaly • Drought index • Estimated precipitation	• More water and re-irrigation scheduling needed
Plant disease	• Vegetation condition index • Vegetation health index	• Consulting agronomist
Frost	• Radar sensors	• Irrigation rescheduling

[a] Examples, but not limited

including the LRB, has a diverse topographic setting, and thus rainfall water flows with high energy when it reaches the terrain surface. Thus, surface-water loss is one of the most challenging issues in Lebanon. However, such challenges can be managed if surface water restrictions (i.e., harvesting) are applied (Shaban 2014).

The implementations to accumulate the surplus amount of water are often infeasible due to many reasons as well as the lack of sufficient financial resources as well as expertise.

Water harvesting can be one of the major adaptation measures applied to cope with the increased water demand during times of climatic variability. In addition, the water shortage is well pronounced in many regions of the LRB. There is an urgent need to apply this technique of water-flow restriction.

Water harvesting can be applied in a variety of dimensions and shapes. It can be implemented in mountainous regions as well as flat terrains (e.g., plains). The majority of water storage includes water from rainfall and snowmelt where the latter plays a significant role.

Even though water harvesting occurs in the LRB (example shown in Fig. 7.5), it needs streaming for larger areal extent with more developed systems. The major aspects of water harvesting in the LRB are as follows:

- Ground ponds (100 m^3)
- Convey channels (500–1000 m^3)
- Mountain lakes (150–200 m^3)
- Earthen dams (1500–2000 m^3)
- Rooftop water (250–300 m^3)
- Depression lakes (1500–30,000 m^3)

Fig. 7.5 Depression lakes are a common water-harvesting technique applied in the LRB (Lake of Miess Al-Jabal, 100-m diameter)

Recently, the agricultural sector in Lebanon has started paying attention to water storage (harvesting) and considered it as a principal instrument to be implemented for water conservation and to face the existing challenges in the water sector. This has been elaborated on two levels:

1. National level: It is well-believed that water collection (i.e., harvesting) will optimally improve the status of the water sector in Lebanon. This has made many governmental entities (mainly the Ministry of Energy and Water and Ministry of Agriculture), and in many instances, with the support of international donors, to cooperate together to establish a large water project. In this respect, among the LRB there are four newly implemented (or under implementation) projects. These are as follows:
   - Canal-800 in south Lebanon (90 mm^3)
   - Khardali Dam (100 mm^3)
   - Shoumarieh Dam (28 mm^3)
   - Bessri Dam (120 mm^3).
2. Institutional level: In this respect, the Ministry of Agriculture, through the Green Plan, dedicated support for water consumers, mainly farmers, to help them execute their small-scale projects to collect water. This in turn shows significant improvement in water conservation and in the agricultural sector in many regions of the LRB. This includes establishing mountain lakes, ground ponds, retaining walls for agricultural terrain, and water-convey channels.

7.5 Conclusion

Agriculture occupies 20–40% (exact figures do not exist) of the total labor in Lebanon, which contributes to about 4–8% of the national income of the country. The LRB, including the Bekaa Plain, composes the major part of these numbers because it accounts for around 20% of the Lebanese territory. It represents the fertile region in Lebanon. Looking at the Litani River in the Bekaa Plain from the surrounding mountains reveals arranged agricultural parcels. However, in this view, several bare soil lands exist due to water shortages and non-profitable agricultural production, which lately have increased in the view of the existing challenges. The problem of water shortages, most notably for irrigation purposes, can be reduced through securing new water sources, by saving water, and by applying efficient irrigation approaches and crop-yield management in this region.

Irrigation systems are well pronounced in the LRB. Many small-scale farmers have started using different techniques and various water-application scheduling. To overcome this issue properly, improving the efficiency of irrigation methods should be implemented. Several methods could be applied to improve the irrigation efficiency. Most of these methods include improving IE through crop productivity and water-use management, consistent scheduling, controlled irrigation systems, and use of EAW.

Under the current climate-change scenarios and repeated drought events, improving irrigation efficiency in the LRB will result in sustainability of the agricultural sector of Lebanon.

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Chapter 8
Assessment of the Sustainability of Water Resources in the Litani River Basin

Nadim Farajalla, Yasmina El Amine and Amin Shaban

Abstract Litani River has become the most significant geo-environmental issue in Lebanon. It occupies concerns at different levels including those of inhabitant decision makers. Yet, the problem is worsening, and many challenges hinder progress in conserving the river water as well as human health. It is an alarming situation and time to take the most appropriate and efficient actions to attain the sustainability of the water resources in the river, which include water quantity and quality. Four salient conditions describe the major challenges in the Litani River Basin (LRB): water scarcity, population growth (natural and refugee influx), rapid urban sprawl, and poor water governance. In this study, an empirical analysis has been elaborated comparing the existing challenges with the requirements for water sustainability. It implies and indicates water availability, environment, and water governance. The calculated Water-Resources Sustainability Index shows poor sustainability of water resources in the LRB, thus indicating an urgent need to embark on a series of actions to ameliorate this poor status.

8.1 Introduction

Water-resources sustainability is a principal component for water conservation. However, many definitions and concepts identify water sustainability. Brundtland's (1987) initial definition of sustainability has to a great extent remained the basis for most discourses on sustainability in many fields with its emphasis on meeting the needs of the present without compromising the needs of future generations. Sustainability may be viewed as a perspective for scientific analysis rather than a purely scientific concept (Alley and Leake 2004). Furthermore, multitudinity is inherent in sustainability; thus, it can be approached from many perspectives

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N. Farajalla (✉) · Y. E. Amine
Isam Fares Institute, American University of Beirut, Beirut, Lebanon
e-mail: nf06@aub.edu.lb

A. Shaban
National Council for Scientific Research, Beirut, Lebanon

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including hydrological, environmental, governance, social, and political (Llamas et al. 2006).

Many comprehensive studies have attempted to apply the sustainability concept with its basic tenets to the management of water resources. Most of the resulting definitions of water sustainability that have emerged attempt to explain the technical aspect of water management with environmental, economic, and social principles. Thus, Loucks and Gladwell (1999) defined the sustainability of water resources as: "water resource systems designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity," whereas Mays (2006) defined it as: "the ability to use water in sufficient quantities and quality from the local to the global scale to meet the needs of humans and ecosystems for the present and the future to sustain life, and to protect humans from the damages brought about by natural and human-caused disasters that affect sustaining life." In all the definitions of sustainable water-resources management, the temporal aspect is clearly present using such terms as "now" and "future." To this end, Rogers (2006) stressed that sustainability is not a static concept because actions taken at one point in time will have positive or negative impacts later on.

Thus, many factors come into play to ensure the sustainability of water resources. For example, Jakeman et al. (2005) stressed that water supply and demand—along with social-economic and production aspects—must be integrated to ensure the improved and thus sustainable development of water resources. Mays (2006) came up with seven requirements to ensure the sustainability of water resources that ranged from quantity requirements for human and environmental health to water quality and renewability of resources to institutional and governance aspects. It may be best summarized that the requirements for the sustainability of water resources are as follows:

1. Water quantity in sufficient amounts to:
   a. maintain human health; and
   b. maintain ecosystem health
2. Minimum water-quality standards to:
   a. maintain human health; and
   b. maintain ecosystem health
3. Long-term renewability of available water resources;
4. Good water governance that includes:
   a. financial and economic components;
   b. institutionalization of water conflict-resolution schemes; and
   c. participatory approach to water-related decision making

Indicators and indices are increasingly used to communicate to policymakers and the public information the status of water resources (Singh et al. 2009). Juwana et al. (2012) state that sustainability assessment using indicator-based methods typically identify those indicators that measure sustainability either qualitatively or quantitatively. When more than one indicator is combined, they form what is called an "index" or a "composite indicator." Several water-resources sustainability indices have already been developed, e.g., the Canadian Watershed Sustainability Index-CWSI (Policy Research Initiative 2007), Watershed Sustainability Index-WSI (Chaves and Alipaz 2007), West Java Water Sustainability Index-WJWSI (Juwana et al. 2009), and Sustainability Index for Integrated Urban Water Management-SIUWM (De Carvalho et al. 2009). These indices use indicators representing the state of the three pillars of sustainable development: environment, economy, and society.

The sections that follow will relate the challenges facing water resources of the Litani River basin (LRB) to the above-mentioned requirements for the sustainability of water resources through a series of scored indicators and indices to represent a simplified assessment of their sustainability.

8.2 Challenges Facing Water Resources in the LRB

The challenges confronting water resources in the LRB are like those faced by the rest of the country and can be grouped into the following main stressors:

- Water scarcity: natural and climate induced
- Population growth: induced by natural and refugee influx
- Rapid urban sprawl
- Poor water governance.

8.2.1 Water Scarcity

The Bekaa Valley, which occupies the Upper Litani River Basin (ULRB), is characterized by a semi-arid climate being the warmest and driest region across Lebanon. Annual precipitation rates in the Bekaa Valley are irregular and unpredictable ranging from 250 to 750 mm, which is significantly lower than the coastal and mountainous regions where annual rainfall vary between 700 and 800 mm and 1200 and 2000 mm, respectively (Geara-Matta et al. 2010). Figure 8.1 shows rainfall variability in four weather stations across the Bekaa Valley as monitored by the Litani River Authority (LRA). Figure 8.2 shows a similar variability in three weather stations monitored by the Lebanese Agricultural Research Institute (LARI) and others in various locations in the Bekaa.

Both figures show wide inter-annual variations around a mean of approximately 570 mm for both sets of data. Monthly variations are relatively consistent in that there is a relatively wet period stretching from approximately October to May followed by a dry period (see Fig. 8.3). However, the rainfall variation has not

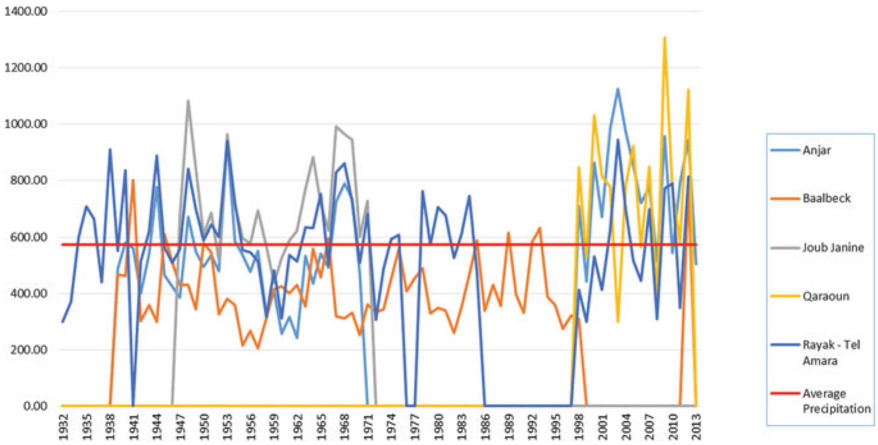

Fig. 8.1 Rainfall variability in weather stations monitored by the LRA

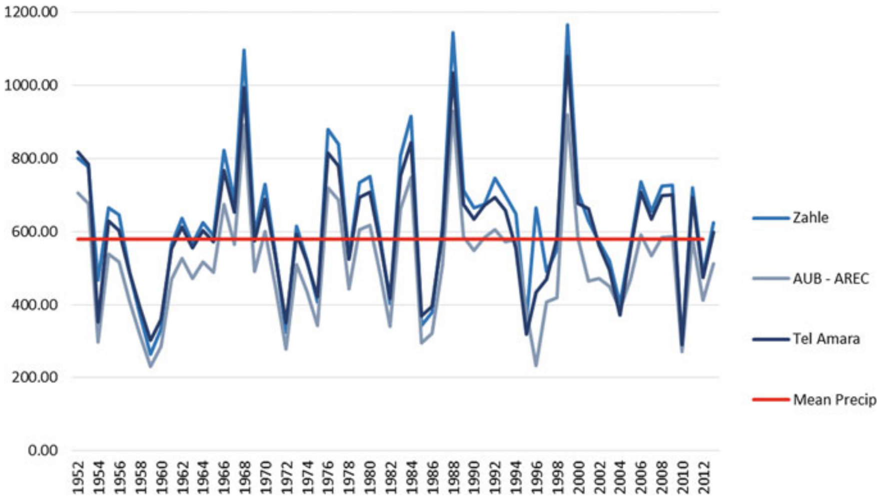

Fig. 8.2 Rainfall variability in weather stations monitored by the LARI and others

shown any decreasing or increasing trend remaining constant during the entire period of >60 years of observation.

Precipitation is projected to decrease in the coming years due to climate change. This is supported by Ramadan et al. (2013), whose analysis of the hydro-climatological response of the LRB showed a drying trend for the period 1900–2008.

