Amin Shaban
Mouin Hamzé

Shared Water Resources of Lebanon

Water Resource Planning, Development and Management

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SHARED WATER RESOURCES OF LEBANON

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AND

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FOREWORD A

Dr. Farouk El-Baz
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The most pressing issue in the Middle East Region is peace among its nations. The next issue of importance is the equitable use of its scarce water resources, particularly those that are shared by more than one country. Thus, this volume is a welcome addition to the series on *Water Resource Planning, Development and Management*.

The authors of *Shared Water Resource of Lebanon* are highly qualified to deal with this particularly difficult issue. Dr. Amin Shaban is a highly-experienced geologist who has acquired skills in the use of satellite image data. He focused attention on the processes responsible for water accumulation, and their passageways into the subsurface as well as into the Mediterranean Sea. Furthermore, Dr. Mouin Hamzé, Secretary General of the Lebanese National Council for Scientific Research encouraged research on the critical issues that face the country with emphasis on water resources. Several of his researchers joined institutions worldwide – including my own – to learn how best to utilize advanced methodologies to better understand of land resources.

Based on the experience of the authors, this book is adequately illustrated to better portray the presented ideas. These illustrations will serve as aides in the understanding of the presented ideas and conclusions. They also serve to familiarize decision makers and non-specialists with the natural setting of the presented data and conclusions.

It is my opinion that this volume would be of great value to students and researchers of the natural environment of the Middle East Region. Furthermore, it should be of significance of decision makers who aspire to resolve problems of share resources before they become issues of disagreement. Thus, I welcome this volume and hope it is met with attention throughout the region.

FOREWORD B

Raya Marina Stephan
International Water Law Expert,
Consultant with International Organizations

It is a privilege for me to write these lines for this book, dealing with the topic of shared water resources, I have been working on since a number of years.

Shared waters represent an important challenge in the Arab Region. Most of the Arab States depend for their waters supply on rivers and aquifers that are shared between two or more Arab and non-Arab States. Lebanon experiences also such interdependency for some its water resources, which therefore need to be managed in a cooperative way with the other riparians in view of reaching its sustainable use and development, and sharing benefits.

The present book, Shared water resources in Lebanon, deals with these topics. It constitutes an eminent contribution to the knowledge on the country's water resources and the issues at stake in their management, when they are shared. It gives certainly an innovative view in this highly sensitive matter in Lebanon, and the region.

Both authors have a well-recognized expertise in water resources. I had met Dr. Amin Shaban many years ago, during various workshops on shared aquifers in the Arab region, and it has been my pleasure to collaborate with him on various groundwater-related issues. I have always appreciated his good knowledge of the topics he dealt with, his sound analysis, and the quality of the work he delivered. Dr. Mouin Hamzé leads the National Council for Scientific Research in Lebanon, which has become under his direction, one of the prominent research institutions on water in Lebanon, and well recognized also at the international level.

This book, published within the series on *Water Resource Planning, Development and Management*, will certainly be useful for the decision makers, and all involved in the management of water resources in Lebanon, and beyond in the region, in dealing with their shared water resources.

PREFACE

Challenges on water resources are the utmost significant geo-environmental problems occurring in many regions worldwide, notably in zones with arid and semi-arid climate. Besides an increasing demand, other challenges have also exacerbated the problem of water resources bringing them under stress. Therefore, water has become a valuable commodity, and this is reflected in the geo-political conflicts between nations, notably those with shared water resources. There are many agreements and treaties established to reserve water rights between neighbouring countries and even within the same country itself. The Arab Region is a typical example where most of the countries are under water poverty threshold (1000 m^3/capita/year). Many implementations have been carried out to secure water resources and balance the supply/demand, yet water is still a coveted material and its scarcity is considered a national problem. Lebanon is one of the countries under water stress, even though it is a mountainous region with available water resources. Hence, Lebanon is witnessing water shortage; besides, there are many other problematic issues related to water whether in the volume or in the quality. Many studies have been carried out to improve the status of water resources in Lebanon; in addition, large-scale projects have also been implemented to tap water, but the problem is still unresolved and complains have increased. It is not an exaggeration to say that Lebanon, with its sufficient water resources, is still a country with poor water supply. One of the major striking challenges on the water resources in Lebanon is the shared water between Lebanon and its neighbouring countries. This book introduces an inventory on Lebanon's physical setting and water hydrology and hydrogeology, and thus puts forth a comprehensive discussion on water sharing. It is a crucial issue to be identified and diagnosed, notably because about 74% of the Lebanese border is shared with other countries, and thus water resources are naturally interrelated with no defined limits. This unfavourable situation has developed because of the political conflicts in the Middle East, which make it unable to act to conserve the shared water resources whether on surface or subsurface. It is of utmost importance to highlight these resources and categorize them according to their geographic extent between Lebanon and its neighbouring areas. The book will discuss the major water-related components, as prerequisite principles for the analysis of shared waters. It will be a helpful tool to further the understanding and devise solutions to conserve the Lebanese quota of shared water.

About this Book

Water resources in the Middle East are barely enough to cope with human demand, and their scarcity is a matter of discussion in many conclaves. However, it must be clarified that Lebanon has a rugged topography that sets it apart from the surrounding regions. Its small area of 10,452 km^2 is characterized by a mountainous terrain marked by several valley systems. Two mountain chains (Mount Lebanon to the west and Anti-Lebanon to the east) extend parallel to the Mediterranean Sea, and are separated by the Bekaa Plain, which comprises a relatively wide depression. Hence, Lebanon has many sources of surface water including rivers, springs, snowfalls and lakes; besides, many aquiferous rock formations and karstic conduits exist where groundwater can accumulate via seeping.

However, complaints concerning the lack of understanding about the imbalanced water supply/demand in Lebanon are often a matter of debate, and the water budget is also not well-formulated yet. Added to the matter of water shortage and deterioration in quality thereof, challenges for water resources have only exacerbated. Thus, there are parallel paths stemming from both natural and human driving forces leading to increasing water stress. Climate change, pollution, over-pumping and the mismanagement of trans-boundary water resources are amongst the geo-environmental problems that affect these resources. In particular, shared water is one of the major water problems in Lebanon.

To put this issue into perspective, more than 74% of Lebanon's border is shared with neighbouring countries, which makes the surface and groundwater intermingle with neighbouring regions; thus, no volumetric measures are known. Two shared rivers exist between Lebanon and its neighbours: one with Syria in the north, and the other with the Palestinian Territory (PT) in the south. In addition, the three major aquiferous rock formations of Lebanon are interrelated with neighbouring regions.

To date, there is no credible study to assess and allocate the shared water resources. Consequently, geo-political conflicts frequently arise due to the obscure nature of the hydrologic conditions. In addition, the absence of treaties and agreements is another reason affecting water sharing, which constitutes the principal cause of water loss. This is totally governed by the unstable political situation in the region.

This book aims to highlight the principles of Lebanon's water resources with new numeric measures. It will also reveal the major elements of the striking challenges. Thus, the fundamental hydrologic aspects of shared water resources in Lebanon, including quantitative measures and the spatial extent of these resources will be illustrated.

IMPORTANT NOTES

Lebanon is bordered only by two Arab countries, Syria and Palestine. Yet, there is still a conflict in the geographic descriptions, notably that the Palestinian Territory is occupied by Israel. Therefore, the following notes should be clarified when reading this book:

- Mentioning “Israel” does not imply any recognition in this entity.
- “Palestinian Terriotry - PT” is mentioned to describe Plaestine as independent country, including the occupied territry by Israel.
- Used terms on “shared water” follow the existing United Nations convention (1997).

Chapter 1

INTRODUCTION

Located along the Mediterranean Basin, Lebanon, with an area of about 10,452 km^2, is known for its sufficient water resources. The mountainous physiography makes it a climatic barrier that captures cold air masses from the Mediterranean and condenses them as rainfall and snow. This is the major reason why the average annual rainfall rate ranges between 700mm and 1500mm, and snow annually covers more than 2000 km^2 of its area. Hence, Lebanon encompasses 15 perennial watercourses (i.e., rivers) and more than 2000 major springs. Moreover, there are many aquiferous rock formations and karstic galleries, which store a considerable volume of groundwater.

Lebanon is described as the “Water tower of the Middle East.” Among the Middle East region, it is a country with a decent level of water availability per capita which is estimated at 1350 m^3/capita/year (Shaban, 2011). However, the current status in the water sector shows different figures, and water supply/demand are not balanced.

Different estimates on the renewable water resources in Lebanon have been obtained. According to many sources (UNDP & FAO, 1983; Jaber, 1995; Bou Zeid and El-Fadel, 2002 and Fawaz, 2007), the average precipitation volume is about 9400 Mm^3/year, and after subtracting the evapotranspiration, it can be divided into:

- 2100 Mm^3/year flowing waters in 15 major rivers.
- 1500 Mm^3/year flowing waters issuing from about 2000 springs.
- 1450 Mm^3/year is estimated for the groundwater resources.

It is obvious that there is adequate water volume with respect to the population size (i.e., about four million people). Nevertheless, water deficit is well pronounced in Lebanon, which can be seen from the intermittent supply and water partitioning, lack of drinking water, and decreased agricultural productivity. Thus, water shortage has become a national issue and debates on water supply regularly occur. In addition, the contamination of water sources has also become a striking environmental problem, notably organic pollution, soil salinization and the use of wastewater and sewages in irrigation.

Even though there are many implementations to reach an integrated water resources management in Lebanon, yet it is commonly known that the problems related to water resources are increasing and becoming dangerous in many ways. The insufficient water supply, in combination with contaminated water, whether potable or irrigation water, results in several health problems, whereas the responsibility is still undefined amongst the different stakeholders.

In general, Lebanon is a country with a unique physiographic setting characterized by remarkable climatic conditions. The physical features of Lebanon govern its water availability and flow/storage regime. Therefore, the physical components/features must be primarily analyzed.

GEOMORPHOLOGY

The diversity in the geomorphology of Lebanon makes it different from the surrounding regions, notably in that it constitutes two remarkable topographic ridges. Therefore, Lebanon is characterized by the three topographic units. These are: the Western Mountain Chains (Mount-Lebanon), Eastern Mountain Chains (Anti-Lebanon). These two units are geologically and geomorphologically isolated by the wide Bekaa Plain (Figure 1.1). Thus, the Lebanese topographic units can be described (according to Shaban, 2003) as follows:

- Mount-Lebanon, which is represented by the coastal zone (a coastal ribbon with less than 5 km, and moderately elevated zones up 500 m) that extends parallel to the Mediterranean Sea. The elevated region of western mountains, where the average altitude is about 1200 m, reaches up to 3088 m at Kornet Esawda.

  In this geomorphologic unit, sharp surface reliefs are predominant, with an average slope gradient of about 60-80 m/km.
- Anti-Lebanon: This represents the mountain chains to the east, adjacent to the Syrian border. They are mostly folded terrain with an average altitude of about 1050 m. The average slope gradient of Anti-Lebanon Mountains is about 50-60 m/km.
- Bekaa Plain: It is a depression located between the previously mentioned two geomorphologic units. This plain has an average altitude of about 850 m, and an average width between 8-10 km, while its slope gradient does not exceed 10 m/km.

In Lebanon, valleys with different orientations are common geomorphologic features between the mountainous and the flat zone, whether the coastal or the Bekaa Plain. They are mainly controlled by the steepness of terrain surface and the existing lithologies. According to Shaban (2003), these valleys are classified as:

1) Consequent valleys that represent streams whose original course is controlled by the existing geological structures and sometimes by the slope aspect of the terrain surface. These valleys could also be consequent with faults, and thus forming "fault valleys." It is a common geomorphologic phenomenon along the western mountain ridges of Lebanon where valleys coincide with stream alignments.
2) Subsequent valleys which represent streams whose main courses follow the alignments of weak lithologies. This is well known in soft rocks such as in the clastic (e.g., sandstone) and argillaceous (e.g., marl) rocks. They exist in Lebanon in different places and with diverse dimensions and orientations.
3) Insequent valleys are streams which have not developed by the previously mentioned factors of the consequent and subsequent streams. They are characterized by irregular alignments, and often developed on heterogeneous rocks, notably at the contact between different lithologies, and well developed through the karstic landforms which are common in Lebanon.
4) Gorges also exist in many regions of Lebanon, especially among the consolidated carbonate rocks. They often show steep to sub-vertical slopes.