As can be seen in Fig. 8.4, the flow of the Litani River is reflective of the seasonal variation in precipitation where flows peak in March–February and are at

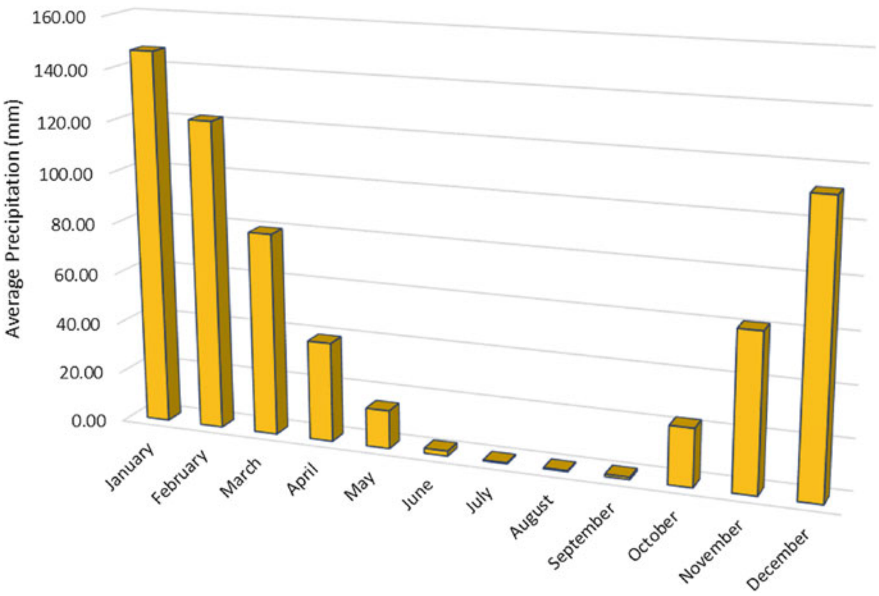

Fig. 8.3 Monthly rainfall variation over the ULRB

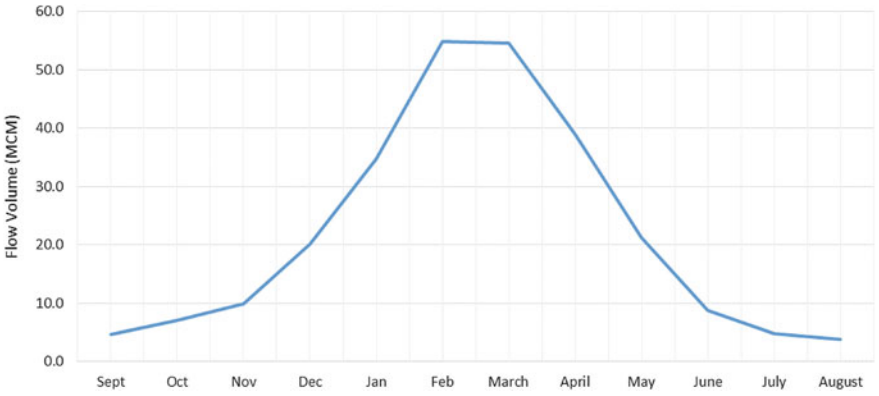

Fig. 8.4 Average monthly flow volume of the LRB

their lowest in August–September. Flow inter-annual variability also follows the rainfall variability (see Fig. 8.5).

Decadal or near decadal precipitation and flow volume averages exhibit a decreasing trend for the period 1932–2010 as shown in Fig. 8.6. The rate of decreased flow volume is more severe than that for precipitation reflecting—in addition to the decrease in precipitation—a decreasing groundwater table due to over-extraction from aquifers in the region. As part of a project funded by the

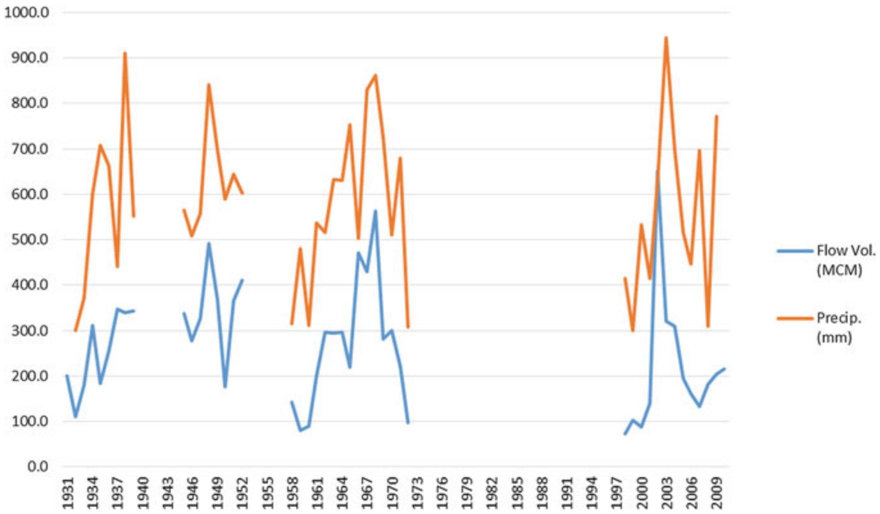

Fig. 8.5 Litani River flow volume and precipitation variations

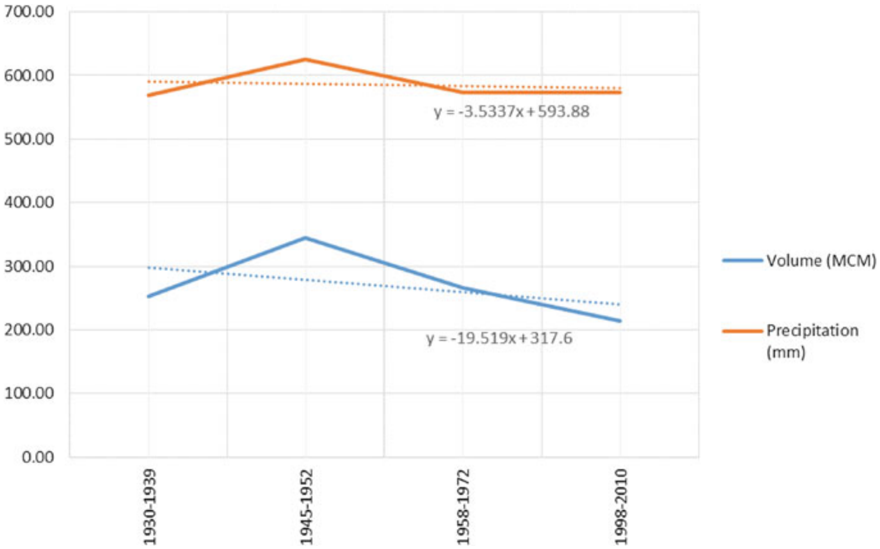

Fig. 8.6 Near decadal comparison in trends for flow volume and precipitation of the Litani River

United States Agency for International Development (USAID) to aid the LRA in monitoring and managing its water resources, the groundwater depth in eight wells throughout the Bekaa Valley was monitored between 2012 and 2016. Most wells exhibited a decreasing trend in depth to groundwater with some more severe than others. Figures 8.7 and 8.8 show examples of these trends.

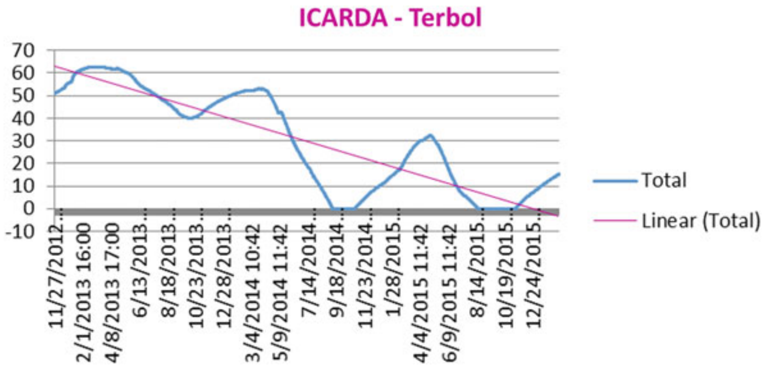

Fig. 8.7 Depth to groundwater at ICARDA's Terbol site (*Source* LRA/DAI/USAID)

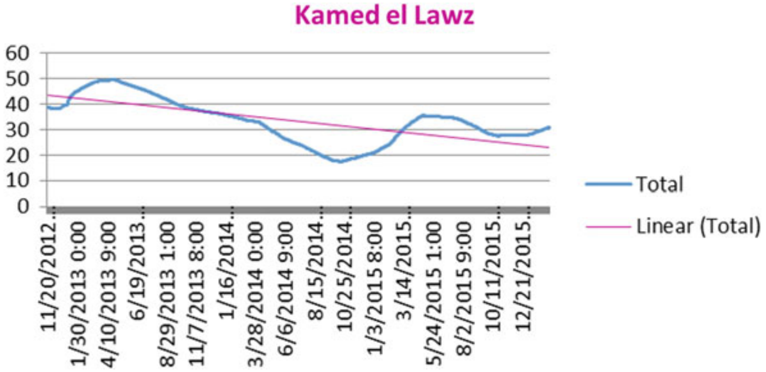

Fig. 8.8 Depth to groundwater at a well in Kamed El Lawz (*Source* LRA/DAI/USAID)

The increase in the depth to groundwater may be related to over-exploitation and reduction in groundwater recharge. Two main reasons could be behind the diminution in recharge: (i) increased impervious areas because of rapidly escalating urbanization; and (ii) a decline in snow cover due to climate change, which is the main source of groundwater recharge. This latter condition is supported by Shaban (2009) who indicated that snow cover in the mountainous regions of the country decreased by about 16% and its duration by 20%.

8.2.2 *Population Growth and Escalating Urbanization*

The population of the Bekaa Valley, where the ULRB is located, has been increasing even before the arrival of the Syrian refugees. According to Lebanon's Central Administration for Statistics, in 2004 the resident population in the Bekaa was 471,209 increasing to 489,865 in 2007 and reaching approximately 540,000 in 2014. At the beginning of 2010, Syrian refugees started moving into Lebanon. By late 2014, >400,000 refugees were registered in the Bekaa Valley. The population increase, which was moving at around 1.1% annually—slightly above the national average of around 0.96% (World Bank 2013)—suddenly shot increased to >28% (Fig. 8.9).

This population increase came along with an increase in urbanization. In Lebanon, nearly 88% of the population lives in an urban setting (UN Habitat 2016). The country has an urbanization growth rate of 3.18%. Faour (2015) put the urbanization rate at 4.53% in 1994 and 7.22% in 2005. Although data particular to the overall urbanization in the Bekaa Valley are not available, anecdotal evidence supports the escalating urbanization rate. This is also reflected in the fact that Zahle, the largest city in the Bekaa Valley, and Baalbeck, the second largest city, both grew at similar rates from 1963 to 2005, i.e., by approximately 1.6% in 1963 to about 5.5% in 2005 (Faour 2015).

Population increase and expanded urban settlements all require additional water and add further stress on available water resources in the region. This stress is further compounded by the pollution of water resources due to uncontrolled discharge of untreated wastewater from the expanding settlements (with all their associated industries and growing economies) and the increasing number of people.

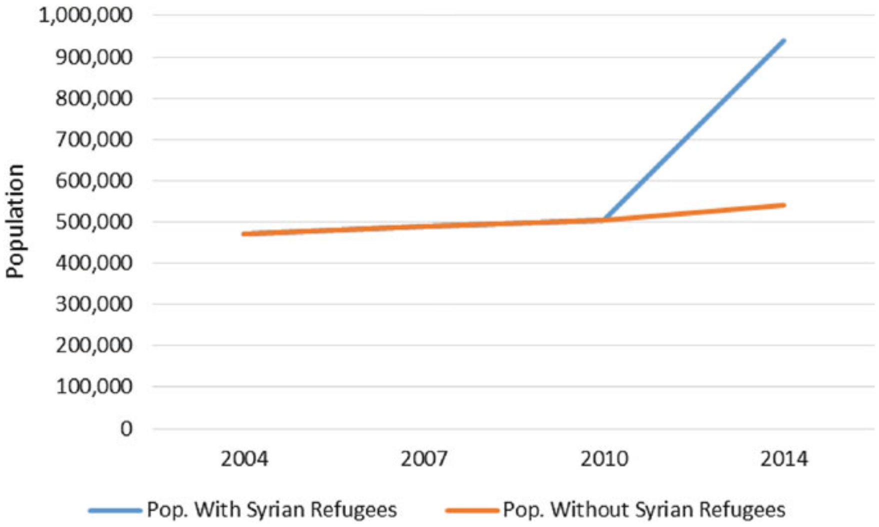

Fig. 8.9 Population growth in Bekaa

8.2.3 Governance

Lebanon's water governance has been in a state of flux in recent years. The water-management sector was reformed through Law 221/2000, which reorganized the governmental institutes responsible for water-resources management into four establishments: Beirut and Mount Lebanon, North Lebanon, South Lebanon, and the Bekaa Valley. The LRA was also recognized as a national organization responsible for the monitoring of all the nation's rivers, not only the Litani. These five establishments have a certain level of autonomy and operate under the umbrella of the Ministry of Energy and Water, which itself reports to the Council of Ministers. The ambiguities within Law 221/2000 have led to some confusion especially regarding the issue of finances and the role of municipalities. In addition, several other ministries and governmental institutions—such as the Ministry of Public Health, Ministry of Finance, Council of Development and Reconstruction, etc. (Farajalla et al. 2015)—are involved in the water sector, thus leading to overlap in jurisdictions and redundancy in efforts.

The two authorities—the Bekaa Water Establishment and the LRA—manage the water resources within the LRB. Their jurisdictions are mostly clearly identified with the former providing domestic and industrial water to consumers, whereas the latter is tasked with providing water to farmers for agricultural purposes. The problem arises in some instances of groundwater access: Both groups tap into the same source with limited coordination, thus leading to over-exploitation of this strategic resource. Furthermore, the issue of wastewater treatment, which Law 221/2000 added to the responsibilities of the Bekka Water Establishment (BWE), has unduly burdened an establishment that has not been prepared to handle the requirements for establishing and operating wastewater-treatment facilities. The lack of large-scale governmental investment in wastewater treatment before the 2000s has increased the pollution of the Litani River due in a large part to uncontrolled discharge of untreated sewage water into it by municipalities within its basin. The International Resources Group (IRG) (2010) estimated that 90% of sewage in the LRB flows into the river untreated. The BWE, in particular, has been suffering from mismanagement and only in past few years has started performing in a more organized manner. The establishment suffers from gross understaffing with only 31% of staff positions occupied (Ministry of Energy and Water 2010). Although the LRA does not currently have a clear formal statement of its mission (IRG 2010), it was originally tasked with water storage and hydropower projects in the LRB, to which other tasks were added ranging from irrigation schemes in the Litani to South Lebanon to surface-flow monitoring nationwide and water-quality monitoring of the Litani.

In addition to the institutional difficulties, financial and infrastructure problems abound. Most of the infrastructure in the LRB is old with an average age of about 30 years (Ministry of Energy and Water 2010). The subscription collection rate for a BWE of 18% is the lowest nationally. This has led to difficulties in investing in, operating, and maintaining infrastructure. In addition, revenue from irrigation water to the LRA is minimal, thus leading to similar constraints.

Data availability and sharing is another problem plaguing the Litani. Several entities collect hydro-climatic data, but cooperation and/or coordination is questionable. The LRA monitors flow in the Litani River and maintains some observation wells to monitor groundwater depths and quality. The BWE monitors flow in springs and does not have a groundwater-monitoring system. LARI has a nationwide network of complete weather stations mostly geared to collect data relevant to agricultural practices. A substantial number of these are in the Bekaa Valley. The National Meteorological Service has a nationwide network of weather stations to serve the civil aviation sector (Farajalla 2015). According to Farajalla (2015), there is no central repository for all the collected data and very little sharing occurs, thus leading to redundancy in data collection.

8.3 Analysis of Challenges

In going back to the requirements for water-resources sustainability and comparing those with the challenges facing water resources in the LRB, the following relationships can be made:

- The LRB is facing scarcity of water due to natural and manmade causes; thus, the requirements “water quantity in sufficient amounts”, and “long-term renewability of available water resources” are apparently those whose adequacy should be gauged.
- Poor water quality results from increasing sewage discharge (domestic and industrial) due to increasing population and expanding urban areas as well as the lack of operational wastewater treatment facilities; thus, “minimum water-quality standards” must be assessed.
- The water-management authorities, the BWE and LRA, are both facing inadequate governance with institutional/regulatory and financial problems. The extent to which the BWE and LRA must go to achieve good governance should be considered.

The challenges facing water resources in the LRB may be grouped into the following indices: water availability, environment, and governance to reflect the above-mentioned requirements. Together, these three indices would give an idea as to how sustainable the water resources are and may also be able to be used to identify areas in which work should be done to attain a certain level of sustainability. A set of indicators has been identified to best describe each index. Scores were developed for each indicator based on international benchmarks or previously established scoring systems found in studies developed by others such as the Asian Development Bank (2013) and International Water Management Institute. All indices and indicator scores are expressed as a status of one of the following:

Table 8.1 Water-availability scoring rubric

Score	Water availability	Description
5	Optimal	*Sustainable WASH* (water sanitation and hygiene) is achieved at the household level in all communities including refugees. Equal access to *safe and affordable* water resources in both quantity and quality is *guaranteed.* Public water supply is *continuous and stable minimizing* water provided by trucks. Risk from water borne diseases is *minimal,* and improved domestic water security is achieved in *the long run*
4	Good	WASH efforts are deployed at the household level; however, conditions are *not optimal* yet. *Equal and safe* access to water resources is *achieved in the short run,* and water affordability has *improved but is not yet sustainable*. Hours of public water supply have *increased*. Incidence of water borne diseases is *low*
3	Fair	WASH conditions are *satisfactory*. *Safe access* to water resources is partially achieved; however, *this access is not equal*. Hours of public water supply have *improved in the short-run*. Incidence of water borne diseases is *fairly stable and not highly frequent*
2	Poor	WASH conditions are *poor*, and *safe water is not always accessible to all households*. Public water supply does *not meet satisfactory conditions*, and the incidence of water borne diseases is *relatively high*
1	Very poor	WASH conditions are extremely poor. Water is not safe for consumption, public hours of water supply are lower than minimal requirements, water-borne disease incidence is extremely high, and basic needs are not met

5 = optimal, 4 = good, 3 = fair, 2 = poor, and 1 = very poor (Table 8.1). Finally, a composite water-sustainability index is presented that is the sum of the average of the three.

8.3.1 Water Availability

The availability of clean and reliable water resources for all is critical to the continuity of any community. Achieving water-resources sustainability means that every individual has access to safe, affordable, and clean water to lead a healthy and productive life.

Three indicators have been selected to reflect this index: total renewable water resources per capita, access to piped water supply per household, and access to improved and shared sanitation. The scoring scale for this index corresponds to the following rubric (ADB 2013):

(1) *Total renewable water resources per capita*
According to FAO AQUASTAT (2015), the total renewable water resources per capita on a national scale are estimated at 769.6 m^3/capita/y representing

available water resources for domestic, industrial, and agricultural purposes. This indicator measures the extent of water scarcity in a country while focusing on the human dimension (Rijsberman 2006). The scoring system for this indicator was based on the Water Stress Index (Table 8.2), the most widely used indicator for measuring water stress on the national level (Rijsberman 2006), developed by Falkenmark (1989):

Accordingly, this indicator received a score of 2 of 4. For consistency, the indicator of total renewable water resources per capita was normalized on a scale from 1 to 5, receiving a final score of 2.5 of 5, which echoes the water insufficiency faced by the basin.

(2) *Access to piped water supply per household*

Safe drinking water is defined as water for ingestion, basic personal and domestic hygiene, and cooking. An improved drinking-water source is defined as a type of drinking-water facility that is designed to protect water resources from external contamination, particularly fecal contamination (UNESCO 2012). According to the National Water Sector Strategy (NWSS) 2010–2020, water-network coverage in the Bekaa Valley extends to 62% of all households. Thus, using the ADP (2013) scoring criteria in Table 8.3, this indicator reflects poor access to water.

(3) *Access to sanitation water supply per household*

This indicator measures the access to improved and shared sanitation facilities per household in the Bekaa Valley. According to the UNDP (2014), 49.3% of households in the Bekaa Valley are connected to the wastewater network, and 50.5% of households are connected to septic tanks. Because there are no available data on the actual conditions of the septic systems in this region, and because most septic tanks in the Bekaa Valley are considered unsafe—they are unsealed and still allow for groundwater contamination (Pierpaoli 2016)—for the purpose of this analysis, septic tanks in the Bekaa Valley will not be considered as "improved sanitation facilities." Thus only 49.3% of households have access to improved sanitation in the Bekaa Valley. Scoring for this indicator followed that of the ADB:

The score of 1, as shown in Table 8.4, for this indicator captures well the current situation in the LRB where the river is highly contaminated with domestic wastewater.

Thus, the score for the Water-Availability Index (IWA) is:

Table 8.2 Total renewable water resources per capita scoring

Water stress index	
m^3/capita/y	Category
<500	1 (absolute scarcity)
500–1000	2 (scarcity)
1000–1700	3 (stress)
>1700	4 (no stress)

Table 8.3 Access to piped-water supply per household

Piped-water access	
Percentage	Category
<60	1
60–70	2
70–80	3
80–90	4
>90	5

Source ADB (2013)

Table 8.4 Access to sanitation per household

Access to sanitation	
Percentage	Category
<60	1
60–70	2
70–80	3
80–90	4
>90	5

Source ADB (2013)

$$I_{\mathrm{WA}} = \frac{2 + 2.5 + 1}{3} = 1.83$$

It indicates that water availability is poor to very poor in the LRB.

8.3.2 Environment

Ensuring the health of the environment, specifically in the case of the BWE and LRA, the health of the Litani River and water-related ecosystems, as well as the inhabitants within the basin, assumes even greater significance. To this end, two indicators were selected for use: one to reflect surface water and the other to represent groundwater. The groundwater indicator has two sub-indicators—groundwater quality and groundwater stress—to capture both the quality and quantity aspects of this index. The SWI also has two indicators: one for the Litani River flow and the other for water quality. The scoring scale for this index, as shown in Table 8.5, corresponds to the following rubric (GWP 2013):

(1) *Groundwater*

(a) *Groundwater Quality*

Limited data are available on groundwater quality, and whatever is available represents a snapshot in time because continuous monitoring of groundwater does not take place in the basin. When there is a dearth of detailed data, often some “substitute” parameters are used to indicate the

Table 8.5 Scoring rubric for the environment

Score	Environment	Description
5	Optimal	River and spring ecosystems have been restored to optimal health meeting optimal environmental flows. Rainfall variability is highly stable, and more than 90% of wastewater is safely treated. Improved environmental water security is achieved in the long-run
4	Good	River and springs are functioning effectively. Water-resource health has been restored at least in the short-term with a potential for more sustainable flows and health in the medium-term. A high percentage of wastewater is safely treated, and rainfall variability is acceptable given global climatic conditions
3	Fair	River and spring ecosystems are functioning at satisfactory levels. River and spring flows are stable in the short term, but pollution levels have not decreased to acceptable levels. Wastewater-treatment plants have increased their treatment capacities, and rainfall patterns are relatively stable across the year
2	Poor	Rivers and springs have fair ecosystem health; however, pollution levels are high. Percentage of wastewater safely treated is low, and rainfall patterns are unstable given current climatic conditions
1	Very poor	River and spring ecosystems are in poor health. River flows and flow fluctuation are low and highly unstable. Rainfall patterns are highly unstable, and the percentage of wastewater safely treated is very low

presence of the parameters of concern that are not measured. As such, according to Conservation Ontario (2003), two main parameters are generally used to assess groundwater quality: levels of nitrates and levels of chlorides. The presence of nitrates usually indicates contamination due to use of fertilizers and/or sewage, whereas the presence of chlorides indicates contamination from intrusion of salt water, industrial discharge, and leachates.

Groundwater-quality data were collected for the following stations—Qoub Elias, Saadneyel, Terbol 1, Terbol 2, Terbol 3, Qaraaoun, Ghazeh', Khyara, Hawsh El Harimi, and Bar Elias—for the year 2014–2015 (latest available data). The parameters evaluated included the following: TDS, nitrates, chloride, alkalinity, pH, and conductivity in pumping and non-pumping wells in the Bekaa Valley. The concentrations from these wells were averaged and are listed in Table 8.6.

Table 8.6 Groundwater-quality data averaged from 10 wells

Parameters	Average concentration from 10 towns
TDS mg/l	422.29
Alkalinity mg/l	217.45
Nitrates NO_3^- mg/l	105.85
pH	7.57
Conductivity µS/cm	843.80
Chlorides Cl^- mg/l	36.33

Using the Conservation Ontario groundwater-quality scoring system, the following score is assigned to the groundwater-quality indicator:
With nitrate/nitrite concentrations much higher than the maximum 20 mg/l, the indicator would have a score of 1; however, with chlorides <50 mg/l, the score would be 5 (Table 8.7). Thus, a fair estimate of this indicator would be to take the average of the two scores, which is 3. This represents a fair state of the groundwater in terms of quality.

(b) *Groundwater Stress*
The level of groundwater stress is determined by dividing the net groundwater withdrawal by the total groundwater recharge rate. Because available data on groundwater are largely estimated, the assessment of this indicator was based on results retrieved from two major studies conducted in the ULRB on groundwater resources. An average value was used for data on net groundwater withdrawals and total groundwater-recharge rate from precipitation and aquifer interchange, which are estimated as listed in Table 8.8..
The groundwater stress (GWS) according to Table 8.9 is: $\mathrm{GWS} = \frac{130}{160} = 0.81$.