Karst landforms is another major aspect of geomorphological features which are developed in Lebanon where the carbonated rocks occur with different dissolution processes (Karstification). It is a widespread phenomenon, especially in the mountainous regions, where large areas of limestone and dolomite are exposed.

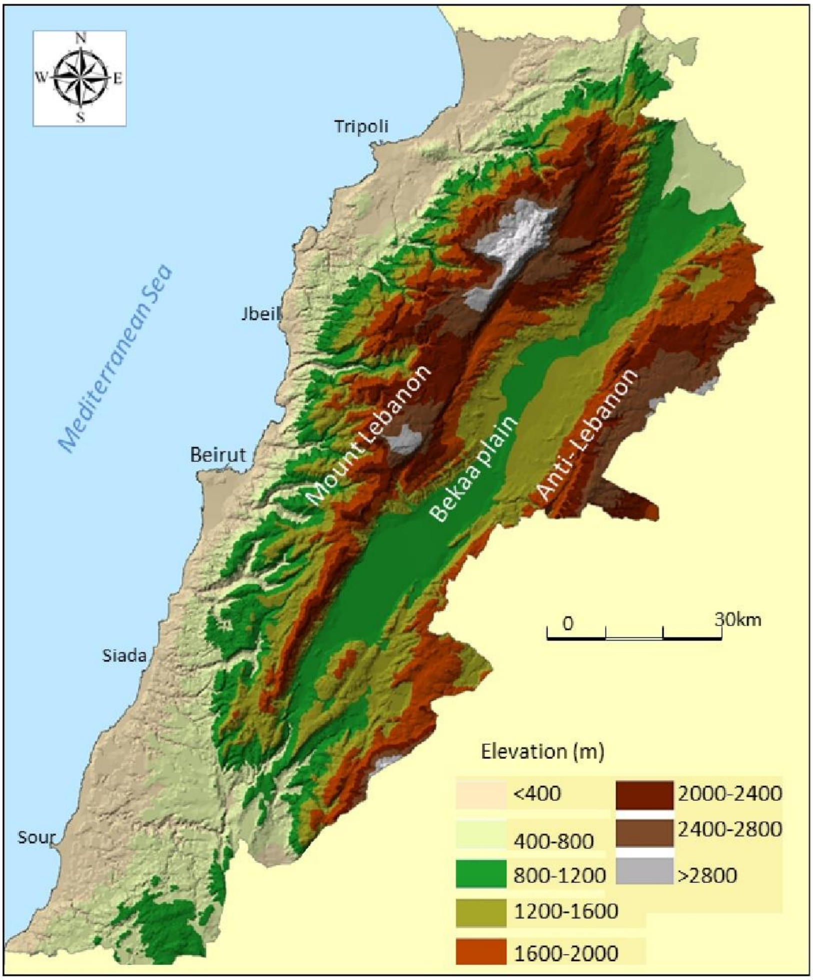

Figure 1.1. Major topographic units of Lebanon.

Thus, karstification occupies a large areal extent in Lebanon, which is estimated at about 65% (Hakim 1985). Fissures are initial spots for the development of karst landforms. Thus, the shape, intensity and density of these fissures control the direction and intensity of dissolution development in carbonate rocks (Khawlie, 2000). They can certainly be considered as structural, lithologic and climatic features, since they own the functions of all. Therefore, rugged topography of huge carbonate rock masses are known with Karnes, lapis and sinkholes (dolines) which are dominant in many parts of Lebanon's mountains.

CLIMATE

Lebanon is usually considered a semi-arid region in the Middle East. However, this is still a paradox, because Lebanon is characterized by considerable water resources, and a rainfall rate that ranges between 700 mm and 1500 mm (averaging about 900 mm). In addition, there are several surface and subsurface water sources. Also, Lebanon is the only geographic region in the Middle East where snow cover remains for several months on the mountain chains covering an average area of 2250 km^2.

Lebanon, with its remarkable topography and relatively small area, encompasses diverse climatic regimes since it receives winds from different directions and with warm, cold and humid types (Arkadan 2008). In addition, the existing mountainous ridges of Lebanon create meteorological turbulences in the orientation and energy of air flows creating rain shadow effect between the major geomorphologic units (i.e., the Mount-Lebanon, Anti-Lebanon and the Bekaa Plain). Hence, cold air masses rise up on the mountains from west and warm descending air picks up available moisture to the east of the mountain ridges resulting finally in climatic turbulences (Shaban and Houhou, 2015).

Precipitation

In Lebanon, precipitation occurs as rainfall and snow. It is unevenly distributed on its terrain, because of the diverse topography, and this in turn results in microclimatic zones. Hence, the average rate of rainfall in Lebanon is still undefined. The latest estimates show that rainfall ranges between 200 mm in the Northern Bekaa Plain and about 1500 mm over the crests. According to the Climatic Atlas of Lebanon (CAL, 1982), the average rainfall rate was 873 mm for the period between 1890 and 1963, while, for the same time period, Rey (1954) stated that 982 mm was the average rainfall rate in Lebanon, whereas, the estimated evapotranspiration in Lebanon was about 53% of the precipitated water volume (Shaban, 2003). However, recent studies show that the average rainfall is about 910mm (Shaban and Houhou, 2015). In this regard, the total raining period in Lebanon is between 60-70 days per year.

Recent estimates obtained by the National Council for Scientific Research in Lebanon - CNRSL (2015) show that the average annual rainfall rate in Lebanon is as follows:

- Coastal zone (<250 m) = <700 mm
- Plateaus (250-750 m) = 700 – 850 mm
- Low heights (750-1500 m) = 850-1150 mm
- High heights (1500-2500 m) = 1150-1250 mm
- Crests (>2500 m) = >1250 mm.

In Lebanon, solid precipitation (snow) is a major aspect of water-feeding sources for the surface and subsurface water. Thus, snow annually covers about 2250 km^2 (i.e., 25%) of the Lebanese territory, with an average depth of about 40-50 cm and reaches in some places to several meters. Thus, sometimes the snowpack remains for a couple of months before getting totally melted, and then the snowpack of the next year may cover snow of the previous year (Shaban, et al., 2014). The first snowfall event usually occurs between late October and November, while the climax of snow melt is often observed between March and April as a result of temperature rise.

Temperature

To a large extent, the temperature in Lebanon is an altitude-related climatic parameter. Thus, lower temperatures range between 5ºC to 10ºC and occur in regions above 1800 m. About 15ºC generally occurs at slightly higher than 900 m, and may reach the range between 1100 m to 1200 m. The coastal zone, on the other hand, is affected by the dampening effect of the sea and has a yearly average temperature about 20ºC.

Therefore, the most updated temperature estimates, according to different altitudes, show the following average annual temperatures:

- Coastal zone (<250 m) = 24ºC
- Plateaus (250-750 m) = 22.5ºC
- Low heights (750-1500 m) = 19.5ºC
- High heights (1500-2500 m) = 18.5ºC
- Crests (>2500 m) =14ºC

The analyzed temperature trends reveal changes in average annual temperature since 1963 towards an ascending trend, where 16.6℃ and 25.1ºC are the average minimum and maximum values, respectively. Moreover, it is obvious that the temperature trend is oscillating at different time intervals, where these intervals are widened since the beginning of 1990s. Thus, remarkable temperature increase has occurred and resulted in an ascending trend of about 1.8℃ between 1963 and 2014 (Shaban, 2014).

As for the relative humidity, it is mainly constant along the coastal zone and oscillating around 70%, and a little lower in the South. Variation in relative humidity in the mountains is very significant: 60 to 80% in winter; 40 to 60% in summer.

According to the GCM simulations, the Middle East Region, including Lebanon, is supposed to witness reduction in rainfall in the region (ESCWA, 1999). Hence, there is a decrease in the rainfall rate between 35-40mm over the last five decades, with oscillations in rainfall patterns and shifting in season timing. Thus, a slight change in the volume of rainfall has been reported over the entire Lebanon, and it shows a decreasing trend in some regions while increasing in other regions (CNRSL, 2015).

GEOLOGY

Lebanon is known by a complicated geological setting. The eastern Mediterranean, particularly Lebanon, constitutes a part of the unstable shelf of the Middle East region. The exposed rocks of Lebanon are greatly affected by the Upper Eocene and Oligocene Alpine orogeny which gave rise to the development of complicated systems of several folds and faults (Beydoun, 1988). The mountain chains are composed of uplifted block folded mountain ranges. These uplifts are almost a horst anticline with flexturing or normal faulting outlining their flanks, while the Bekaa depression is strictly a graben syncline marked by the Yammounah Fault (Beydoun, 1972).

Stratigraphy

Several studies have been done on the stratigraphy of Lebanon with emphasis to studies done by Dubertret (1953, 1955) and Beydoun (1972, 1977 and 1988). The exposed rocks of Lebanon, which have aged from the Middle Jurassic period, exhibit sedimentation in the marine environment until the Middle Eocene, with carbonate rocks making up the largest part of the succession. About 65-70% of Lebanon’s territory consists of carbonate rocks (i.e., limestone and dolomite). In addition, there are stratums of marl, sandstone and clay.

Moreover, volcanic rocks and certainly basaltic ashes exist. There are seventeen rock formations composing the entire stratigraphic sequence of Lebanon (Table 1.1).

Table 1.1. Stratigraphic succession of the exposed rocks in Lebanon (Shaban, 2003)

Era	Period	Epoch	Sub-age	Lithology	Thickness* (m)
Cenozoic	Quaternary	Holocene		Marine deposits, river terraces	Variable
		Pleistocene		Dunes, alluvial deposits	Variable
	Tertiary	Pliocene		Limestone, marl, volcanic s	360
		Miocene	Vindobanian	Limestone, sandstone	320
			Burdigalian	Marly limestone	80
		Eocene	Lutetian	Limestone, chalky limestone	800
			Ypresian	Limestone, marly limestone	370
Mesozoic	Cretaceous	Upper	Senonian	Chalky marl	400
			Turonian	Marly limestone, marl	200
		Middle	Cenomanian	Limestone, dolomitic limestone, marl	700
			Albian	Marly limestone, marl	200
			Aptian	Dolomitic limestone	50
				Argillaceous sandstone, marl, limestone	250
			Neocomian-Barremian	Quartzite sandstone, mixed with clayey	Variable
	Jurassic	Upper	Portlandian	Oolithic limestone	180
			Kimmerdjian	Dolomite, limestone	200
		Middle	Oxfordian	Volcanic materials, marly limestone	Variable
			Callovian	Dolomitic limestone, limestone	650

*Cumulative thickness (exposed and covered).

Structures

The structural framework of Lebanon has an essential role in the geographic distribution of different lithologies. It is substantially governed by the tectonic activities and the resulting tremendous rock deformations. Lebanon as a whole encompasses complicated regional faulting and folding structures where the majority of structural geology of Lebanon implies the extension of the Red Sea Rift System Fault, which spans from the Red Sea-Dead Sea and Tiberius Lake and then within Lebanon where it is shaped by the Yammounah fault, and results the major geomorphological units (Figure 1.2). Thus, there is a regional folding of rock masses in the Mount Lebanon and Anti-Lebanon ranges which have been cut by sets of nearly parallel strike-slip fault systems, resulting in fracture zones. Mount-Lebanon mountain ridges represent a regional monoclinic structure, and different rock folds and flexures occur among this structure with several aspects and dimensions.

Hence, fault systems in Mount-Lebanon extend diagonally from the mountains to the coast. These are almost wrench faults with strike-slip (i.e., lateral) displacements, and many of them are more than 10km in length. These major faults are often accompanied by sets of relatively minor ones. Whilst, the Anti-Lebanon represents folded (anticline and syncline), there are also several plunging anticlines which exist in many localities of the Bekaa Plain.

The two major structures (faults and folds) result in secondary rock deformations, with fracture systems as the most dominant deformation aspect, notably within the hard rock formations, such as the case in the carbonate rocks.

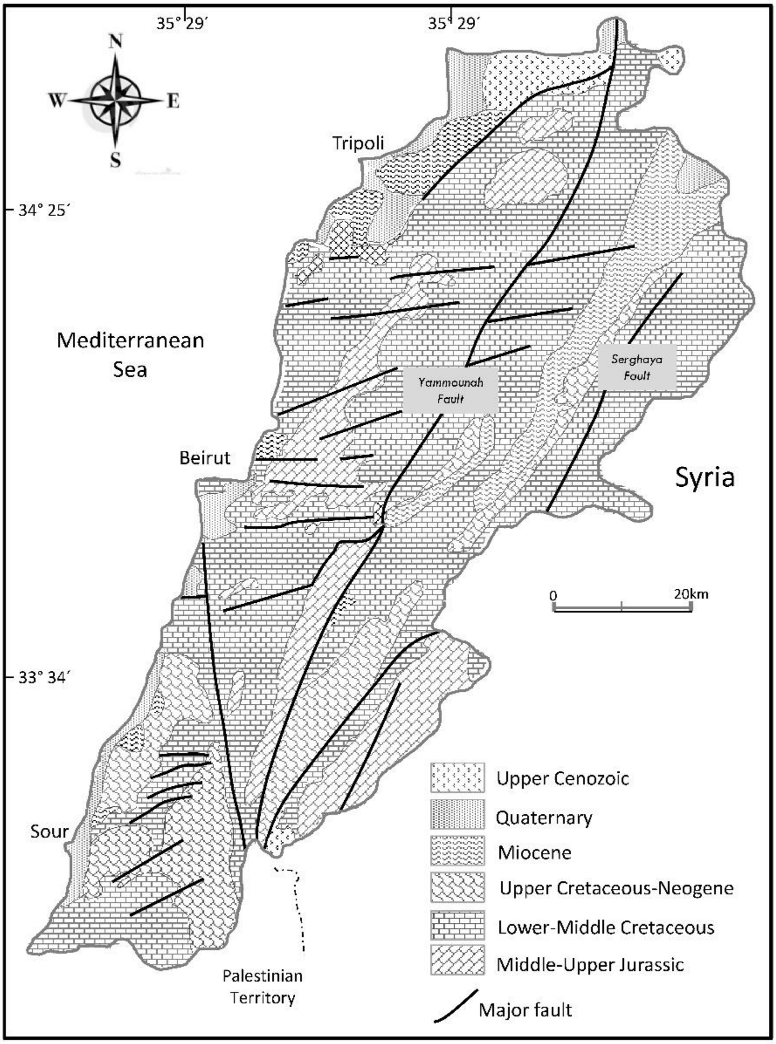

Figure 1.2. Geologic map of Lebanon (Modified from Dubertret, 1955).

Another structural process, which can be combined with lithological and meteorological factors, is the dissolution of carbonate rocks (i.e., Karstification), which is a widespread phenomenon in Lebanon, notably among the huge exposures of limestone. According to Hakim (1985), around 65% of the terrain in Lebanon is karstified with different dimensions and aspects. There are: 1) surface karsitfication, such as karnes, lapis, dolines; and 2) subsurface karstification, such as karstic conduits, grottos and shafts. The latter are considered potential routes for groundwater.

Faults and fissures, as a result of mechanical action and/or oogenesis, are essential parameters for the creation of the subsurface karstification types. The shape, depth and density of these fissures will control the direction and development of the future karstification (Khawlie, 2000).

WATER CONSUMPTION

There is an unfavorable status on the water sector in Lebanon. Many regions are witnessing severe water scarcity and the available water supply is not sufficient to cope with even the major domestic needs. Also, water contamination is a common phenomenon that has had a negative impact on several resources whether on surface or subsurface. In the light of this, it is not an exaggeration to say that Lebanon is a country under water stress, notably since the demand is only one-sixth of the water availability. Hence, all obtained analyses, trends and scenarios point out to unfavorable water conditions.

Nowadays, the demand for water has risen in all Lebanese regions, and there is an obvious decline in the volume of surface and subsurface water. Therefore, the discharge from most rivers and springs has reduced by more than 60% over the last five decades. Besides, there is also a decline in the pumping rate from the water wells, and this is accompanied by a lowering of the water table. This has caused the people to indiscriminately use all the available water without any control through direct pumping from rivers and springs, and increasing the number of boreholes.

The uncontrolled situation on water sector is seen from the large number of drilled wells. For example, in the capital Beirut, the distribution density of water wells ranges between 400 and 500 wells/km^2 (Khawlie and Shaban, 2003), and most of these wells are privately-owned and are randomly located. Similar is the case in the other regions in Lebanon, and this has resulted in depletion of the water table and drying up of many springs as well as occurrence of saltwater intrusions in the coastal aquifers, which has become a widespread phenomenon.

The largest portion of water in Lebanon is allocated for the agricultural sector where about 68% of the consumed water goes to irrigation. Besides, the domestic and industrial sectors consume 26% and 6%, respectively. Recent surveys show that water consumption in the rural areas is greater than that in the urban areas of Lebanon. Therefore, the domestic use was estimated at 185*l*/day/capita and 165*l*/day/capita in the rural and urban areas; respectively.

Yet, the estimation of water allocation in Lebanon is still under debate. For example, Lonergan and Brooks (1994) estimated the per-capita water availability in Lebanon at 950m^3/year, while the estimate introduced by Shahin (1996) was much higher at 3750m^3/year. This contradiction is also applied to the unified water supply and demand. Shaban (2011) conducted a detailed survey on the water availability and consumption in Lebanon wherein the water availability was found to be 1350 m^3/capita/year, while water demand is estimated at 220m^3/capita/year. Nevertheless, the availability has decreased lately due to the existence of Syrian refugees and recent surveys reported that water availability reached 1100 m^3/capita/year (Shaban, 2016).

Water supply from rivers, in the early 1970s, exceeded 85% of the total water supply in Lebanon, besides 15% from groundwater abstraction. This changed over the years to until late 2000s where groundwater supply reached about 45%. The governance approaches and control on groundwater abstraction applied by the Ministry of Power and Water, and certainly the obliged requests for drilling permission for boreholes, again reduces the pumping from groundwater as illustrated in Figure 1.3.

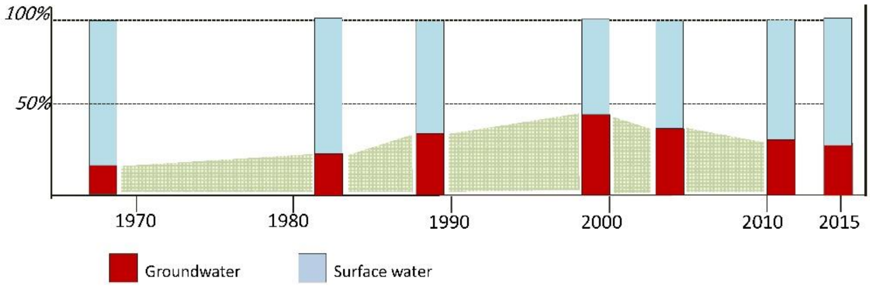

Figure 1.3. Supply from surface water and groundwater in Lebanon (1970-2015).

Recently, there has been a dramatic increase in the demand for water as a result of, in addition to climatic variability, population growth and the concomitant increase in the growing usage of water. For example, the domestic consumption of water in Beirut was 30, 50, 84, 112 and 200 *l*/day/capita for the years 1870, 1912, 1944, 1959 and 2007; respectively (Fawaz, 2007).

In this respect, a comparative analysis has been done on different aspects of water supply in three typical Lebanese cities including the capital Beirut. It is obvious that water supply from the formal water sector does not exceed the 40% of water demand in all cities. The remaining portion of water demand depends on the implements used by the individuals (i.e., by consumers).

Therefore, several alternatives are implemented by individuals to substitute water deficit; in particular, there are the private wells, water sold by tanks and tractors (Figure 1.4). There are also many methods for water collection (harvesting) including those from mountain lakes in the rural areas (Shaban, 2016).

This status gives a clear picture on water shortage and mismanagement in the water sector in Lebanon. In addition, water trading adds a financial burden on the consumers. For this reason, privatization of the water sector has been frequently recommended as an alternative solution for water sector in Lebanon.

Figure 1.4. Water tankers, a common observation in Lebanon.

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Chapter 2

SURFACE WATER

Surface water in Lebanon is the sum of the visible water sources and the aspect of water which makes Lebanon described as a water-rich country. However, these sources have lately become stressed, and some of them have even been totally exhausted whether by the climatic variability or by the increasing human demand. Therefore, the volume of surface water in Lebanon has declined, and the sources have become chemically and biologically contaminated.

Considering the identical water cycle elements, however, all these elements can be found in Lebanon. Therefore, surface water constitutes rivers and intermittent streams, natural lakes, springs, snow cover and wetlands. Thus, the volume of Lebanon's surface water (liquid) is estimated to be more than 3600 Mm^3/year. Additional portion of surface water formed by solid precipitation (i.e., snow) is estimated as 2200 Mm^3/year (Shaban et al., 2004). Moreover, there is another portion of surface water which must be accounted for which is represented by the lakes and ponds, which are more of the artificial type. This portion comprises about 475 Mm^3/year.

Water among these sources is embedded in different hydrologic regimes, and thus it is difficult to make an accurate estimation for the volume of surface water. However, rough accounts according to the precipitated volume of water reveal that surface water in Lebanon constitutes more than 60% of the precipitated water, which can be as rainfall and snowmelt.

RIVERS

The number of rivers in Lebanon is still a matter of contradiction, notably after the existence of some dry years and due to direct water pumping from river courses. Thus, sometimes 17 rivers are counted in Lebanon, but this number is not accepted by many researchers who believe that only 15 perennial watercourses can be considered as rivers. However, the author accepts that only 10 rivers exist in Lebanon under the current physical and anthropogenic conditions. This contradiction is mainly about the continuity in the discharge of these rivers. Hence, many of the Lebanese rivers are no longer perennial ones, and the run-off lasts only for a couple of months, which categorize them as “streams” or “ravines,” but not as rivers. The Lebanese rivers that run along the Mount-Lebanon are short (less than tens of kilometres) and with small-scale catchment areas (<500 km^2).

The most adopted number of Lebanese rivers is fourteen (Figure 2.1). These rivers are either coastal rivers or inner ones. They can be described as follows:

1) Coastal Rivers: These are watercourses which are discharging in the Mediterranean Sea. Except the Litani River, all coastal rivers originate from Mount-Lebanon, and are characterized by relatively short length (i.e., less than 70km). The ten coastal rivers (excluding the Litani River) run along steep sloping terrains, with high flow estimated at 5-10km/hour on average.

This is one of the reasons behind water loss in Lebanon where surface water runs to the sea.

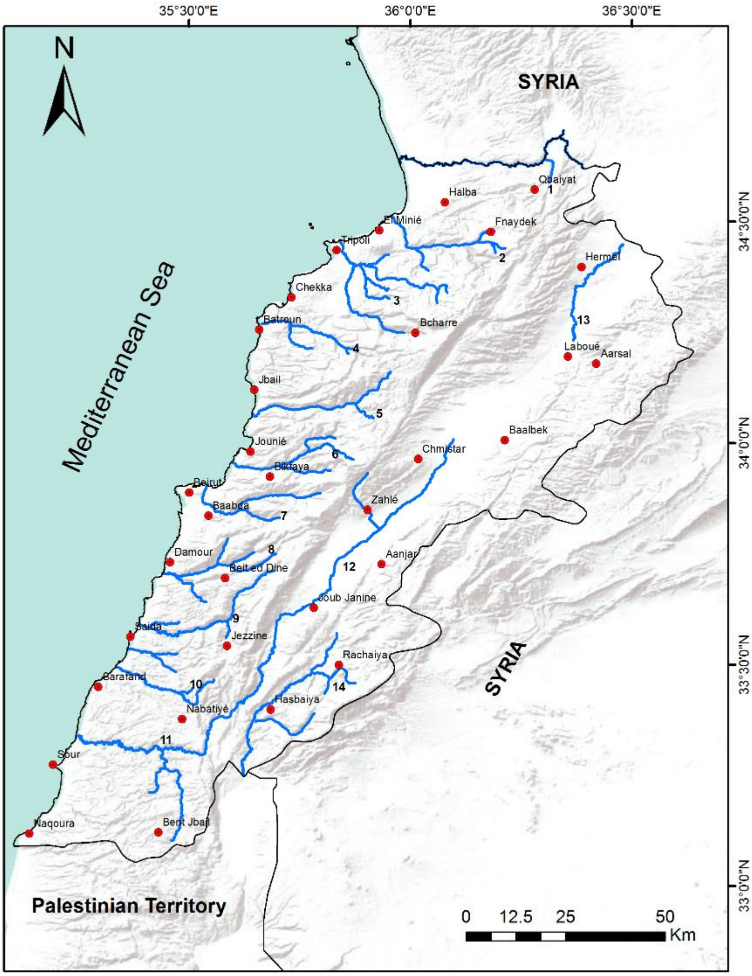

Figure 2.1. Rivers of Lebanon.