A literature review did not yield a scoring system for this indicator; therefore, one was developed specifically for it herein:

1. A very poor score of 1 is allocated if GWS >1, meaning that groundwater withdrawals are higher than recharge rates, thus indicating a very high level of depletion of groundwater resources.
2. Equal percentiles of 25% are allocated to other scores favoring lower rates of abstraction compared with recharge.
This index scored poorly with a score of 2, quite correctly mirroring the wanton drilling of wells in the Bekaa and the uncontrolled extraction from aquifers.

The total score for the Groundwater Indicator is: $\mathrm{GWI} = \frac{2+3}{2} = 2.5$

(2) *Surface Water*

(a) *Surface-Water Quality*
Here too, there are very limited data. Several studies have looked at the quality of the water of the Litani, but these have been far apart and do not represent continuous monitoring. Analysis was made using data from the

Table 8.7 Scoring for groundwater quality

Nitrate and nitrite (mg/l)	Chloride (mg/l)	Point score
0–30	0–50	5
3.1–7.0	51–100	4
7.1–10	101–150	3
10.1–20.0	151–200	2
>20.0	>20	1

Table 8.8 Groundwater withdrawals

Source	Net groundwater withdrawals (Mm^3/y)	Total groundwater recharge (Mm^3/y)
USAID water balance (2011)	150	210
USAID groundwater modelling within the ULRB (2013)	110	109
Average	130	160

Table 8.9 Groundwater-stress scoring

Groundwater stress	
Percentage	Category
>100	1
75–100	2
50–75	3
25–50	4
0–25	5

Table 8.10 Water-quality parameters and weights

Water-quality parameters and weights	
Parameter	Weight
Dissolved oxygen (mg/L)	0.17
Fecal coliform/100 ml	0.16
pH	0.11
BOD (mg/L)	0.11
Temperature (°C)	0.10
Total phosphates mg/L (as PO_4)	0.10
Nitrates mg/L (as NO^3)	0.10
NTU	0.08
TDS (mg/L)	0.07

same ULB study collected in the upper, middle, and lower zones during the period of May–August 2013. The National Sanitation Water Quality Index (Brown et al. 1973) was used to score this indicator. From this method, a set of weights is derived for an ensemble of parameters as follows (Table 8.10) (USAID 2013):

Average measurements for each of the above-mentioned parameters were calculated for the period of May–August 2013 in the upper, middle, and lower part of the Upper Litani River and were then multiplied by the assigned parameter weight (Table 8.11).

Using the National Sanitation Water Quality Index scoring system (Table 8.12), the indicator score was found to be 2.

Here too, the indicator picked up the poor condition of surface water in the Litani.

Table 8.11 Water quality weighted score for each parameter

Water-quality index			
Parameter	Average	Weight	Score (average × weight)
Dissolved oxygen	4.88	0.17	0.83
Fecal coliform	27.61	0.16	4.42
pH	8.10	0.11	0.89
(BOD)	19.74	0.11	2.17
Temperature	19.33	0.10	1.93
Total phosphates	10.34	0.10	1.034
Nitrates	2.05	0.10	0.21
Turbidity	45.88	0.08	3.67
TDS	355.07	0.07	24.85
Total water-quality index			40.01

Table 8.12 Surface water quality score

Surface-water quality	
Range	Scale
0–25	1
25–50	2
50–70	3
70–90	4
90–100	5

(b) *Litani River Flow*

The Mansourah-Joub Jannine station has the most temporally extensive flow data for the Litani River and was thus selected as the representative of the total flow from the upper Litani catchment area above the Qaraaoun Reservoir. Domestic-wastewater discharge into the Litani River is pervasive and widespread constituting most of the flow in summer according to some anecdotal evidence. For this reason, a less straightforward approach was adopted in analyzing Litani River flows.

Based on historic analysis of precipitation trends in the Bekaa and across Lebanon, the decade 1930–1940 was chosen as a reference for the river's minimal environmental flow. Indeed, this decade is characterized as a very dry period with overall precipitation rates being lowest compared with other decades from the 1870s until the late 2000s (Farajalla 2017). In addition, during this decade population in the Bekaa Valley was much lower than the current population; thus, anthropogenic activities (such as over-abstraction from rivers and groundwater) are expected not to influence river flow. Furthermore, sewage networks were practically nonexistent, so sewage flow would not have affected the river's flow. Dry-season flow during this decade was thus considered as the Litani's minimal environmental flows, thus reflecting the natural low flow of this regime with minimal anthropogenic interferences. Accordingly, this indicator measured the average dry-season flow (from May–September) from 1998 until 2011 in the Litani River compared with minimal environmental flows represented by the average dry-season flow from 1931 to 1939 (Table 8.13).

The scoring system for this indicator was developed according to the following rationale (Table 8.14):

An optimal score of 5 is awarded for average dry-season flow greater than minimal "environmental" flows as determined previously, i.e., a value of ~ 4.0 m^3/s. Equal intervals of 1 m^3/s were used to generate the other categories. Because the average dry-season flow turned out to be 1.52 m^3/s, the indicator was given a score of 2.

The total score for the Surface Water Indicator is: $\mathrm{SWI} = \frac{2+2}{2} = 2.0$. Therefore, the overall score for the Environment Index is: $I_{\mathrm{E}} = \frac{2+2.5}{2} = 2.25$, which is expected given the poor condition of the river and all the current hype about the government finally putting together a plan to clean it up.

1.1. Governance

Governance will determine the level to which communities can use as well as protect their water resources. This also includes the financial sustainability of water supply and wastewater services given the importance of this aspect in making available water resources in adequate quantity and quality.

It was extremely difficult to find methods to score such elements as a quality of administration as well as the number of personnel and their capacity to perform their tasks, etc. Therefore, the assessment of this index was based on indicators for

Table 8.13 Dry-season slows for 1931–1939 and 1998–2011

Litani River drainage system	Average dry season flow (May–September) (1998–2011) in m^3/s	Average dry season flow (May–September) (1931–1939) in m^3/s
Litani-Joub Jannine	1.52	4.32

Table 8.14 Scoring for Litani River flows

Litani River flow	
Average dry-season flow (m^3/s)	Category
<1	1
1–2	2
2–3	3
3–4	4
>4	5

which a scoring protocol could be developed. As such, no assessment was made of the laws and regulations governing the sector because scoring these is impossible. The following indicators were used to assess staff capacity through the number of positions filled, the number of staff per network connections, and the financial aspect through water accounting (water unaccounted for) and sufficient revenue against expenditures.

(1) *Capacity Staffing*

   (a) *Number of positions filled*

   The BWE has only 241 of 787 staff positions (minimum required by law) assigned, thus leaving a vacancy of 69% (MEW 2010).

   The scoring system was established based on the premise that the BWE is seeking to fill all positions assigned to it (Table 8.15). The scoring system for this indicator adopts an equal-interval subdivision on a 20% basis. A score of 5 is given to an establishment in which 80–100% of its positions are filled, which indicates highly satisfactory work conditions in terms of availability of personnel to perform the needed tasks. A score of 3 is given to an establishment with 40–59% of its positions filled, thereby indicating average ability to meet its needed tasks. A score of 1 is given to an establishment which has 0–19% of its positions filled, thus signalling poor work conditions and, in turn, potentially poor performance.

   The score of 2 properly reflects the dire staffing conditions that the BWE, and to a lesser extent the LRA, find themselves in.

   (b) *Number of staff per network connection*

   Staffing per network connection is a tricky indicator in that it is a good qualifier to the number of positions filled, but it could also be misleading in that the qualification of the staff would not have increased, and the level of automation of the networks is not reflected anywhere. Also, a low number of staffing per connection will directly influence the ability of the establishment to sustain good water service to end-users because this will influence the ability to monitor and maintain the operating water systems. In contrast, a high staffing number per 1000 connections indicates inefficient use of human resources (WSP 2009), which also may confirm the presence of corruption within the system where a higher number of employees is hired compared with that needed, thus leading to financial losses. There is a near-consensus that the best practice is to have 2–3

Table 8.15 Scoring for the number of positions filled

Percent of positions filled	Score
80–100	5
60–9	4
40–59	3
20–39	2
0–19	1

Table 8.16 Scoring for number of staff per network connection

Number of employees/1000 connections	Score
2–3	5
1–2 or 3–4	4
4–6	3
6–10	2
0–1 or >10	1

employees/1000 water connections (Idelovitch and Ringskog 1995; MOEW 2010).

The scoring system developed for this indicator follows the following rationale (Table 8.16):

- A score of 5 is given establishments having 2–3 employees/1000 connections, a situation that is considered to be best practice.
- A score of 4 is given to establishments having 1–2 or 3–4 employees/1000 connections.
- A score of 3 is assigned to establishments having 4–6 employees/1000 connections.
- A score of 2 is given for establishments having 6–10 employees/1000 connections, values that are parallel to underperforming countries of Latin America having 5–10 employees (Idelovitch and Ringskog 1995).

A score of 1 is given to establishments having either 0–1 (understaffed) or >10 employees/1000 connections.

It would however be very difficult to assess how well this indicator picks up the reality.

The total score for capacity staffing is: $\mathrm{CS} = \frac{2+4}{2} = 3.0$ reflecting a fair condition that may need further investigation to assess its veracity.

(2) *Financial aspect*

(a) *Water Accounting—Water Unaccounted For*

Unaccounted for water (UFW) is a cause of revenue and resource losses for water establishments (Wallace 1987). These causes behind unaccounted for water can be related to either physical losses from the water network (such as leaks or evaporation) or metering where metering might be inaccurate/inexistent or is being greatly affected by illegal water connections (Hudson 1964).

After reviewing work by MOEW (2010), Sharma (2008), (WHO/UNICEF 2015), and AWWA (2016), the following scoring system was developed:

- A score of 1 is attributed to UFW percentages >35%.
- A score of 2 is attributed to UFW percentages of 25–35% where the upper limit corresponds to the world's average and is very close to the average of MENA (Middle East and North Africa) and thus so is any value >35%.
- A score of 3 is attributed to UFW percentages of 10–25%

- A score of 4 is assigned to UFW percentage of 5–10%, which is the limit between acceptable and intermediately acceptable UFW levels and which also considers the best practices
- A score of 5 is attributed to UFW level of 0–5%.

Thus, the score for this sub-indicator turned out to be as shown in Table 8.17.

(b) *Sufficient revenue against expenditures*

The annual revenue of the LRA was US$15.1 million in 2008 (USAID 2010). The LRA expenditure for same year was US$13.3 million (USAID 2010). The corresponding operation expenses = (US$15.1 million/ US$13.3 million) = 1.135. No information was readily available for the BWE.

A review of the literature (Barnes 2015; Jordan n.d.; Moody's Investors Service 1995) yielded the following scoring approach to this sub-indicator (Table 8.16):

- A score of 1 is attributed to water establishments that have operational ratios of 0–1, which indicates that the system is operating at a loss.
- A score of 2 is attributed to water establishments that have operational ratios of 1–1.2, which indicates that the establishment is not operating at a loss but is also not meeting the 1.2 value suggested by Jordan (n.d.).
- A score of 3 is attributed to water establishments that have operational ratios of 1.2–1.5, which parallel to the minimal OR values of 1.2 and 1.5 suggested, respectively, by Jordan (n.d.) and Moody's Investors Service (1995) required for financially healthy water systems.
- A score of 4 is attributed to water establishments that have operational ratios of 1.5–2.
- A score of 5 is attributed to water establishments that have operational ratios >2.

Table 8.17 Unaccounted for water score

%UFW	Score
0–5	5
5–10	4
10–25	3
25–35	2
>35	1

Table 8.18 Scoring for sufficiency of revenue against expenditures

Operational ratio	Score
>2	5
1.5–2	4
1.2–1.5	3
1–1.2	2
0–1	1

The score for the LRA's OR = 1.135 attaining a score of 2 indicating that the LRA is not operating at a loss, yet it must improve its OR to ensure its safety in terms of self-support (Table 8.18).

The total score for the financial aspect is: $\mathrm{FA} = \frac{2+1}{2} = 1.5$ indicating a very poor financial perspective for the authorities.

The Governance Index score is thus $I_{\mathrm{G}} = \frac{1.5+3}{2} = 2.25$, again a low score indicating poor performance.

WRSI

The overall WRSI score using the above indices yields:

$$\begin{aligned}\mathrm{WRSI} &= \frac{\text{Water Availability Index} + \text{Environment Index} + \text{Governance Index}}{3} \\ &= \frac{1.83 + 2.25 + 2.25}{3} = 2.11\end{aligned}$$

8.4 Conclusion

The water of the Litani River is mismanaged, and this has been reflected on many related sectors with a special emphasis on agriculture and energy in addition to the socioeconomic sector. This is alarming because the implementations performed to remediate the existing status did not meet their objectives, and the problem continue to worsen. There is an urgent need to ameliorate the factors acting in this unfavorable situation, and plans for the sustainability of water resources in the LRB should be considered.