2) Inner Rivers: These are four rivers, where the first two are generated from the Bekaa Plain (Orontes and Litani Rivers), the third one (El-Kabir) is generated from a number of springs located in Syria and along the northern extension of Mount

Lebanon, and the fourth river (Hasbani-Wazzani) is fed from the Hermon Mountains. Except the Litani River, which originates from the Bekaa Plain and extends to the coastal zone to the outlet in the Mediterranean, the rest three inner rivers are shared watercourses.

There is a significant difference in the discharge rates between the Lebanese rivers (Table 2.1). This is due to the hydrologic and hydrogeological characteristics in water surface basins. For example, some rivers with larger catchment area have less discharge rate than other rivers with smaller catchment area (Shaban et al., 2009).

Table 2.1. Major characteristics of the Lebanese Rivers

No	River	Average annual discharge *(Million m^3/year)*	Watershed Area *(km^2)*
1	El-Kabir	222	303*
2	El-Bared	152	277
3	Abou-Ali	275	468
4	El-Jaouz	65	196
5	Ibrahim	395	326
6	El-Kaleb	250	231
7	Beirut	95	213
8	Ed-Damour	210	333
9	El-Awali	270	293
10	Sinik	75	102
11	El-Zahrani	80	142
12	Litani	335	210
13	Orontes	420	1983*
14	Hasbani-Wazzani	225	645*

*Area within Lebanon.

Hence, the discharge of these rivers is seasonally fluctuating, and the average mean discharge is estimated at 1.4 m^3/sec and 3 m^3/sec from the coastal and inner rivers, respectively. The peak flow in the Lebanese rivers is found to exist often between March and April when snow melting is at its highest. However, the discharge from these rivers is well pronounced and some have shown a decrease in the discharge of about 70% over the last few decades. The decrease in the discharge of rivers and springs has been remarkable between 1975-1980 and 2000-2005 (Figure 2.2). It is also obvious that most of the rivers have intermittent flow during the dry seasons. In addition, it is not an exaggeration that all rivers in Lebanon and their tributaries are contaminated with levels exceeding the international standards.

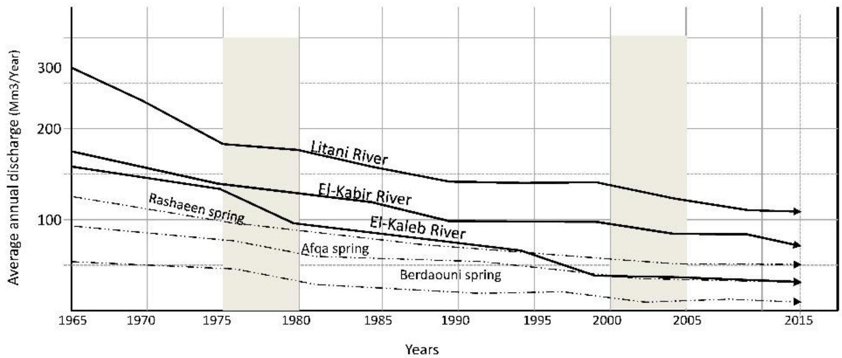

Figure 2.2. Example showing the changed discharge in selective rivers and springs in Lebanon.

SPRINGS

There is large number of springs in Lebanon, and most of them are with considerable discharge (Table 2.2). Springs in Lebanon are distributed in several regions where they are fed by rain and snow (Figure 2.3). The largest number of these springs discharge form the carbonate rocks (i.e., limestone and dolomite), which are mostly fractured and karstified. These rock stratums are often interbedded with impermeable layers, such as marl and clay, which provide a chance for overland flow of groundwater along the contacts between bedding planes. Therefore, the most dominant types of springs in Lebanon are:

1) Ordinary springs: These are a known spring type in Lebanon that occur when permeable, fractured and karstified limestone and dolomite rock masses overlay impermeable marly and clayey rocks; thus, an overflow occurs along the contact between the two. They are commonly spread and known for their relatively steady discharge rate, such as Ain Ez-Zarqa Spring (2.44 m^3/sec), which is a principal source for the Orontes River (Al-Assi River) near Hermel.

Table 2.2. Major springs of Lebanon

No	Spring	Discharge *(m^3/sec)**	No	Spring	Discharge *(m^3/sec)**
1	Afqa	4.62	14	Shoukkar	1.15
2	Jeita	4.48	15	Hasbani	0.76
3	Rouaissat	3.55	16	Labouh	0.75
4	Wazzani	3.47	17	Al-Laban	0.74
5	Adoniss	3.37	18	Qadisha	0.72
6	El-Aarbaain	3.11	19	Qeb Elias	0.69
7	Yamouneh	2.82	20	Sannine	0.63
8	Ain Ez-Zarqa	2.44	21	Aamiq	0.53
9	Antelias	2.20	22	Ras Al-Ain	0.52
10	Anjar	2.00	23	Chamsine	0.46
11	Barouk	1.58	24	Chtoura	0.45
12	Al-Assal	1.43	25	Et-Tasse	0.43
13	Berdaouni	1.41	26	Khrayzat	0.31

*Average discharge in wet and dry seasons.

2) Fault springs: These are a known type of springs in Lebanon due to the fracturing systems. They mainly occur along faults which may cut different lithologies. Therefore, these faults may develop into karstic conduits by the influence of carbonate dissolution, and the resultant will be water outlets along both structures (fault and karstification). A good example of this type of springs is the El-Aarbaain Spring (3.11 m^3/sec) near Yammounah village.

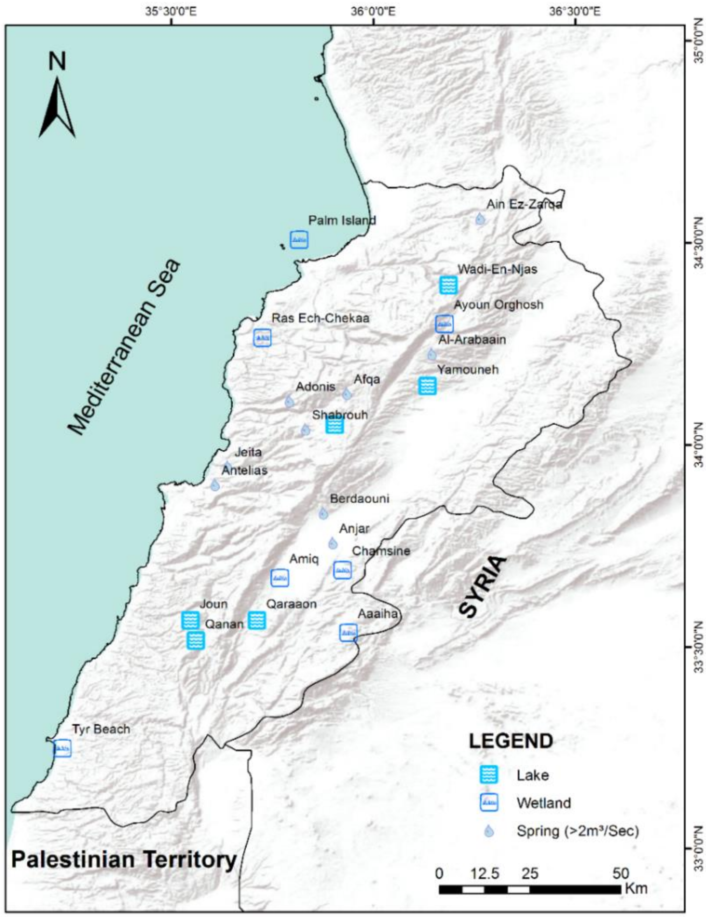

Figure 2.3. Major surface water nodes in Lebanon.

3) Karstic springs: The development of karstification among the carbonate rocks provides a chance for the occurrence of undefined number of springs. This type exists in the Cenomanian and Jurassic limestone and dolomites of different altitudes. Karstic springs always have a relatively high discharge rate, but it abruptly declines when the feeding sources do not add additional volume of groundwater. Afqa Spring (4.62 m^3/sec) and Jieta Spring (4.48 m^3/sec) are good examples of the karstic springs in Lebanon (Figure 2.3).
4) Off-shore springs: These are remarkable types of springs which occur along the Lebanese coast, as well as most of the littoral zones along the Eastern Mediterranean. These water sources represent invisible rivers, and are characterized by considerable volumes of water. They are originated when groundwater finds a hydrologic route and outlets into the sea. The outlet can be directly at the shoreline or at a distance from the coast. They represent significant unconventional sources of water in the littoral zone of Lebanon where a number of fault systems and karstic conduits span between the terrestrial aquifer and open in the marine environments.

Studies in this respect, using airborne Thermal Infra-Red (TIR) surveys, were conducted along the Lebanese coastal stretch. They focused on identifying freshwater seepages into the sea. Primarily, an airborne TIR survey was carried out in 1972 by FAO along the entire coastline of Lebanon. Another airborne TIR survey was carried out by CNRSL in 1997. The concept of identification of these springs implies the differentiation between the cold water from the groundwater seeps and the warmer seawater. Hence, 40 off-shore springs were recognized in the 1972 survey, besides 27 others in 1997 (CNRSL, 1999). However, a number of such springs have dried out as a result of over-exploitation of the feeding aquifer on-land, as well as the existing climatic variability.

Shaban et al. (2005) applied detailed description for these springs and their sources on-land. They estimated that these invisible water sources are discharging about 450 Mm^3/year, which is equivalent to the volume of water let out by the three coastal Lebanese rivers. Thus, recommendations for better management and exploitation of these sources were put forth.

LAKES AND RESERVOIRS

Natural and artificial lakes and reservoirs commonly exist in Lebanon. The natural ones have resulted from the suitability of the topographic setting where several depressions occur and build up by different geomorphological and geological factors. These develop in terrains where soil and rock are suitable to store water as surface storage (lake). Therefore, a large number of surface water storage occurs in Lebanon. They have different mechanisms of water seepage and accumulation, and thus diverse dimensions and shapes exist.

The topographic landforms in Lebanon, notably the low-lands and depressions make it feasible to construct artificial barriers to retard surface water flow, such as dams, reservoirs and pondsto allow water to accumulate behind/ or among these hydrologic barriers. Therefore, six major artificial lakes with relatively large dimensions are known in Lebanon (Figure 2.3). However, the Lake of Qaraaoun, which was constructed in 1962, has the largest areal extent with about 4.3 km^2, followed by the Shabroh Dam which occupies the second place and was built in 2001 (Table 2.3).

Another commonly spread aspect of artificial lakes, but with limited area extent, are the mountain lakes, which are widely distributed in Lebanon. They are mostly built as private implementations taken by inhabitants. These lakes are distributed in the mountainous regions where they are fed largely from the melting snow, as well as from rainfall. Thus, more than 2500 mountain lakes have been accounted for in Lebanon. The average capacity of these lakes is estimated at 1500-2000 m^3.

Table 2.3. The major artificial lakes and reservoirs in Lebanon

No	Lake	Estimated area *(km)*	Estimated capacity *(Mm^3)*
1	Qaraaoun*	4.30	220
2	Bessri*	0.041	128
3	Markaba*	ND	54
4	Hermel	ND	50
5	Shabroh	0.165	8.0
6	Aanan*	0.023	3.0
7	Wadi En-Njas	0.046	0.75
8	Besha'ani	0.002	0.70
9	Jouret El-Balot	0.013	0.45
10	Kawashera	0.001	0.40
11	Yammounah	0.004	0.04

*Belongs to Litani River.

WETLANDS

A number of water saturated localities (wetlands) exist in Lebanon, resulting landforms with remarkable landscapes and ecosystems. These typical landforms are viewed mainly from the frequent existence of water bodies on the terrain surface and the saturated substratum. There are many physical elements that contribute to the existence of wetlands. The existing wetlands in Lebanon are found in regions with defined geomorphology and water feeding mechanism, which are governed mainly by the geological setting and the hydrology and hydrogeology where they occur. They are mostly characterized by low-lands and depressions, long raining periods (November-April) and the existence of aquifers (Shaban et al., 2016).

Yet, the recognition of wetlands in Lebanon is not well determined. However, seven major ones were identified as shown in Figure 2.3, Table 2.4. In the designating of these wetlands, however, two major dimensions are often considered to presume their existence. This implies the duration of water saturation (i.e., water retention), and the spatial distribution of the saturated land (i.e., dimensions). However, there are four Lebanese wetlands that have been designated in the RAMSAR list for global wetlands (Table 2.4).

Table 2.4. Major wetlands of Lebanon (UNESCO-IHP, CNRS, 2015)

No	Wetland	Estimated area *(km^2)*	Description
1	Aamiq*	2.8	Several natural ponds of freshwater in the carbonate rocks.
2	Aaiha	3.2	Low-lands where water seeps from the neighbouring mountain chains and fill these lands.
3	Chamsine/Anjar	0.85	Watercourses running water from Chamsine and Anjar spring and feed Litani River.
4	Palm island*†	5.5	Three isolated islands almost covered by saline water, notably among the karstic ponds.
5	Cliffs of Ras* Ech-Chakaa	7.0	Jointed cliffs (~200m) of carbonate rocks adjacent to the sea.
6	Sour Beach*	0.72	Elongated watercourse occurs from a number of artesian springs running water to the coast.
7	Ayoun Orghosh	0.47	Surface water in a depression land. They seep from the adjacent mountains, which fed mainly from snowmelt.

*Wetland designated in the RAMSAR list.

†Marine wetland.

Even though most of the wetlands in Lebanon are considered as natural reserves, yet they are utilized for different purposes, notably for irrigation, and this brings them under pressure, notably in the view of the changing climatic conditions.

Typical examples are the wetlands of Aamiq, Chamsine/Anjar and Tyre Beach. Nevertheless, the problem of water deficit has also touched these remarkable sources, and hence most of these wetlands have been affected by human interference. Moreover, some of them have been greatly affected and became totally dry such as that of Cliffs of Ras Ech-Chakaa.

SNOW

The snow that accumulates on the Lebanese mountains is in fact the main source that feeds surface and subsurface water. This solid aspect of precipitation extends to the elevated area of Lebanon. It covers, in average, more than 20% (i.e., about 2250 km^2) of Lebanese territory where it shapes the two Lebanese mountain ridges (Mount- Lebanon and Anti-Lebanon). It remains in the solid state for a couple of months over the years and sometimes it is covered by the new snowing event of the year after.

The number of snowing days are also altitude-related, and they are distributed as: <1, 1-2, 3-4, 15-16, 37-38 and >65 days/year for the altitudes: <500m, 500-1000m, 1000-1500m, 1500-2000 m, 2000-2500 m and >2500 m, respectively (Mhawej et al., 2013).

Recently, many studies have attempted to monitor and assess the volume and regime of snow cover in Lebanon. Hence, it is believed that snow melt contributes a substantial portion to the discharge of rivers, springs, and in the replenishment of groundwater reservoirs. Abd EL-Al (1953) estimated that more than 60% of water in the Ibrahim River is fed from snowmelt. Recent studies using satellite images to measure the water volume in the form of snow in Lebanon calculated the amount of water from snowmelt on Mount-Lebanon at about 1100 Mm^3 per year (Shaban et al., 2004). In addition, other studies have estimated the average water volume resulted from of the melting of snowpack at about 2800 Mm^3 per year over the entire Lebanon (Shaban and Darwich, 2013). This is equivalent to about 58.5% of water volume in rivers and springs in Lebanon.

The physical characteristics of snowpack have been well demonstrated for Lebanon. This was to deduce the relationship between snow-water equivalent and depth with respect to other physical characteristics, such as altitude, exposure, terrain lithology, etc. (Shaban et al., 2014). Moreover, the depth of snowpack in relation to altitude was performed in field surveys for 275 sites. Thus, measurements for snow depth at different altitudes and according to selected months of the years were applied. Figure 2.4 shows the depth-altitude relationship over the months of the year. It shows, for example, that snow with 1m depth generally exists above altitudes of about: 2900 m, 2700 m, 2500 m, 2300 and 2100m for the months of October, April, November and March, February and January and December; respectively.

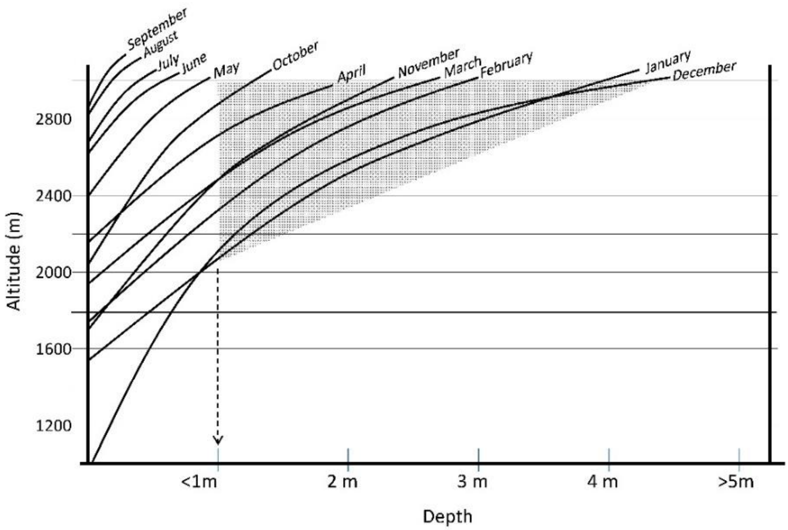

Figure 2.4. Relationship between snowpack depth and altitude in Lebanon.

According to Shaban et al. (2014), the geographic distribution of snowpack in Lebanon was monitored to figure out the dynamic changes over different months, as well as over a series of years. One of the most important physical processes related to snow behaviour is the melting rate of snowpack. This was also investigated in field experiments, and results show that the average melting rate is about 6.28 m*l*/sec (Shaban et al., 2014). This can be considered as relatively high rate due to the increased temperature in the last few decades (i.e., about 2°C). This has also been reflected on run-off and infiltration regime.

The development of space techniques have added value to the studies related to snow cover monitoring, which was tedious to do before. These techniques, depending largely on different types of satellite images, enabled identification of the spatial distribution of snow cover in space and time. It can discriminate the snow cover area and density between different years according to the changing climatic conditions (Figure 2.5). Thus, the trend of snow cover area, including accumulation and melting regime, was precisely determined by using short revisit (daily) satellite images, such as Modis-Terra, which 250 m spatial resolution and can be retrieved twice a day.

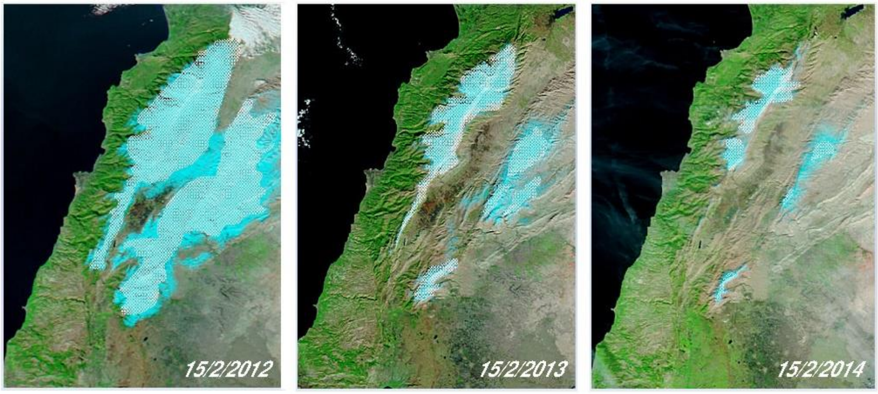

Figure 2.5. MODIS-Terra images of different years showing snow cover in Lebanon.

For more credibility, however, satellite images (MODIS-Terra) for the years between 2000 and 2013 were processed to determine the snow cover area. Consequently, remarkable changes in snow cover area over different years were reported. Therefore, snow cover area in Lebanon, over the investigated time period, shows 1853 km^2 and 6522 km^2 for the minimum and maximum snow areas. There was also noticed an occurrence of more than one peak (i.e., snow storms) with different accumulation behaviour. This can be attributed to the origin of the snowstorm (e.g., tropical storm, regional, etc.) as well as the shifts in seasonal timing as noticed lately in Lebanon (Shaban et al., 2013).

As per the investigated time interval, however, the average snow cover area was found to be about 2344 km^2. Considering the mean depth of snowpack, as investigated in the field, which is 0.80 cm with diverse geographic setting and characteristics, the total water volume in a solid state (snow) is about 1900 Mm^3 at a static time period (Shaban and Darwich, 2013).

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Chapter 3

GROUNDWATER

The assessment of groundwater sources in Lebanon remains more difficult than surface water because groundwater is invisible. Moreover, water experts rely on a terrain surface's signs to presume the scheme of water storage and flow beneath Earth's surface.

Like surface water resources, groundwater in Lebanon is widely tapped (Shaban, 2010). While contamination is dominant, the aquiferous rock formations are subjected to intensive abstraction. This is well observed from the large number of drilled wells. For example, in Saida, one of the major coastal cities in Lebanon, the distribution density of water wells is in the range of 150 to 200 wells/km^2, and most of these wells are privately owned and chaotically located. This number is expected to be four times or more in Beirut, the capital of Lebanon. As a result, a remarkable depletion in the water table and dryness of many springs as well as saltwater intrusions in the coastal aquifers has become a wide phenomenon.

Before the 1970's, a number of studies and projects were conducted to assess and exploit groundwater resources in Lebanon. For instance, the project obtained by the United Nation Development Program (UNDP) in 1970 demonstrated the major hydrogeological elements of

Lebanon. Additionally, several research studies were also elaborated, but they tackled case studies on different topics and on selected regions (Khair et al., 1994; Khawlie, 2000). However, the hydrogeological regime of Lebanon is still undefined. It needs to be updated and new hydrological and anthropogenic elements should be included. Therefore, researchers, such as Shaban (2003, 2010); Shaban et al. (2005, 2007), and UNDP (2014), again started conducting studies and projects using new technologies and tools of analysis to clarify the hydrogeological framework of Lebanon.

Yet, there is contradiction in the understanding of the hydrogeology of Lebanon. This is attributed to many reasons, particularly the dramatic changes in groundwater flow/storage regime, and the undetermined water flow in the karstic systems as well as the intensive fractures that deliver groundwater to unidentified destinations.

Generally, Lebanon is characterized by a complicated geological setting due to the active and intensive tectonics. This criterion substantially acts in controlling the groundwater regime, including its flow and storage among different substrata. Therefore, groundwater behavior must be viewed from the patterns and density of rock deformations, as well as from the existing lithological facies. For this reason, in groundwater assessment, terrain characteristics must be primarily considered. This includes the infiltration (i.e., recharge) rate from terrain surface.

As previously mentioned, the stratigraphic succession of Lebanon in composed of seventeen rock formations and it is characterized mainly by faults, fractures, and karsitfication systems. In addition, there is a tremendous intervention between permeable and impermeable rock layers. Hence, groundwater in Lebanon is a renewable water source that feeds directly from rainfall and snowmelt, and thus, it is characterized by fast hydrologic cycling (i.e., rapid-flow hydrologic journey).

AQUIFERS OF LEBANON

The existing rock formations in Lebanon are characterized by different lithological properties that enable them to store, transmit, or retard the flow of groundwater. Therefore, different hydrogeological regimes exist, which are described as follows:

1) Aquifer: Rock mass or stratum that is able to store water in economic value.
2) Semi-aquifer: It is an aquifer, but the amount of stored water is often less.
3) Aquiclude: An impermeable rock stratum that acts as a barrier to the transmission of groundwater.
4) Aquitard: This rock stratum retards groundwater flow, but does not prevent the flow of groundwater from one aquifer to another.

Among the seventeen rock formations in Lebanon, six are aquiferous, and the rest are aquicludes or aquitards. Three out of the six aquiferous ones are considered as excellent aquifers, as they have been tapped for long. They are attributed to the Eocene, Cenomanian (Cretaceous), and Kimmeridjian (Jurassic) ages. The rest three (out of the six aquiferous formations) are considered as semi-aquifers. Therefore, the six aquiferous rock formations and the hydrogeological column of Lebanon (Figure 3.1) can be described as follows:

1) Kimmeridjian (~200 m): Massive, thick-bedded, highly fissured, jointed, and well karstified limestone and dolomitic limestone, interbedded with thin, marly limestone, as well as frequent horizons of chert nodules.
2) Cenomanian (~700 m): Massive limestone, highly fractured, jointed, and karstified dolomitic limestone and limestone with some thin beds of marly limestone.