In this respect, sustainability indices were investigated in this study to determine how responsibilities the LRB can be categorized, and this was based on a comparative analysis between the existing challenges and the requirements for optimal water sustainability. The sought target was the WRSI.

The resulting WRSI score highlights the poor sustainability of water resources in the LRB, thus indicating an urgent need to embark on a series of actions to ameliorate this poor status. As was shown by the selected indicators and indices, the coverage or access to water must be improved as must be the access to proper sanitation. Water quality, both surface and groundwater, must be improved through a series of actions, the first of which would be to build and properly operate wastewater-treatment facilities. Groundwater extraction must be controlled, and the flows in the Litani be must be regulated to ensure minimum environmental flows in the latter and a certain strategic reserve from the former. Finally, governance in all its aspects must be reorganized and revitalized to ascertain that both the LRA and the BWE are adequately and competently staffed while ensuring low water and financial waste.

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Chapter 9
The National Plan for Litani River Remediation

Talal Darwich, Amin Shaban and Mouin Hamzé

Abstract Analysis of the state of water-quality deterioration and land degradation in the Litani River Basin (LRB) and the governmental response is elaborated in this chapter. This is based on the projects and programs run in the basin starting from the mid-1990. Results of the assessment showed that the main sources of contamination in the basin imply a chaotic urban expansion with resulting loss of arable lands and pressure on water resources in terms of both quantitative and qualitative aspects. Dumping of domestic sewage into streams caused significant bacteriological contamination. A dangerous disposal of liquid and solid waste, including industrial and municipal waste, was observed, which put an increasing pressure on the chemical contamination of surface waters. The LRB represents the most intensive agricultural areas of the country, and thus bad agricultural practices result in the excess use of chemicals and accumulation of nitrates and soluble pollutants in the soil–water ecosystem. Several national and international projects have been tackling water pollution and ecosystem management of the LRB since the early 1990s as pure scientific interests, non-sustainable follow-up, and use of outputs and tools for the protection and monitoring of water quality in the basin. In 2006, an inter-ministerial committee recommended the elaboration of a business plan to identify the measures and alleviate the pollution in the Litani River and the Qaraaoun Reservoir. In 2012, the Lebanese government established a national multi-ministerial committee for depollution of the watershed led by the Ministry of Environment. The final business plan for combating pollution in the Qaraaoun Reservoir, elaborated by the United Nations Development Program, was adopted in 2013. In 2014, a committee was established to supervise the implementation of a road map for the remediation of the Qaraaoun Reservoir. In 2016, a loan of US$55 million was provided by the World Bank for the implementation of the approved plan.

T. Darwich (✉) · A. Shaban · M. Hamzé
National Council for Scientific Research, P.O. Box 11-8281
Riad El Solh, 1107 2260 Beirut, Lebanon
e-mail: tlldarwish@gmail.com

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9.1 Introduction

The Litani River, the largest surface-water resource in Lebanon, spans a long distance, draining from the northern Bekaa Plain to the southern part of Lebanon, where it outlets into the Mediterranean Sea near the city of Tyre. Since the early 1990s, the basin has been subject to extensive urbanization, traffic, industry, and intensive agriculture. Coupled with climate change and decreasing rainfall, human pressure, and dumping of untreated solid and liquid wastes into the river, these factors have converted the river into an extremely polluted stream that threatens public health, environmental quality, and ecosystem functions.

Early attempts to assess water and soil quality showed slight accumulation of nickel (Ni) and chromium (Cr) in the surface water and in the soil of central Bekaa Pain (Darwich et al. 2000; Ministry of Environment (MOE)/United Nations Development Program (UNDP)/ECODIT 2010). The detection of urban expansion using remote-sensing techniques between 2000 and 2010 showed a 63% urban increase in the country expansion on fertile soils (Food and Agriculture Organization of the United Nations [FAO] 2012; Hamzé and Darwish 2014). Chaotic urban sprawl and pressure from solid and liquid domestic wastes as well as contamination from industrial activities threaten agricultural production, food security, ecosystem services, and the implementation of the sustainable development goals (SDGs) related to hunger, poverty, clean water, responsible production, and sustainable cities.

The major and the two largest pressures on the basin-water quality are agriculture and municipal wastewater (MoE/UNDP/Earth Link & Advanced Resources Development [ELARD] 2013). In intensive agriculture, frequent fertilization and irrigation increase the risks of pollutants being discharge beyond the root zone, which end up in harvested crops or groundwater. Loss of nutrients from agricultural lands by means of leaching and water erosion is suspected as one of the important non-point sources of contamination (Yang et al. 2007). Intensive agricultural practices in the Litani River Basin (LRB) show over-application of chemicals (e.g., fertilizers, insecticides, and pesticides) and lack of sustainability. Strong indications of severe ecological damage and eutrophication of rivers and lakes also exist (Möller et al. 2003; Thompson et al. 2007; Darwish et al. 2011; MoE/UNDP/ELARD 2013).

The assessment of water quality showed a large degree of bacteriological contamination caused by direct dumping of untreated sewage water in the river and tributaries (Dib and Issa 2003). Findings on soil and water chemicals and biological quality have been presented to national stakeholders including farmer associations, municipalities, ministries, parliamentary, and scientific communities.

9.2 Committees for Combating Pollution

In 2011, a plan was created to combat the pollution in the Litani River. In 2012, the Lebanese government created a national committee to design a national plan for remediation of the Litani River. The committee came up with an executive 5-year action plan with a total budget of US$850 million to solve the problem of pollution in the LRB.

In 2013, a business plan based on the action plan of the 2012 committee was designed to implement the actions on river depollution. Consequently, in 2014 (ongoing), a national committee was established by virtue of the Council of Ministries (Decree 32 of May 9, 2014) to follow the implementations of the road map for combating pollution in the Qaraaoun Reservoir; thus, the plan was adopted by the UNDP.

The committee, for the follow-up of the implementations of the road map, met and produced monthly reports on the progress and gaps of the actions taken. The Litani River Authority (LRA) was nominated as the Committee General Secretariat. Thus, it was accorded to submit periodic reports to the Council of Ministries every 6 months.

The committee, to follow-up the proposed road map, is composed of official Lebanese institutions as follows:

- Ministries of Environment, Energy and Water, Agriculture, Industry, Public Health, and Interior and Municipalities.
- Agencies: CDR, LRA, Bekaa Water Establishment (BWE), and National Council for Scientific Research–Lebanon (CNRS-L).
- Main municipalities within the LRB.

According to Moussallem (2016), the proposed program of the road map implies moving from studies to policies and then from policies to actions followed by mending implementation gaps. This process consists of the following components:

1. **Solid waste**: This involves activating ongoing/or secured funding including the following:
    - Italian Cooperation/UNDP/MoE (approximately 1.7 million EUR): Baalbeck Integrated Solid Waste Management (ISWM) master plan, collection equipment
    - European Union (EU)/OMSAR-Office of the Minister of State for Administratitve Reforms (14 million EUR): Baalbeck (sorting and composting plant; biogas; sanitary landfill) plus Zahle (composting plant and sanitary landfill) plus Jeb Jennine (support to S&C plant plus sanitary landfill) plus other facilities outside the region of interest
    - World Bank (WB)/MoE: additional statistical workshop studies are needed.
2. Municipal wastewater: This includes activating the planned initiatives with the recently secured funding (WB/CDR/Ministry of Water and Environment [MoEW] [US$50 million loan]), which includes the following:
    - Expansion of sewage collection to connect to Zahle wastewater-treatment plant (WWTP) (Greater Zahle including Karak and Ksara, Saadnayel, Qaa El Rim, and Hezzerta).
    - Expansion of the sewage network to connect to THE Annjar/Majdel Anjar WWTP.
    - Expansion of sewage network to connect to the Ablah, El-Ferzol, and Aitanit WWTPs.

3. Agricultural pollution: This implies the mobilization of funds for the agricultural sector and land use as follows:
   - WB Loan (US$50 million) includes a component to increase the adoption of integrated pest-management practices (MoA/FAO).
   - GEF/UNDP/MoE grant (approximately US$3 million) for sustainable land management.
4. Industrial pollution: This includes the funds from WB/MoF/MoE/BdL US$15 million loan and IC/MoE €2.3 million grant (LEPAP). It aims at improving the compliance of the industrial sector with the environmental legislation through technical assistance (United States Energy Information Administration, EA/CAP European Agriculture/Common Agricultural Policy, etc.) and soft loans (approximately 0% interest).
5. Governance through the WB loan: This will be implemented by the following agencies:
   - The LRA to make improvements in water quantity and water-quality monitoring.
   - The BWE for capacity building.

9.3 Materials and Method

The Bekaa Plain is considered one of the most fertile lands of the country. It is also the major fruit-, cereal-, and vegetable-producing region. According to the Ministry of Agriculture MOA–FAO census (2011), the Bekaa Plain represented approximately 42% of the total agricultural area and almost 50% of the irrigated Lebanese land. Soils of the Bekaa Plain are mostly clayey in texture. Improper agricultural practices might place the soils, groundwater, and plants under risk of nitrate contamination.

The fertilization policy in the open field consists of applying large amounts of low-solubility compound fertilizers with a high-salinity index as land-preparation phase. This quantity is followed by different amounts of nitrogen (N) carriers, which make N application, for instance, far exceed the demands of plant growth and development as well as good yield target.

Satellite imagery of Landsat TM-5 (30-m spatial resolution) was used to detect land use and urban agglomeration between 2000 and 2010. Land-use change was assessed using the Lebanese Land Use Planing “Mode D'Occupation des Sols” MOA (2010) and compared with the soil map of Lebanon at 1:50,000 scale (Darwich et al. 2006).

A literature survey was performed using several data sources to identify the achieved implementations, programs, and plans and whether these actions were taken by the government or performed between the government and other local, regional, or international entities. Thus, the collected data and information were analyzed in a chronological sequence. Therefore, with the actions taken, the gaps and recommendations were the results.

9.4 Results and Discussion

9.4.1 Urban Expansion and Solid-Waste Disposal

Urban expansion is one of the important causes of water-quality deterioration and land degradation in the LRB. Comparing the land-cover map of Lebanon with the expansion of urban settlements between 2000 and 2010, it was found that there was a total loss of 308 km^2 of soil resources. Among lands converted into concrete, a total of 194 km^2 (63%) belong to agricultural lands, whereas 53 km^2 (17.2%) and 50 km^2 (16.2%) of chaotic urban sprawl occurred at the account of wooded land and grassland, respectively. In addition, <11 km^2 (3.7%) of recent urban development expanded on unproductive land. For example, downscaling to traditional agricultural areas located in the governorate of Zahlé, Central Bekaa, showed a loss of 12 km^2 of prime arable lands by chaotic urban expansion, which expanded from 30 to 42 km^2 between 2000 and 2010, respectively (Fig. 9.1).

The increase of urban pressure has resulted in several solid waste–disposal sites located near the Litani River and its tributaries. Most of the threats come from littering and surface runoff. The quantity of solid wastes varies between 1.5 and 30 tons/d, most notably in Bar Elias and Jeb Jannine with direct dumping into the river. Municipal, industrial, and health-care waste-disposal practices in vicinity of the river pose serious threats to the soil and water quality because potential overflow of

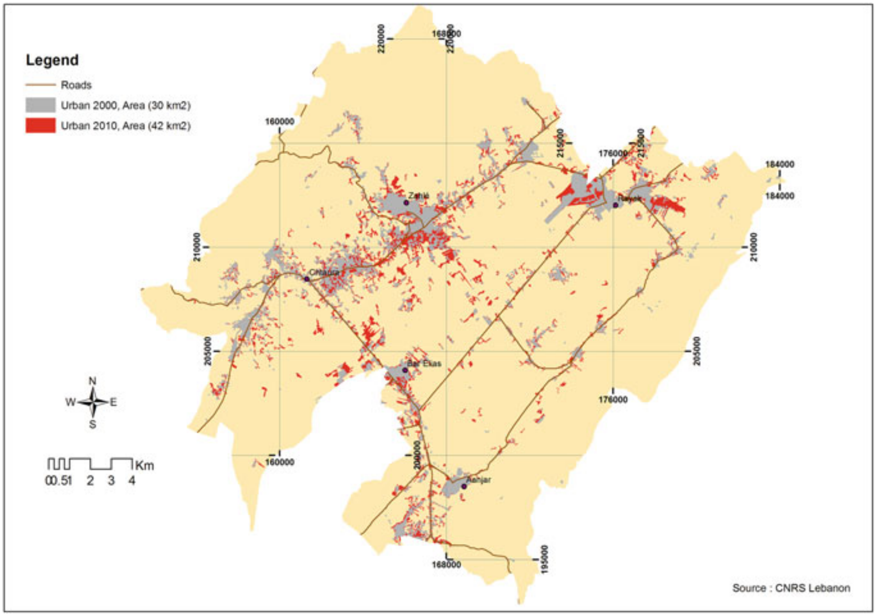

Fig. 9.1 Land-use change of Zahle governorate detected from Landsat images (CNRS 2010)

leachate from the sanitary landfill has been observed. Direct dumping into the river was also noticed in all zones (MoE/UNDP/ELARD 2013). Currently, there is one sanitary landfill (constructed by a WB-funded project) in Zahlé serving a large area and receiving approximately 130 tons/d. Two additional sanitary landfills are under construction: one in Baalbeck with a capacity of 100 tons/d (with funding from the Italian Cooperation) and a small one in the city of Jeb Jennine (funded directly by the municipality). The quantity of solid waste generated in villages and towns located in the ULRB was estimated at 650 tons/d in 2011. However, this amount is likely to have increased substantially due to the influx of Syrian refugees, which has increased the population of this area by at least 50% (WB 2015). Hence, the large exposure to contamination of public health and the environment and the high vulnerability of food quality are directly affected by the quality of the soil and irrigation water.

9.4.2 Contamination by Domestic and Industrial Wastewater

The second direct cause of deterioration of the water and soil quality in the LRB is the direct ejection of wastewater into open-water bodies and the use of contaminated water (Darwish et al. 2008). The wastewater sector in the Bekaa Plain is estimated to have generated 45.4 mm^3 in the year 2010 with an annual load of 15,553 tons of biochemical oxygen demand (BOD). This load will become 21,575 tons in the year 2030 when the volume of generated wastewater is estimated to reach 62.9 mm^3 (MoE/UNDP/ELARD 2013). Factories in the basin produce effluents loaded with solid or liquid organic pollutants, which are largely biodegradable. Other industries generate a mixture of organic and inorganic effluents that may contain hazardous compounds in water.

The business plan identified 294 industrial establishments, which were prioritized in relation to their distance from the river and their impact on water quality. The priority group 1 contains large-scale industries and industries that fall within 400 m from the Litani River and its tributaries that discharge their effluents directly into the river and the nearest flowing water stream or body (MoE/UNDP/ELARD 2013). Medium- to large-scale industries not falling under this category were classified into priority group 2: A total of 60 and 69% of these industries generate liquid effluents, respectively. The small-sized industries located farther than 400 m from the surface-water body pose insignificant threat to water quality due to the dilution effect. The pressure from these industries was assessed into low, medium, high, and very high based on distance from the water bodies and their estimated daily wastewater discharge.

Poor-quality effluents contain a high concentration of suspended solids—such as herbicides, pesticides, total petroleum hydrocarbon, p-chlorophenol, bacteria, and other pathogens—found in river sediments (Abu-Shrar et al. 2003; MoE/UNDP/

ELARD 2013). The large exposure of the Litani watercourse to domestic and industrial wastewater discharge is evident from the organic matter concentration, which is measured as chemical oxygen demand or total organic carbon and from the concentrations of ammonia, nitrite, and heavy metals in the sediments of the river and the Qaraaoun Reservoir.

The impact from sewage water is also evident from the salinity of the water (ranging from a few hundred to reaching values exceeding 1000 μS/cm) and its bacteriological analysis indicating the presence of pollutants originating from human sources (USAID 2003; Dib and Issa 2003). This means that both water and soil resources in the area are prone to pollutants derived from the unsafe treatment and disposal of industrial and domestic wastewaters.

Poor river-water quality provides little chance for aquatic-life survival, thereby resulting in banning its domestic and swimming use. Dilution along the river stream makes water reaching the Qaraaoun Reservoir not harmful (MoE/UNDP/ELARD 2013). Using this water for irrigation can be practiced under controlled conditions for the choice of crops due to the presence of fecal coliforms.

9.4.3 Contamination from Poor Agricultural Practices

Agricultural land use in Lebanon might be represented by the vegetation; simple rotation of field crops such as potato and wheat; and permanent orchards with fruit trees and vine grapes. A total of 44% of arable land is irrigated by surface water, 22% by groundwater, and the remaining by a combination of the two techniques (MoA/FAO 2011).

A serious threat to soil and water quality is posed by the mismanagement of agricultural practices. The most important constituents of agricultural runoff and water seepage are chemicals and non-degradable pesticides applied by local farmers at almost twice the recommended dose, which end up in waterways with irrigation overflow (MoE/UNDP/ELARD 2013). The fertilization policy in the open field consists of applying large amounts of low-solubility compound fertilizers (>1500 kg/ha) with high salinity index as land-preparation phase. This quantity is followed by different amounts of N carriers reaching 800 kg/ha, which makes N application, for instance, far exceed the plant-growth and -development demands and good yield target. Both applications and irrigation using low-quality waters bring other byproducts such as heavy metals (cadmium [Cd], lead, arsenic [As], zinc, vanadium [V], Cr, and copper), which can be detected in the river. The reservoir sediments were found to exceed the world average concentrations in lakes for As, Cd, mercury, and V (MoE/UNDP/ELARD 2013).

Farmers, who admit to the effect of different sources of contamination, need capacity building for the sustainable management of chemical inputs and irrigation in agriculture. It is the responsibility of the government to provide clean water for domestic and irrigation uses and secure active extension service in cooperation with the private sector.

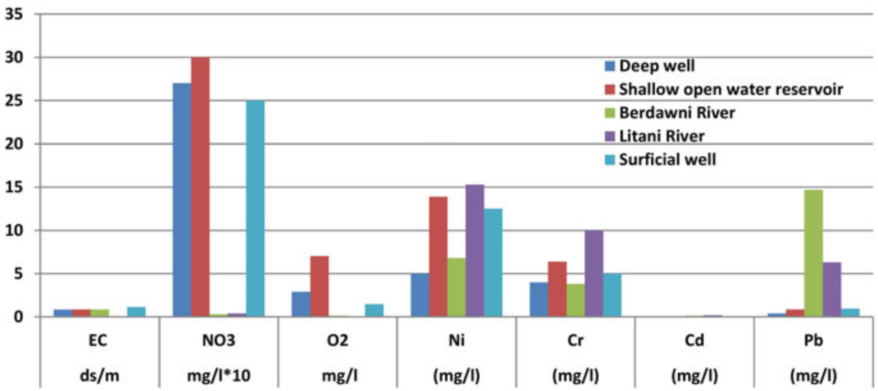

Fig. 9.2 Main chemical characteristics of surface and groundwater resources in Bekaa Plain of Lebanon

The final business plan did not assess the impact of pollution on groundwater. Other studies in the area showed that human activities, industry, manufacturing, and agriculture resulted in slight accumulation of some heavy metals in the soil with a possible contamination of shallow water table with Ni, Cr, and nitrates (Darwish et al. 1999; El-Fadel et al. 2001). The spatial assessment of soil quality in Bekaa Plain showed excess fertilizer input and irrigation using low-quality water as the main factors behind heavy-metal input to the soil–groundwater system (Möller et al. 2002). Poor crop rotation, low water quality, and fertilizer-use efficiency has resulted in nitrate accumulation in the soil and groundwater system (Darwish et al. 2008). Soil nature with basic pH, high saturation with bivalent cations, and enrichment with active clay minerals provide significant protection effectiveness and resilience toward possible heavy-metal transfer to deep groundwater aquifers. The shallow water table is, however, highly vulnerable to the accumulation of heavy metals (Fig. 9.2).

However, indications for a greater leaching potential of soluble pollutants within the soil can be derived from the high concentrations of nitrate down to a 5-m depth found in vegetable monoculture and-fruit trees cultivation in Central Bekaa Plain (Fig. 9.3). Nitrate accumulation in the soil can pose problems not only to the soil–groundwater system but also to public health.

9.4.4 Community Response and National Depollution Plan

As a long-overdue reactive response to the pollution of water resources in the watershed, which have affected the water quality in the Litani River and the Qaraaoun Reservoir, an inter-ministerial committee, assigned by the Lebanese Prime Minister, proposed the elaboration of a business plan to alleviate this

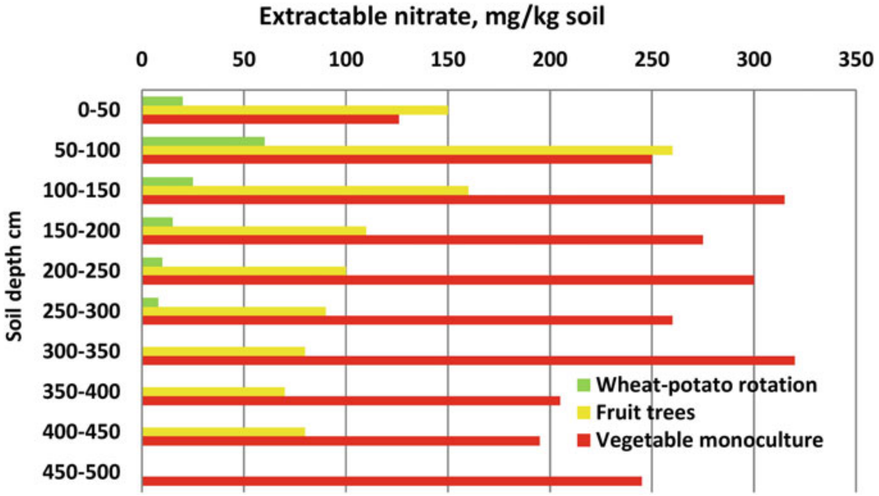

Fig. 9.3 Depth distribution of soil nitrate (N_{min}) as a function of different land use

pollution. The governmental policy statement, adopted in 2009, was reflected in the work program of the MoE (2010–2012). The Prime Minister issued, on 02 August 2012, resolution N 102/2012, in which a national committee for the depollution of the reservoir was formed. The committee consisted of representatives of all governmental institutions, ministries, and research centers. The meetings of the national committee were hosted by the MoE and the Minister of Environment, who acted as the head of the committee. In January 2013, after several meetings and consultations, the committee elaborated a "road map" for a 5-year management plan and estimated the cost to combat pollution in the Litani watershed. The plan defined the stakeholders and actors and encompassed immediate, middle-term, and long-term actions to cure the problem.

Among the urgent measures, the committee recommended, under the responsibility of the BW, Ministry of Energy and Water, LRA and in cooperation with the National Council for Scientific Research, the following measures with an estimated total cost of US$233.33 thousand:

1. Establish artificial wetlands to divert discharged sewage water until the treatment plant system is ready.
2. Follow a holistic approach for the construction of sewerage canals and treatment plants linking these two elements together with the help of skillful staff and by working at full capacity for the safe collection and treatment of sewage waters.
3. Create temporary protected household holes to collect sewage water, which can be emptied and transported to the treatment plants when they become functional.
4. Clean the river, most notably under bridges, and remove obstacles to prevent floods.

5. Create a mandated multi-ministerial committee to forbid and fine any discharge of solid and liquid wastes into the river.
6. Continue to monitor the quality of the Litani River through the LRA, which has been executing this task since 2006.

The middle-term measures contained the following actions to be executed under the responsibility of the LRA, Ministry of Energy and Water, and MoE:

1. Activate the role of the private sector and municipalities to execute environmental projects.
2. Reconsider land use in the watershed based on the outputs of the national land use–planning project and monitor its application.
3. Clarify the mandate and define the implementing agencies and their role.
4. Define the appropriate mechanism to secure funding for operational and maintenance cost.
5. Disseminate this plan through the media to increase public awareness.
6. Issue water laws and its implementing decisions, including the water police, and set the mechanism of its link with the environmental prosecutor.

The long-term measures focused on the integrated water resource management in the watershed under the responsibility of a full-fledged Watershed Agency, The Water Basin Authority “سلطة الحوض”. Moreover, the committee elaborated the measures to treat the sources of pollution such as solid-waste collection, separation, composting, and disposal. This plan, with an estimated cost of US$14 million, recommended the closure of chaotic solid waste–disposal sites and their rehabilitation together with the treatment of hospital wastes.

For the treatment of contamination caused by wastewater, and in agreement with decree 8471/2012, the 5-year plan recommended the following:

1. Execute the plan by the MoE and Wastewater Master Plan for the establishment of sewage water–treatment plants in the Litani watershed in cooperation with the Council for Development and Reconstruction with an estimated cost of US $206.66 million.
2. Set the execution plan and schemes for the safe disposal and use of sludge according to the standards elaborated by the FAO.
3. Implement the recommendation of the FAO study on the safe use of treated sewage water.

The work plan also allocated US$2.66 million for the treatment of industrial pollution through immediate and midterm measures:

1. Priority action to review the legal and environmental status of most polluting industries and impose their environmental commitment.
2. Complement the preparation to launch the project dealing with the point source of pollution, which will be funded by the WB.
3. Implement the project, above which loans will be secured, allowing the industry to obey the environmental laws.