3) Callovian Dolomitic Limestone (>650 m): It is relatively deep, and exposed in rare patches.
4) Neocomian Sandstone (variable thickness): It exists with clayey intervening and is almost exposed on surface, which results in large numbers of seepages.
5) Aptian Dolomite (~50 m): It is characterized by cliffy exposure, which has extensive vertical jointing, and thus, unable to store water (Figure 3.2).
6) Eocene Limestone (>1000 m): It often appears with marl and chalky facies.

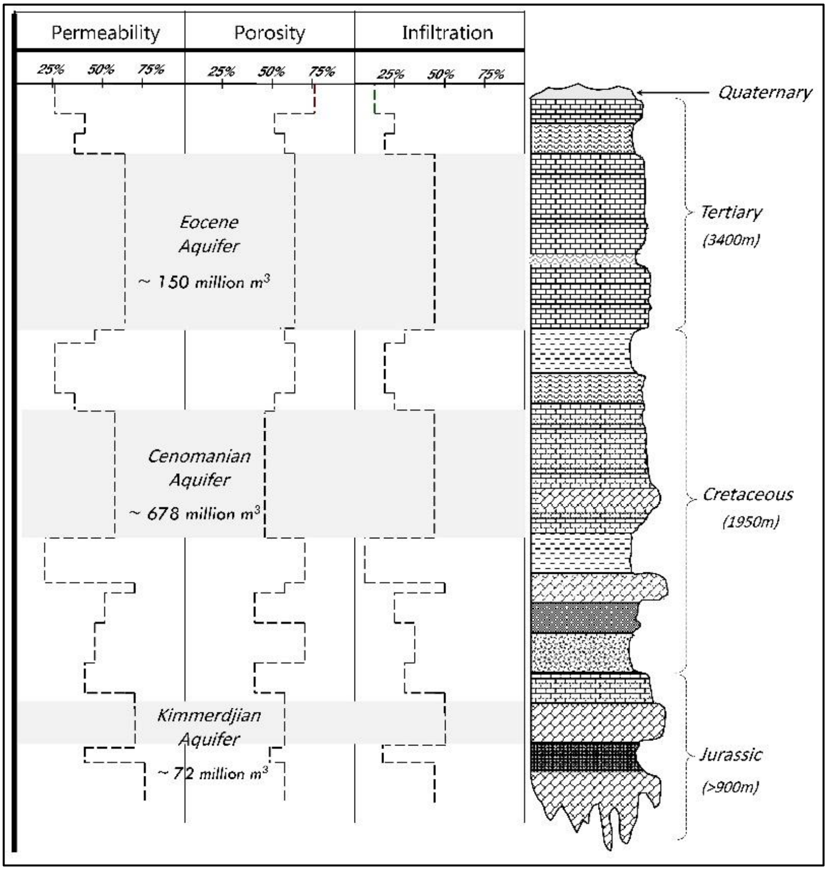

Figure 3.1. Hydrogeological column of Lebanon.

Figure 3.2. Typical Aptian dolomite outcrop of Lebanon.

In Lebanon, intensive fracture systems, secondary porosity, and karstification are the characteristic features of the major aquifers. This increases the degree of permeability and porosity, which is about 40% in some regions (UNDP, 1970). The area of exposures of the three major aquifers in Lebanon can be summarized in Table 3.1.

Table 3.1. Areas of exposures of the aquiferous rock formations in Lebanon

Rock formation	Geographic distribution (Area km^2)		
	Mount Lebanon	Anti-Lebanon	Bekaa Plain
Eocene limestone	490	-	110
Middle Cretaceous (Cenomanian)	2888	2350	120
Upper Jurassic (Kimmerdjian)	550	810	90
Total	3920	3160	320

Even though these three aquifers encompass good hydrogeological characteristics, the exploitation of groundwater is more dominant from the Cenomanian aquifer. This is due to the wide geographic exposure of this aquifer that is estimated as 4190 km^2 over the Lebanese territory. It also has a relatively shallow water table (i.e., 300 m–350 m in average) that makes it more accessible to dug boreholes.

Considering the areal extent, total rock succession, and depth of water and porosity, the volume of groundwater can be assessed. For example, the volume of groundwater in the largest aquifer of Lebanon (i.e., Cenomanian) is estimated at 687 Mm^3 (Figure 3.1). The Eocene and Jurassic aquifers also have considerable amounts of groundwater storage, as shown in Figure 9, which are estimated at 150 Mm^3 and 72 Mm^3, respectively. However, exploitation of the Eocene aquifer is almost limited due to the restricted areal extent. The exploitation of the Jurassic aquifer is also limited to a considerable depth.

The Upper Aptian rock formation is another succession, which is characterized by high permeability and porosity, but it is not potential for groundwater storage because of its relatively thin rock sequence (~50 m). In addition, it constitutes a cliff structure where groundwater easily seeps in.

The geographic distribution of the three aquiferous rock formations in Lebanon is structurally controlled, notably that the tectonic elements of Lebanon are well developed. Therefore, the exposures of the aquiferous rock formations do not represent their actual geological extent, and thus, the controlling geological parameters must be considered when locating groundwater-potential zones. In other words, the extension of stratum of the aquiferous rock formations must be determined by measuring the dips of bedding planes, as well as account for the known stratigraphic sequence.

INFILTRATION AND RUN-OFF

Infiltration and run-off are two related hydrological processes, as they reflect the percolation of water from surface to subsurface media and the flow along major valley systems. Thus, they represent the water flow vertically and laterally, and then, contribute largely to the water cycle and the water distribution as a whole.

Infiltration (or percolation) of water from surface into substratum and through diverse terrain materials is governed by many factors. These factors remain undefined between different hydrologists, as they especially depend on the areas of investigation.

In Lebanon, there are no precise measures for evaluating the infiltration rates over different terrain surfaces. However, the infiltration rates for different rock lithologies in Lebanon were illustrated in the study elaborated by UNDP (1970). The infiltration rates, as shown in Table 3.2, are in the range of 0 (negligible) to 41% of the precipitated water (UNDP, 1970); hence, it averages between 15%–20% for Lebanon.

Table 3.2. Infiltration capacity of rock formations in Lebanon (Adapted after Abbud and Aker, 1986; UNDP 1970)

Period	Formation	Infiltration* (%)	Run-off (%)
Quaternary		4.-20	15-20
Tertiary	Pliocene	Negligible	20
	Miocene	35	9-30
	Eocene	28-45	3-12
Cretaceous	Senonian	Negligible	15-49
	Cenomanian- Turonian	34.5-41	2-10
	Upper Albian- Cenomanian	14.5-41	2-10
	Upper Aptian- lower Albian	Negligible	20
	Lower –Upper Aptian	13-15	37
	Lower Aptian	Negligible	20
	Neocomian-Barremian	10	45
Jurassic	Portlandian	-	-
	Kimmerdjian	39-41	6-11
	Oxfordian	-	
	Callovian	39-41	6-11

As a double-fold function of infiltration, however, run-off is another significant hydrological parameter that affects groundwater. It is usually considered as a primary component of water journey. Run-off is often measured in the field after considering many flow parameters. Hence, this hydrological component is controlled by several hydrological elements, particularly the drainage density, surface slope, channel slope, surface roughness, and lithology. In addition, human interference has a major role on the run-off rate and the flow regime and pattern. These elements are also accounted for the infiltration process. However, the case of run-off in Lebanon is similar to the case of infiltration, and thus, no creditable estimations have been applied, except very few. One of these estimations was elaborated by Abbud and Aker (1986).

Table 3.2 also shows run-off rates in percentage with respect to the precipitated water for different rock formations exited in Lebanon. It reveals that the run-off rate is in the range of 2% to 49%, which is almost in reversible proportion with infiltration. Therefore, the run-off rate averages between 10%–15% for Lebanon.

For both processes, the infiltration and the run-off, it is obvious that some lithologies have considerable rates. Thus, the dolomitic limestone of the Cretaceous and Jurassic ages owns an infiltration rate above 40%, which is attributed mainly to the secondary porosity (i.e., fractures and karstification). Besides, the highest run-off rate is 49%, which is dominant in the Senonian marl, which is impermeable lithology.

Recently, the measuring of water infiltration and run-off has been well pronounced by using new techniques of remote sensing where large geo-spatial assessment can be carried out for different regions. Even though this has been applied briefly in Lebanon, it is an initiative for further applications.

In this respect, Shaban et al. (2005) and CNRSL (2015) applied a systematic approach to deduce the infiltration property for Lebanon. This approach is based on modeling the influencing factors on the water flow to the substratum. Therefore, these factors were elaborated and then converted into digital geospatial data that are needed to obtain the thematic maps (e.g., soil, lithology, fractures, etc.). It is largely done from satellite images (e.g., Aster, Landsat ETM). The analysis and processing of the elaborated factors were carried out using the Erdas-Imagine and Arc-GIS software. Consequently, a final map was produced showing several infiltration categories (Shaban et al., 2005).

Results also reveal that approximately 57% of the coastal zone of Lebanon (coastal plain and Mount-Lebanon) is characterized by high recharge property.

Similar applications to presume the run-off rate have also been applied in Lebanon using the advanced space techniques and geo-information systems. In this case, the Digital Elevation Models (DEMs) were established from stereo satellite images. These models (i.e., terrain surface schemes) represent 3D topographies and they enable the extraction of surface slopes and flow directions with their attribute data. These two variables help estimating the run-off velocity and regime (Ibrahim et al., 2015).

KARST GROUNDWATER

Groundwater in karst aquifers has a complex setting, which makes it different from other aquifers. Thus, subsurface karstification is characterized by high heterogeneity, resulting in groundwater flow in large voids, high flow velocities up to several hundreds of m/h, and high flow rates up to some tens of m^3/s (Bakalowicz, 2005).

In Lebanon, karstic aquifers are tremendous among the carbonate rock masses of Mount-Lebanon and Anti-Lebanon ranges. These aquifers largely constitute of linear dissolution conduits, galleries, and shafts with non-uniform behaviors, shapes, and dimensions. This makes it difficult to be delineated. Therefore, groundwater storage and flow in the karstic aquifers are totally different from those stored in the ordinary rock stratum among the rock voids or between bedding planes.

The relationship between the epikarst zones and subsurface karst has been well-evidenced (Shaban, 2003; Shaban and Khawlie, 2006). Therefore, there is an obvious hydrological connection between the epikarst, where karns, lapis, and many other surface karsts exist, and their extension into the subsurface stratum. Hence, high infiltration rate occurs where epikarst exists, and then, surface water easily percolates along fissures and joints.

Several cavities and grottos in Lebanon represent exposed outlets for large-scale conduits. The latter forms long water-bearing tunnels such as the Jietta Grotto, which is about a 9 km-long conduit. Furthermore, more than 250 large-scale karstic cavities connected with the water-bearing conduits in Lebanon. They range from 50 m to >8000 m in depth. Hence, there are seventy-five major karstic springs joined with these conduits, having an average discharge of about 250 *l*/sec. There are also twenty-five submarine springs (i.e., groundwater discharges) that are attributed to karstic conduit flow (Shaban and Khawlie, 2006). The development of the conduits and the related cavities are mainly attributed to structural features where surfaces of weakness exist (e.g., along the contacts of bedding planes), which consequently form the spacing along which carbonate dissolution takes place.

Several studies have been conducted on the karstic phenomenon in Lebanon, with a focus on the hydrological parameter (Azar, 2000; Edgell, 1997; Guerre, 1969; Hakim, 1985; Shaban et al., 2000; Somma et al., 1998). Therefore, much concern has been given to sinkholes (i.e., dolines), because these karstic features are considered to be sources for groundwater recharge. Hence, sinkholes have the potential for water infiltration. Notably, they occur at high altitudes where snow remains for a long time, and thus, these depressions (sinkholes) capture thick snowpack succession. The melting of this snow regularly contributes to recharging groundwater in the carbonate rocks (Shaban and Darwich, 2011).