4. Establish corrective regulations providing promotion to classified industries such as a decrease in tax and subsidized electricity.
5. Provide moral support to committed entities (industry, tourism, gas stations) such as diplomas and certificates and disseminate through the media. Strongly fine the uncommitted entities.

In the agricultural sector, the plan recommended to allocate a similar amount of funds (US$2.66 million) to cure the problem of pollution derived from agricultural activities, under the responsibility of the MoA, such as the creation of active extension service to optimize the excess use of chemicals and fertilizers and improve soil conservation, product quality, and water efficiency in irrigation through the promotion of effective irrigation techniques. The total estimated cost of the depollution plan is US$226 million.

9.4.5 International Response and WB Loan to Depollute the Litani River

Since the detection of the first signs of water pollution in the Litani River basin in the early 1990s, the official environmental policy was mainly reactive with temporary solutions to remediate the results without halting the sources of pollution. The international community responded with a series of projects aiming at the management of the water in the Litani River and the Qaraaoun Reservoir such as the Qaraaoun Pollution Prevention Project (P147854) (WB 2015). Previous projects —such as the German–Arab project, Protection and Sustainable Management of the Soil and Groundwater (funded by BGR [1997–2003]), which focused on heavy-metal accumulation in the Litani River, groundwater, and agricultural soils of the upper Litani watershed—assessed the state of pollution.

In 2000, the Swedish set an Environmental Master Plan for the Litani River and the Qaraaoun Reservoir catchment area. The IDRC funded the project, Towards an Ecosystem Approach to Sustainable Management of the Litani River Watershed, Lebanon, 2004–2007, which addressed both the institutional and local community for the establishment of a program for real-time assessment and monitoring through trained employees from local municipalities provided with analytical kits to carry regular quality test analysis as well as the launching of warnings when the local community observed any anomalies in water color or smell. USAID project Litani Water Quality Management (2007–2013) addressed the assessment and monitoring of water quality through capacity building and establishing a long-term water monitoring system involving the local community. However, these projects did not really achieve a sustainable follow-up and management of project outputs during the post-project period.

The national water strategy advocated by the Ministry of Energy and Water on 27 December 2010 and approved in 2012 by resolution N2 of 9 March 2012, paved the way toward proactive governmental policy. This 10-year plan (2011–2020) defined water deficiency in a dry year for Lebanon at the range of 283 mm^3 and decided for the construction of damps and distribution canals at a total cost of US $9.84 billion. For sustainable water management, the strategy defined the need for a more efficient water-distribution system to limit the water that was unaccounted for near the level of best practices (10%) by decreasing the current water-distribution loss equivalent to 48%, which is 13 and 10% greater than the world and MENA averages, respectively.

The strategy called for an increase of the current 60% coverage of the wastewater network and very low contribution of treated water to the national water use (8%). To achieve these issues, the strategy identified and proposed the solution to manage institutional gaps; to address financial, legal, and environmental constraints; and to specify that national capacity building must ensure clean water for social, irrigation, and industrial needs on a sustainable basis. The national plan for the depollution of the Litani River is the first implementation of the road map possessing a proactive character to manage water demands and water use in the country.

The plan was discussed with international donors, and on 2 September 2016, Lebanon signed and ratified a loan agreement with the WB to provide a US$55 million loan to the Lebanese government to manage pollution derived from municipal sewage, promote good agricultural practices, improve solid-waste management, and address water-quality monitoring and capacity building. The principal payment dates were defined, beginning 15 October 2022 through 15 April 2029. The signed agreement focuses on the improvement of municipal sewage collection and treatment of wastewaters, the promotion of good agricultural practices including integrated pest management, the training of stakeholders, and the implementation of a program at the farm level including solid-waste management, water-quality monitoring, and capacity building.

Works have started on the depollution of the Litani River basin, but there are several main ongoing and planned large and small projects that can bridge the currently implemented project. Among the internationally funded large projects, we cite the FAO–Swedish International Development Cooperation Agency project to improve water accounting, water productivity, and sustainable water use; the Swiss Cooperation Irrigation Project; the FAO–United Nations Economic and Social Commission for Western Asia project on adaptation to climate change in the green areas; and the Netherlands–Institute for Hydrological Education, Delft–IHE-Delft and Netherlands-Waternet project dealing with water productivity and accounting, water harvesting, water recharge, water recycling, and efficient water use at the level of thee farmers' plot. Among the national projects funded by CNRS-L, we can mention the monitoring of pollution in the Qaraaoun Reservoir using remote-sensing tools, the efficient irrigation of field crops under drought conditions, and the irrigation of forage crops using saline water. This cooperation is important for national institutions and personal capacity building.

9.5 Conclusion

Chaotic and uncontrolled urban expansion has caused the loss of productive lands and deteriorated the soil–groundwater system. Unsafe disposal of solid wastes and liquid wastewater has contaminated surface-water bodies, and weak agricultural practices have contributed to the accumulation of nitrates and other soluble contaminants in both shallow and deep groundwater aquifers.

It is not excluded that industry might have contributed to the point accumulation of some heavy metals detected through previous assessments. Nevertheless, with revival of the national conscience for safe and sustainable uses of water resources, new funding shall be secured to treat the industrial pollution, and attention must be paid to the legislative aspects and mandates of the LRA and BWE. The availability of funding to improve the *status quo* on the Litani River is well pronounced from the viewpoint of several international entities.

Needs will arise for additional capacity building, staff recruitment, training, updated laws, and decrees for the successful and sustainable implementation of the National Plan for Litani River Remediation.

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Chapter 10
Conclusion and Discussion

Mouin Hamzé and Amin Shaban

10.1 Overview

It is obvious that the Litani River has been given more attention than the other water resources in Lebanon. Issues on both the individual and institutional levels have been raised since the 1950s aiming to conserve the river water and make it a substantial component for the Lebanese economy and development.

The significance of the Litani River extends several hundreds of kilometers outside of its hydrological system. The volume of water discharged from the river basin is equivalent to 24% of the net rainfall received by the entire country of Lebanon. The river provides water to approximately 42% of the irrigated land in the country and supplies water to approximately 1 million people. It also provides approximately 500 MW of hydropower, which is equivalent to 22% of the electricity needs of Lebanon.

This water body, which must be well protected, is being subjected to severe human interference. This has been witnessed for two decades now. The negative interference implies an influence on the water quantity and quality. However, the impact of quality deterioration is most harmful because it adversely affects the human health and life as well that of the environment.

As for the quantity aspect, there is excessive pumping directly from the watercourses of the river without any control either on the pumping locality or volume. This is also accompanied by uncontrolled groundwater abstraction at different depths, and thus the average number of boreholes is estimated at 75–100/km^2.

As for the quality aspect, the volume of sewage water flows from different sources into the river, and the Qaraaoun Reservoir is estimated to have an area between 40 and 45 million m^3, which is delivered from 45 villages and 3 cities

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M. Hamzé (✉) · A. Shaban
National Council for Scientific Research,
P.O. Box 11-8281 Riad El Solh, Beirut 1107 2260, Lebanon
e-mail: hamze@cnrs.edu.lb

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(i.e., Baalbeck, Zahle, and Jeb-Jannine). This volume of sewage water equals approximately 13% of the total river discharge.

There are approximately 350 factories in the Litani River Basin that pour their wastes directly into the river. Added to this, weak agricultural practices are well pronounced, and they result in the excess use of chemicals and fertilizers where a high percentage of nitrates and soluble pollutants in the soil–water ecosystem already exist.

Although many studies have been performed about the river, and several projects have been established in addition to the committees instituted to combat the deterioration of the river water, it is still not an exaggeration to say that the Litani River is in jeopardy.

Therefore, complaints by individuals, the media through advertisements, and campaigns mobilized about the river crisis have become a daily feature, and there is a debate about why the deterioration in the river still exists and why it has been exacerbated. This situation motivated the decision makers who are concerned with the Litani River to organize a national day campaign in October 2016 for cleaning up the river's tributaries. This was done in cooperation with the local municipalities and inhabitants (Fig. 10.1).

Fig. 10.1 The national campaign for cleaning up the Litani River

There are different reasons to justify this inquiry, which include the following:

The increased number of polluters accompanied by the chaotic increase of human activities.

The sources of pollution are well defined in each region; however, there is still lack of serious implementations to terminate the sources as follows:

1. Absence of the required implementations (e.g., infrastructures, landfills, treatments plants, channels, etc.) to mitigate or decrease pollution.
2. Absence of transparency, which leads to corruption and exhaustion of the financial resources.
3. Lack of coordination and cooperation between the concerned sectors on water resources, agriculture, and environment.
4. Weakness in the application of legislations for water consumption from the Litani River and Qaraaoun Reservoir.
5. Lack of consolidated environmental policies and legislations. The existing environmental laws are almost generic and not well applied.
6. Lack of awareness and sometimes the poor ethical conduct of polluters.

10.2 Highlights

To analyze the core results and findings that have emerged from this book, the highlights of each chapter are concluded and shown in the analytical response for the assessment and the current challenges of the Litani River. This part is well illustrated in Table 10.1.

10.3 Insights of Inhabitants

Apart from scientifically based data and information, as well as the justifications introduced by the governmental sectors, the insights of the local inhabitants are usually of great significance to identify the geo-environmental problems because they are in situ observers and the first ones to be touched by the side effects of these problems. Thus, it is often necessary to interact with the inhabitants to develop solutions and predict future scenarios that are based on their experience and knowledge of the environment they live in.

Usually inhabitants raise their voice by way of media tools, e.g., NGOs, or by staging protests to catch the attention of decision makers, but this is not always the case. In the Litani River Basin (LRB), there are obvious complaints from the inhabitants. Actually, it is like the call to defend actually comes from the Litani River itself, which is described by many inhabitants as the “the wail of death.”

Table 10.1 Main highlights and analytical responses to the assessment and current challenges facing the Litani River[a]

Highlights	Analytical response
Chapter 1	
The Litani River Basin (LRB) constitutes about 20% of Lebanon's territory	It occupies a significant part of the country
There are a great number of studies and research projects on the LRB	There is obvious concern about the river by many stakeholders (academics, experts, politicians, etc.)
31% of the income within the LRB is from agriculture	This shows the importance of the river water, notably for the agricultural sector
River water is also reaching large areas outside of the LRB	The river's benefits extend outside its basin
The river is the major source for hydropower	The Litani River has a substantial involvement in the energy sector
There are several human-related challenges severely affecting the river water	Humans negatively interfere with the river
Chapter 2	
The Litani River Authority (LRA) is the oldest administrative body. It has recently suffered from administrative shortcomings	The LRA must be given attention and be conserved
The LRB is characterized by many natural features, such as plains, springs, wetlands, natural reserves, etc.	Natural features in the LRB give it environmental value which should be protected
The largest and most efficient projects applied to the Litani River have occurred since 1995, and the Qaraaoun Dam is the largest of its type in Lebanon	Lessons learned from previous applications on the Litani River must be considered, notably in view of large water projects
The Litani River Master Plan for irrigation is considered as the most successful water project in Lebanon	
Chapter 3	
The geomorphologic setting of the LRB characterizes it with plenty of water resources	The river should be a major source of pure water
The dominant geometry of the LRB accelerates water flow between tributaries and the primary watercourse	Water harvesting must be considered at several confluences along the river's course
The majority of water-feeding sources are springs, which are hydrogeologically controlled by snowmelt	Water resources among the LRB must be protected not only at the point source, but also over the catchment area
Groundwater exists at different levels among the carbonate rocks	Groundwater is available in the LRB, but its investment should consider different depths
The LRB occupies about 24% of Lebanese agricultural areas	The river is the most significant agricultural resource in the country
Chapter 4	
Severe aspects of pollution including mainly solid and liquid wastes are widely spread in the river water. Also, the sources of pollution,	Pollution is a widespread phenomenon in the LRB and it includes several sources

(continued)

Table 10.1 (continued)

Highlights	Analytical response
which are anthropogenic, agricultural and industrial are clearly identifiable	
Nitrate content reaches maximum levels due to excessive agricultural input	There is no control on agricultural practises. This is accompanied by farmers' lack of knowledge
Heavy metal content is very high. Cr is 5 times above its normal level, while Cu is 800 times its normal level	A high content of heavy metals is well pronounced in the water and a direct reason for cancer-related diseases
Microbial contamination is well pronounced; total and fecal coliforms show high levels	Microbial contamination is a fundamental reason for many diseases, with contamination being significant in Litani River water
Chapter 5	
The evolution of the physico-chemical and ecological status of the Qaraaoun Reservoir was assessed and compared to previous studies	There is much concern about the Qaraaoun Reservoir
The Qaraaoun Reservoir is monomictic, stratifying in Spring and Summer providing a different physico-chemical composition throughout the water column	Pollution in the Qaraaoun Reservoir implies the entire water body, but its level differs seasonally
The trophic state of the Qaraaoun Reservoir has not improved during recent years, classifying it as a hypereutrophic lake	There is obvious exacerbation of the unfavorable trophic state of the Qaraaoun Reservoir making it a dangerous water body
Toxic cyanobacterial blooms of *Microcystis aeruginosa* and *Aphanizomenon ovalisporum* affect the potential uses of Qaraaoun Reservoir water due to their ability to produce toxins	Toxic bacteria are widespread in the Qaraaoun Reservoir
Effective management of the Litani River is highly recommended to improve the water quality of the Qaraaoun Reservoir	There is a clear appeal to protect the Qaraaoun Reservoir
Chapter 6	
Groundwater in the upper Litani River Basin is highly vulnerable to contamination	The vulnerability of groundwater to contamination requires intervention
High levels of nitrate, total dissolved solids and fecal coliform, exceeding standard limits for drinking water and irrigation purposes in different zones across the basin, are evident	Groundwater is also found to be contaminated and cannot be used for domestic use
Agricultural practices and domestic wastewater, with solid waste from urbanized agglomerations in the basin, form the main sources of pollution	Sources of groundwater pollution are well defined
Levels of pollution are expected to become more serious in the near future due to the high numbers of Syrian refugees directly using the watercourse, in addition to projected climate change conditions	The outlook is alarming, notably because of new challenges, such as the displacement of Syrian refugees

(continued)

Table 10.1 (continued)

Highlights	Analytical response
Chapter 7	
Flood irrigation is a commonly followed method in the LRB, with few applications using efficient irrigation	Irrigation using river water does not follow systematic approaches
There is excessive pumping of river water for irrigation purposes, regardless of water quality	Water pumped directly from the river is not subjected to quality monitoring
Uncontrolled numbers of boreholes are dug in the LRB where groundwater is chaotically abstracted, and thus the piezomeric level has dropped 40–50 m	There is excerbated groundwater abstraction which affected the discharge and the water table level
Water harvesting in the LRB can be an efficient method of water conservation	Water harvesting on different spatial scales must be considered
Weather forecasting has proved to be a successful tool in agricultural management, thus, long- or short-term forecasting is elaborated by Lebanese Agariculture Research Institute (LARI)	Early warning systems and new technologies should play a role, with LARI representing a success story in this regard
Chapter 8	
There is unplanned and rapid urban sprawl	Urbanism must be well managed and urban expansion should be planned for
Precipitation is projected to decrease in the coming years due to climate change	Measures for adapting to climatic variability must be elaborated
There is poor water governance in the LRB and coordination between concerned institutes is sometimes limited	Water governance, through consolidated coordination and cooperation between institutes, is a must
Water Resources Sustainability Index (WRSI) score highlights the poor sustainability of water resources in the LRB	On the institutional level, water resource sustainability in the LRB is a priority
Chapter 9	
A response to, and elaboration of, a business plan to depollute the river basin is being discussed	There is a promising initiative which must be elaborated
Short-, medium- and long-term anti-contamination measures and stakeholders' roles are highlighted	Periodical monitoring is recommended
An international response to, and World Bank loan for, the depollution of the Litani River are reviewed and progress made in the implementation plan is presented	Financial resources must be secured for the depollution of the river
A national committee is following the road map for combating pollution in the Qaraaoun Reservoir	There is official concern with the issues facing the Litani River

[a] The analytical response and the highlights appear for only 9 chapters, with Chapter 10 being the conclusion and discussion

Time is crucial because the river is under severe stress, and daily problems exist. Recently in May 2017, the inhabitants of Bar Elias (a town in the middle of Bekaa) closed the river tributary spans in their village after announcing the status of tens of cancer cases among the people in this town. In addition, at the end of May this year, there was a strike by people in the Bekaa region complaining about the intolerable situation of the river and its effects on local inhabitants.

A survey has been performed in the representative cities and villages in the LRB to identify the general impression of inhabitants about the status of the Litani River. This survey included 124 inhabitants distributed as 86 and 38 people living in the Upper and Lower Basins, respectively. The survey inquired about the reason behind the deterioration of the Litani River. Therefore, the results were almost agreed upon between most of the inquired people as shown in Fig. 10.2.

There is a clear understanding from inhabitants that the governmental sector, including high-level decision makers and concerned ministries, is the main responsible agency for the deterioration of the Litani River. Thus, it was concluded from the survey that 39% of the responsibility is due to the government, and this implies the lack of concern shown by many decision makers to the Litani issue despite the press propaganda elaborated about the river. In addition, there is a lack of coordination between governmental institutions to implement projects related to water-supply management and depollution of the river water.

In this regard, the inhabitants cited several examples such as the issue of non-operational wastewater-treatment plants established in many regions along the Litani River. However, operationalization of most of these plants is continues to be postponed due to a lack of electricity. The reason behind it is non-accordance between concerned governmental institutions to arrange a sufficient electricity supply for these plants.

Municipalities were categorized in the second rank of the obtained survey, and their extent of responsibility was 19% (Fig. 10.2). This was attributed, as declared

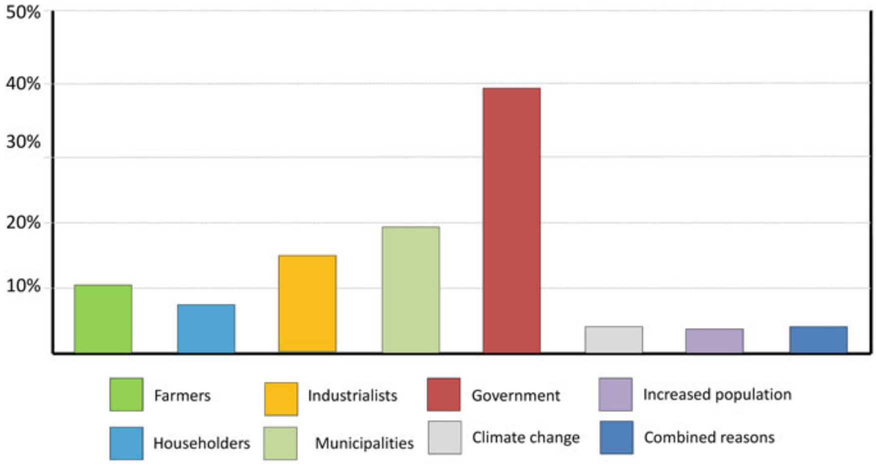

Fig. 10.2 Results of the obtained survey on the responsibility for the Litani River's deterioration

by inhabitants, to the lack of transparency, most notably in that many of these municipalities follow favouritism, and in many cases it was mentioned that some municipalities break the laws and policies and condone many illegal behaviours that cause river deterioration and encroachments. The examples given—such as the direct dumping of solid waste or the conveyance of liquid waste directly into the river course by many people close to these municipalities—were shocking.

The industries' responsibility to the Litani River's deterioration was also considered by many people, and it was ranked at 14% in the survey results (Fig. 10.2). Hence, the negative impact from the industrial sector is well-pronounced in the LRB, notably in the Upper Basin. In this respect, a manifesto was disseminated lately by the Ministry of Industry including 215 industrial institutions (i.e., factories and manufacturers) that are not environmentally controlled and of which 110 institutions release organic pollutants, 77 solid wastes, and 28 chemical pollutants.

In addition to the above-mentioned reasons for the deterioration of the Litani River, there are other factors, too. These are mentioned by the inhabitants as follows: 10% farmer and agricultural practices, 7% households and domestic wastes, 4% climate change and variability, 3% population increase including the issue of Syrian refugees, and 4% combined reasons mostly from the previously cited ones (Fig. 10.2).

10.4 Proposed Strategy

It is not feasible to develop appropriate solutions to combat the existing deterioration of the Litani River because there are many entangled factors acting together resulting in a miscellany of negative elements. This issue therefore requires that a national strategy be built and applied during a couple of years to decrease the existing effects and to address the sources of pollution. Therefore, a draft strategy can be proposed based mainly on the discussion introduced in the chapters of this book plus knowledge about the river's situation.

The exacerbation of the river's status compels the application of rapid implementations and plans for long-term implementations. Therefore, the proposed strategy in this chapter implies two principal pillars for the rapid and long-term actions as shown in Fig. 10.3. Hence, the financial resources to achieve these actions can be derived from the funds and aids provided by international donors. Some of these resources can also be the responsibility of the local municipalities.

10.4.1 Rapid Implementations

This aspect of implementations represents the urgent actions which must be taken in a very short time, as the current status is very alarming. This in turn can be achieved by the cooperation and coordination between the concerned institutes from different ministries. These implementations can be summarized as follows:

Fig. 10.3 Proposed strategy to combat deterioration in the Litani River

1. River clean-up: This implies the removal of garbage and all kinds of solid wastes as well as sediments from the tributaries of the river, most notably the primary ones. It should begin in localities where river confluences and diversions exist. In addition, this should be applied to streams of narrow cross-sections and in small tunnels.
2. Stop industrial dumping: Because the factories and manufactures affecting the river pollution are well identified, rapid action should be taken to stop these sources of pollution unless they improve their situation (effluent-disposal methods), and this must be accepted by the Ministry of Industry.

   In this respect, the aggregate and sand quarries—which are also widely distributed along the river course, most notably in the Lower Basin—should be included in this implementation, and this will be the responsibility of the Ministry of Environment.
3. Displacement of illegal settlements: This has become one of the challenging issues affecting the Litani River because illegal compounds and urbanized clusters are widely distributed along the river banks. This has been exacerbated lately after the displacement of Syrian refugees who have chosen to settle nearby water resources regardless of the water quality itself.

   According the satellite images, there are approximately 350,000 Syrian refugees living within a buffer zone of <500 m from the primary watercourse of the Litani River (Fig. 10.4). Therefore, there must be a plan to relocate these settlements to localities with less affected natural resources.
4. Widening stream sections: This is almost completely a technical implementation to facilitate the flow of water into its passageway in the river where narrow

Fig. 10.4 Satellite image (Ikonos) showing the Syrian refugees along the Litani River (Ghazeh area, Bekaa)

cross-sections of the streams exist. It can be integrated with the river clean-up implementation.

5. Organization for Litani River Protection: It is a must to institute a creditable organization to follow-up the protection of implementations in the Litani River. It can be a continuation of the existing committees (e.g., Committee for the Follow-Up of the Implementations of the Road Map for Combating Pollution in the Qaraaoun Reservoir). However, the proposed organization should work permanently, and it can be a part of the Litani River Authority.

10.4.2 Long-Term Implementations

These implementations are precautionary actions that must be taken in the shortest time and should also work within a sustainable framework. Therefore, these implementations should also be built on strategic plans by the coordination between the concerned governmental sectors. Hence, the long-term implementations can be summarized as follows:

1. Establishing monitoring systems: This implies a miscellany of testing and measuring systems including mainly laboratories for water analysis, fixed flow meters along river courses, etc. This must also be accompanied by a field campaign to periodically measure water table and discharge in boreholes.

2. Executing environmental police: This is an initiative to be implemented only in villages and towns where the river and its tributaries flow. It is commonly followed to protect and enhance the environment and natural resources and to empower people for enforcing all laws. Thus, the environmental police serve in controlling all aspect of encroachments on the river and its related resources.
   According to the number of villages and towns located directly on the Litani River, approximately 75 environmental policemen are needed for this task. This task can be controlled and regulated the Ministry of Interior and municipalities.
3. Establishing protection fences: These are a sort of steel fence with gates that is fixed along the flood plains of the river from both sides. They can be designed to avoid any distortion in the landscape and the natural view. These fences, which can be connected with small gardens, can be established in villages and town where the river flows. They can also be controlled by the environmental police.
4. Wastewater treatment: This is already performed in many parts along the LRB. However, the largest part of existing treatment plants is still non-functional due to many reasons, mainly due to the lack of coordination and cooperation between the concerned institutes as mentioned previously. The existing treatment plants must be operated, and a number of new ones should be established with uniform coverage among the entire LRB.
   In this respect, the sustainability of operation of these plants should be accounted for and well-managed. This can be achieved if continuity in fuel supply and maintenance are considered. In addition, operation and maintenance of these plants require permanent employees to be hired.
5. Establishing sanitary landfills: The issue of landfills in the whole country of Lebanon has similar concerns as the Litani River. Chaotic landfills exist in the LRB, many of which are located on the flood plains of the river tributaries where solid wastes and decayed materials affect the river water as well as the groundwater.
   Therefore, any strategic plans for solid-waste management must include the Litani River. These can be indirectly related to the dumps unloaded into the river or to the landfills that affect groundwater even if they are not exactly on the river course itself.
6. Elaborate environmental legislation: Many laws have been elaborated, more specifically **Law 444/**2002 **(Law** for the Protection of **Environment**). However, there is still a need to have more specified environmental laws, most notably ones that can treat in-depth the issues of environment and water resources. These laws help in understanding the allowed and prohibited tasks.

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