In this respect, the structural elements that control the existence of subsurface karstification are also given attention, notably that these elements are well developed in the hard carbonate rocks, which completely respond to the tectonic effects. Therefore, several aspects of the geologic structures play a role in the development of subsurface karst, such as faults intersection where caves are formed (Shaban and Khawlie, 2006). Also, the resulting weak surfaces and remarkable spacing between bedding planes, which exist due to the geologic structures and then dissolution, take place along these features. For example, Jietta Grotto in Lebanon is developed along the hinge of an anticline, and thus, it tends to percolate into groundwater in sufficient quantities.

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Chapter 4

Challenges on the Water Resources of Lebanon

As per the physical status of water resources in Lebanon, with a focus on the natural availability of these resources, it is believed that people in Lebanon can be simply provided with the amount of water they need. However, the current status does not reflect this, and complaints on water supply are often raised (Shaban, 2014). Hence, there is an obvious imbalance between supply and demand, which is also accompanied by the issue of water contamination. Therefore, it can be said that Lebanon is facing striking challenges on its water resources.

It is a paradox that Lebanon is ranked at the top of the list of water availability in the Middle East, but it is also at the lower ranks in water supply. Therefore, Lebanon is threatened by several physical and anthropogenic problems that make it a country under water stress. Implementations, studies, and plans are usually applied to reduce the effect of this unfavorable status. Even though Lebanon established a water strategy in 2010, no positive changes have been sought on the water sector since more than 30 years.

NATURAL CHALLENGES

Natural (i.e., physical) processes, in many cases, play a negative role in the hydrologic regime of water. This is mainly governed by the terrain features where water moves/ stores, as well as by the material of the terrain itself (soil and rocks). Generally, these are the constraints for water exploitation. This is well pronounced for surface and subsurface water sources. However, when these constraints remain unsolved and develop with time without solutions, they become challenges. This is also applied to constraints that are created from human interference. Hence, identifying the natural challenges on water resources will help in selecting the treatment approaches for any water-related problem.

In Lebanon, natural water challenges strongly hinder the feasibility of water resources. Normally, there is no way to completely treat the natural setting, but there many ways to adapt to it. For example, it is impossible to ignore the steep slopes along which water runs very fast, but water can be restricted, and then, properly tapped.

Climatic Oscillations

The debate on climatic conditions in Lebanon has been well discussed in Chapter I. It shows that the climatic trends in Lebanon are still unclear due to the lack of comprehensive and updated meteorological data series. This in turn makes it difficult to precisely presume the future climatic behavior, thereby creating difficulty in predicting incoming meteorological trends and their impact on the related disciplines, with a focus on water resources, agriculture, and food security.

The debate on the climatic concepts in Lebanon implies unsolved questions. This inquires the following: Has there been any change in the rainfall rate? Has there been a reduction in the area of snow cover? Has there been an increase in temperature? The answers to these questions remain obscure/contradictory among different researchers. Therefore, discrepancy in the results of several studies regarding the applied analyses, projections, scenarios, and models has been raised (Bou-Zeid and El-Fadel, 2002; Karam, 2009; Lovallo et al., 2013; Ramadan et al., 2013).

A number of research studies and projects analyzing the meteorological status in Lebanon has been applied by Shaban (2011), CNRSL (2015), and Shaban and Houhou (2015). In these analytical applications, detailed and comprehensive climatic data were used and utilized in many cases from remotely sensed products (e.g., TRMM, NOAA, etc.). In addition, these studies were based on advanced statistical methods (Lovallo et al., 2013; Telesca et al., 2014), such as the Fisher-Shannon method and the Singular Spectrum Analysis. The results of these studies and projects show that changes on the climatic parameters exist in Lebanon, but they might be different from the known concepts; therefore, the following points can be concluded:

1) Little decrease in the rainfall rate has been noticed over the last four decades. It was estimated between 35 mm and 40 mm. Hence, a produced rainfall map shows that some regions in Lebanon (52% of Lebanon) experienced an increase in the rainfall rate, besides the 48% increase (CNRSL, 2015).
2) There has been a change in the rainfall pattern, which was diverted from ordinary to torrential rain where intensive rainfall occurred.
3) There has been an obvious shift in the timing of seasons (e.g., summer coming late, etc.). This is reflected in many aspects of life, notably, agriculture (e.g., plantation dates, irrigation scheduling, etc.).
4) There has been an abrupt change in the daily meteorological conditions, even from one day to another. This is well known in

the changing temperature over the same day, which may reach to about 10^0 C difference within a couple of hours.

5) There has been an increase in the average annual temperature, which has been estimated at about 2°C over the last five decades.
6) No remarkable change has been observed in the snow coverage area and density over the past three decades, as deduced from satellite images processing, but the melting rate has increased due to temperature increase and raised sunlight radiation.
7) The calculated humidity index shows that the western Lebanese mountain range (i.e., Mount-Lebanon and the coastal plain) is a humid zone and not as believed (i.e., under drought condition).

Morphology

The morphology of Lebanon, as previously mentioned, is not uniform, and there are rugged topographies dominated by steep terrains. This steepness controls water run-off and overland flow from the mountainous ridges toward the low land and to the sea as well. This morphological criterion results in significant challenge in the energy of surface water flow, which is high, and then, chances of capturing water become low. Therefore, “water loss” is one of the challenges on surface water in Lebanon, which must be considered for proper investments in running water.

The rugged morphology of Lebanese terrain shapes and controls the dimensions of rivers and streams (i.e., short and meandered) and makes the flow time interval limited (i.e., few hours from sources to outlets) to reach the final destination at the sea. This is the reason why surface water harvesting has always been proposed, and thus, dams, conveying channels, and lakes are recommended.

Geologic Setting

The geology of Lebanon plays a significant role in the water flow/storage regime. It governs the surface water flow and helps in the percolation of water to the subsurface stratum, as well as controls groundwater storage above the impermeable rock layers. Also, the geology of Lebanon is characterized by fractures that allow water to flow within the fracture voids and karstic routes. This has been well demonstrated by several studies obtained in Lebanon (Aoudeh, 1974; Canaan, 1992 and Arkadan, 1992). Hence, the existing lithologies with the accompanied structures represent effective agents on the uncontrolled water regime. For example, along a steep sloping surface with impermeable rocks, water rapidly runs than along a steep surface with permeable rocks; therefore, in the second case, water infiltrates beneath the rock and recharges groundwater, while in the first case, water is usually lost before any utilization.

According to Shaban (2014), the geological elements in Lebanon mainly control the water regime, and many researchers have considered them as the most significant physical challenges. Nevertheless, such elements are tedious to be managed or they can be partially controlled. They can be summarized as follows:

1) Fracture systems: These include all rock deformations, such as faults, fissures, and joints, which cut among different geological rock formations. Even though these systems can be considered as potential hydrogeological zones on which groundwater may flow or be stored, they can also play a negative role in the seepage of groundwater into the sea, as well as into a very deep (unreachable) aquifer.
2) Karsitfication: This complicated geo-hydrologic phenomenon is usually described as an undefined hydrologic element because

of the irregular dissolution routes that are difficult to be delineated while studying the behavior of groundwater.

Shared Water

Shared water is one of the major challenges in Lebanon and it cannot be treated separately from one side at the national level. Therefore, limited national capacities, plus political conflicts in the areas of water governance and water resource management have regional implications, and can often be identified as the main reason for the inability and/or unwillingness of governments and institutions to discuss, coordinate, and cooperate on shared water issues (ESCWA, 2005).

Lebanon, with its small area, has a distinguished geographical setting. The mountainous ridges forming Lebanon makes it a regional water divide. Therefore, about 74% of Lebanon's perimeter is bordered with other countries where political conflicts occur, which are largely reflected on the water resources shared among these countries. In this respect, Shaban and Douglas (2008) estimated that between 25% and 30% of the Lebanese water resources are shared water resources. This results in an additional stress on the unfavorable water resources in Lebanon. Hence, shared waters in Lebanon are discussed in details in the next chapter.

CHALLENGES OF HUMAN INTERFERENCE

Anthropogenic influence on water resources is a major striking challenge that has remained unsolved in Lebanon, notably with the increased population size and the new demands for water. Therefore, the negative human interference and lack of proper management affect the water quantity and quality, as in the case of Lebanon. The most influencing aspects of human interference on water resources in Lebanon are the following:

Increased Water Demand

While the demand for water does not exceed 220 m^3/capita/year, the estimated water availability in Lebanon is about 1350 m^3/capita/year. Besides, water supplied by the governmental sector in Lebanon does not exceed 35%–40% of the total demand, which is equivalent to about 83 m^3/capita/year. The rest of the water is the responsibility of the consumers, which adds more financial load on people to buy water from different sources, or to execute small-scale projects to collect water. In many cases, this creates unsafe use of water (i.e., contaminated) and results in many diseases, which have often happened in many regions facing water shortage in Lebanon.

The existing water shortage in Lebanon resulted in a number of negative behaviors in consumers, especially in farmers, who need to continue their agricultural trade. Therefore, a chaotic exploitation of water has become a common task, such as increasing the number of boreholes, direct pumping from rivers and springs, etc. This is reflected on the volume of water, whether from surface sources or from groundwater. According to Shaban (2014), the increase in water demand in Lebanon can be attributed to the following reasons:

1) The increase in the population size that is about 2% annually, which means that about 9 Mm^3 –10 Mm^3 of additional water is required every year. This will make water demand increase in the future, as most projections predicted a higher increase of population in Lebanon.

2) The demand has increased due to additional human requirements. This is referred to recent water requirements that were not known before, such as car washing, tourist resorts, swimming pools, etc.
3) The existence of non-accounted water, or the non-revenue water, which has increased lately, and attributed to water loss before any utilization, such as leakage of water due to old infrastructure.
4) The absence of economic policies, such as non-licensed boreholes, absence of water meters and tariffs, etc., to regulate water consumption (Shaban, 2016).

Water Quality

Rarely has a source of water in Lebanon been found pure, notably the surface (easily accessible) water sources. Thus, contamination is a widespread geo-environmental problem in Lebanon. This has also affected bottled water, which is supposed to be very pure and healthy. Hence, analytical results show that 80% of bottled water in Lebanon is contaminated biologically or chemically, and in many instances, it’s both. According to Shaban (2016), quality deterioration in water sources in Lebanon can be attributed to the following reasons:

1) Old infrastructures to cope with newly established urban settlements.
2) Absence of waste disposal plants, whether for liquid or solid wastes.
3) Non-protected replenishment areas of major springs, rivers, and even groundwater.
4) Excessive use of fertilizers in cultivated lands.

5) Lack of legislations and laws for the environmental conservation of water.

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Chapter 5

PRINCIPLES ON SHARED WATER

CONCEPTS ON SHARED WATER

Water, the naturally widespread material, flows along the easiest pathways and accumulates when obstacles appear. Thus, it is not governed by any human ownership, cadastral or national borders, or any aspect of man-made land limitations done. Hence, it is commonly found that water sources intermingle between the established limits and borders. However, when these borders are transected by water sources, conflicts often arise and debate on how much water can be used by each region along the existing border.

As a general understanding, shared water between two or more regions (countries) is always a matter of debate. This is not only applied at the national level between neighboring countries, but also between consumers in the same country. This gave rise to the concepts of "water right" and "water ownership." In this regard, there are lots of the problems created by sharing water within the same country, which resulted in improper management and exploitation of these sources.

According to Frey (1993), it is essential to know where sharing water comes from or where it goes after consumption or its potential use by other individuals downstream from a known location. However, it is important to recognize four basic elements of water resources that may result in an unfavorable status in the water sector. These are as follows:

1) The value of water resources as an essential sustaining resource for life.
2) Water, in many regions worldwide, is unavailable with respect to demand.
3) Uneven water distribution across the land masses.
4) Water is often shared and it crosses national boundaries. Therefore, the issues of effective water resource management have become even more complicated.

Definitions of Shared Water

Many terminologies, like transboundary or international water, are used to describe shared water resources. Thus, there is no fixed definition, and the related concepts are usually found to be contradictory. While some authors use the term "shared" and others use "transboundary" or "international," these three terms have different meanings.

For example, Draper (2007), who used the term "shared water," stated that this water exists either as surface water or in subsurface, which is shared by two or more nations. UN-Water (2008) used the term "transboundary water," which refers to sharing rivers, lakes, and inland water as a whole and aquifers. Here, open oceans, territorial seas, and coastal waters are excluded explicitly. In this respect, Wolf (2007) described giant river basins, such as Nile, Danube, etc., as "international water." Besides, shared natural resources, as illustrated by Beyene and Wadley (2004), are those that are capable of traversing a boundary because they are animate creatures.

According to Shaban (2010), the most understandable definition for any aspect of water that is shared between two or more countries should be built in the way that a water body spreads over, whether on terrain surface or in the substratum, which includes the dynamic and static states of water bodies, and its sources, orientation, and many other controls influence the water distribution.

For example, the interrelation between two or more countries sharing a water body extends to different national borders and has no considerable movement (e.g., lake, aquifer), which will be totally different from another water body running (e.g., river or spring) from one country to another. In particular, groundwater has no considerable movement and no defined source, whereas water running along a river has point(s) source that one country can control before it flows into another. Hydrological and hydrogeological considerations must always be accounted for when assessing sharing of water.

Therefore, it must be made clear that the nomenclature or definition is an utmost indicative and should be used in describing shared water resources. The following are the most convenient definitions used by the author:

1) Shared water: Any static water body that is shared by two or more countries. Thus, the movement of water is minimal and no point source of water can be identified. This includes mainly all water bodies with geographic polygon(s) or cluster, such as the aquifers, lakes, snowpacks, watersheds, and wetlands. It can also be applied to a water route, such as a river, when it represents the national border between these countries (Figure 5.1).
2) Transboundary water: This represents the dynamic water body (i.e., water with considerable flow rate) that is shared between two or more countries. It often occurs with identified point-

sources and outlets. Thus, sharing water is mostly represented by linear water routes that span from one country to another, such as rivers, streams, springs, karstic conduits, and water-bearing faults (Figure 5.1).

3) International water: This may include one of the above shared waters, but it often points to the global or regional view of sharing water resources. In other words, the term "international water" is always applied when talking about sharing water in a large geospatial view, such as saying: international water in the Mediterranean basin or in the Economic and Social Commission for West Asia (ESCWA) regions, or in the Arab region, etc.

However, the term "shared" is more comprehensive and is widely used to describe the sharing of water between different regions. In this respect, the title of this book is assigned as "shared water."

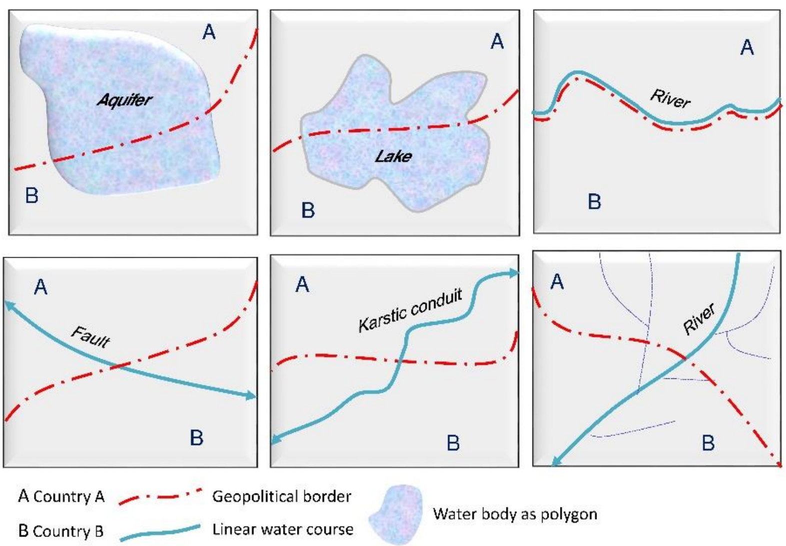

Figure 5.1. Spatial aspects of shared water resources.

Factors controlling the interaction and cooperation between water-sharing countries are viewed from different aspects. According to LeMarquand (1990), a shared riparian nation can be subjected to multiple, complicated foreign policy factors that may impact sharing waters. These factors include the following:

1) Image that represents the concern of a nation for its international image.
2) International law with the concern to abide by the established legal rules.
3) Linkage, as the perceived connection between water and other issues.
4) Reciprocity, which is a desire for mutual commitment and obligation.
5) Sovereignty, which implies the stress placed upon autonomy.

Shaban (2010) and Shaban and Douglas (2008) established a diagnostic analysis for the factors that must be considered during the assessment of shared water resources. These factors can be summarized as follows:

1) Area: The spatial distribution (i.e., geography) of shared water resources should be well determined. This includes all acting dimensions laterally and vertically. In addition, the national border limits must be fixed. This will help in classifying the quota of water for each of the sharing countries. Moreover, the determination of the spatial distribution must consider the replenishment zones where water feeds the entire body of the shared water.
2) Orientation: The general terrain orientation, or sloping aspect of the terrain surface, is one of the significant factors influencing water body and the locality where it is located. This implies the start points (i.e., source) and the outlets for linear water bodies,

as well as the high land (or upstream) and low land (or downstream) for the water body with a polygon shape.

3) Feeding sources: This is always the key issue in the existing conflicts between countries on shared water resources. Thus, the source where water originates should be very well identified. If the source is represented by a node or point-source, it can be better managed, but in other sources, such as the replenishment zones in an aquifer or a spring, the geography of these zones should be primarily identified.
4) Flow energy: The flow velocity is a function of several parameters, including the slope, lithology, and the number of existing tributaries that are connected to the primary watercourse or river. Thus, any influence on these parameters will affect the water flow regime and the volume of run-off. Therefore, these parameters should be well investigated while assessing shared water.
5) Exploitation: One of the principal factors contributing to the relationship between sharing or riparian countries those are in a political conflict with each other. Sometimes, this conflict exaggerates, as has happened in many regions. Therefore, treaties and conventions are often signed to regulate the exploitation in each country in accordance with the geographic distribution of the water body, feeding sources, and other influencing parameters. Thus, the exploitation must be agreed between the sharing countries. For example, the execution of a dam on the upstream or the high lands will affect water discharge in the downstream region.
6) Legal aspects: This factor is related to the exploitation, and acts in managing the exploitation processes and the works done on the shared water resources. Therefore, legal agreements and collaboration between the sharing counties will facilitate the exploitation with goodwill between these countries.

The natural distribution of water bodies, whether on surface or subsurface, makes it cross many national borders. This is mostly governed by the natural setting of these bodies. These water bodies may create social and economic interdependencies between societies if there are no conflicts between them, followed by agreements drawn to use this water equitably. They are vital for developing economically, reducing poverty, and contributing to the attainment of the Millennium Development Goals (UN-Water, 2008). Therefore; it has rarely occurred that a water body, with considerable extent, was not shared between two or more countries. In this regard, according to Draper (2007) and UN-Water (2008), the following figures address the global view:

1) Two lakes and 268 transboundary river basins worldwide, which comprise half of the Erath's land and account for an estimated 60% of global freshwater flow.
2) 250 rivers are shared between two or more nations.
3) Over fifty rivers are shared between three or more nations.
4) More than 90% lives in countries that share water basins (surface and subsurface)
5) A total of 145 states include territory within such basins, and thirty countries lie entirely within them.
6) About two billion people worldwide depend on groundwater, which includes approximately 300 transboundary aquifer systems.

Thus, nine countries share the river Rhine in Europe, whereas the Mekong River is shared by six countries in Southeast Asia. There are eight countries sharing the Zambezi River in Southern Africa. Therefore, approximately 40% of the world's population depends on these shared rivers, and thus, they need effective cooperation among riparian countries for the planning and management of these shared waters, which is essential in the face of the growing demand for water and the potential adverse impacts in the river systems, because of upstream usage (Draper, 2007).

Aspects of Shared Water

The aspects of shared water resources should include perennial and temporary resources of different scales (Shaban and Douglas, 2008). This must also include all related elements as mentioned previously. They can be summarized as follows:

1) Groundwater reservoirs (aquifers): Groundwater is the body of water that is stored in the rock stratum. It is characterized by high permeability and porosity. Often, these rock strata extend over long distances (e.g., several hundreds of kilometers), and they own considerable thickness of several hundreds of meters. The characteristics that govern the aquifer productivity of groundwater are variation in thickness, aquifer cap rocks (confined or unconfined), as well as the physical properties of aquifer rocks. About 300 groundwater basins are shared by two or more countries (ADB, 2009).
2) Rivers: These are permanent watercourses, which span along easier topography and may transect different countries. In a worldwide figure, there are about 215 international (large-scale) rivers (ADB, 2009), plus a big number of small-scale rivers.
3) Lakes: These include natural depressions filled with water, which last for long time over the year. In other cases, they remain filled with water permanently. They are often shared by two or more riparian countries, which are located adjacent to the lake, regardless which side they share from, as they all have access to the same water body.

4) Drainage systems: These watercourses, like rivers, often have no continuity in discharge (seasonal streams). They also transect different topographic regions. Nevertheless, they have an essential role in deriving water along national borders, mainly because they feed the primary watercourses (i.e., rivers).
5) Springs: Several groundwater outlets are represented by springs, where water seeps from rocks, and then, spans/ shares along national borders. These sources of water, in most cases, represent the major sources providing water for rivers and to groundwater as well.
6) Snowpack: Usually snow is viewed as a static body and included as a shared water resource. However, from a hydrological point of view, snow is a dynamic element and its geographic distribution (coverage) is similar to the extent of watershed (catchment area) where it extends over national borders on different elevated regions. However, melting snow flows as water in different directions, and thus, it is significant to be accounted as a shared water source.
7) Water-bearing conduits: These are well-known subsurface karstic, especially in the Mediterranean region where groundwater flows. However, the specific karst water circulation creates a lot of difficulties in the delineation of these routes, notably when they are internationally shared (Bonacci, 2004).
8) Water-bearing faults: This criterion represents fault alignments that cut from one country to another. However, if these faults act as water-bearing routes, they should be considered as shared water bodies. Like water-bearing conduits, these faults are considered as hydrogeological elements, and they are well pronounced in many regions.

Tools for Studying Shared Water

The assessment of shared water has often had a miscellany of methods and tools applied for different water sources. Thus, investigating groundwater is tedious than that of surface water, but studies, depending on the geological maps, could do a preliminary analysis of the geographic distribution of aquifers (Khawlie and Shaban, 2003), which can facilitate the analysis to deduce the extent of subsurface water reservoirs. This can also be applied to the linear geological structures and karstic conduits along which groundwater transports. In the case of surface water, the delineation of watershed will be primarily obtained and followed by determining the flow of water from the connecting tributaries.

Generally, the tools used for analyzing a shared terrain, including its resources, often depend on a miscellany of thematic maps, with a special emphasis on maps for topography, cadaster, hydrology, hydrogeology, and geological maps. Recently, these maps were integrated with data and information from satellite images, which are used to update the available thematic maps and to apply monitoring approaches (Shaban, 2010; Shaban and Douglas, 2008).

The combination of these maps in conjunction with ground geological and hydrological data can help adjoining countries to better diagnose shared water resources. However, erroneous delineation and reading of these maps will result in misunderstanding, consequently creating conflict between these countries. Also, denial of the international laws adds to the problem of shared water issues.

Hence, a number of approaches and tools can be utilized, including the advanced techniques (Figure 5.2). Thus, the applied steps can be summarized as follows:

1) Preparing the available thematic maps (topography, geology, cadastre, etc.) in digital (electronic) forms, including the adjacent regions between the neighboring regions. This can also include any available data records, such as rainfall, flow energy, water-related constructions, etc.
2) Manipulating the available thematic maps and their supplementary data in the Geographic Information System (GIS) to enable modifying, measuring, calculating, drawing, and storing data and information related to water resources between the neighboring regions.
3) Applying corrections and calibrations on the delineated geospatial data, including rivers, streams, geological boundaries, location of springs, etc., notably those located at the border between the adjoining countries.
4) Using remotely sensed data whenever needed, especially, in monitoring large geospatial entities, such as the snow cover delineation, lakes, wetlands, as well as in applying different applications for further data elaboration, such as extraction of digital elevation models (DEMs). Also, satellite images with different special and temporal resolution can be useful tool, such as MODIS-Terra, Aster, Landsat, and Quick-bird satellite images.
5) Applying ground measures and data survey (whenever applicable) to identify the names and ownership, water consumption and other related data on shared water resources at the border area.

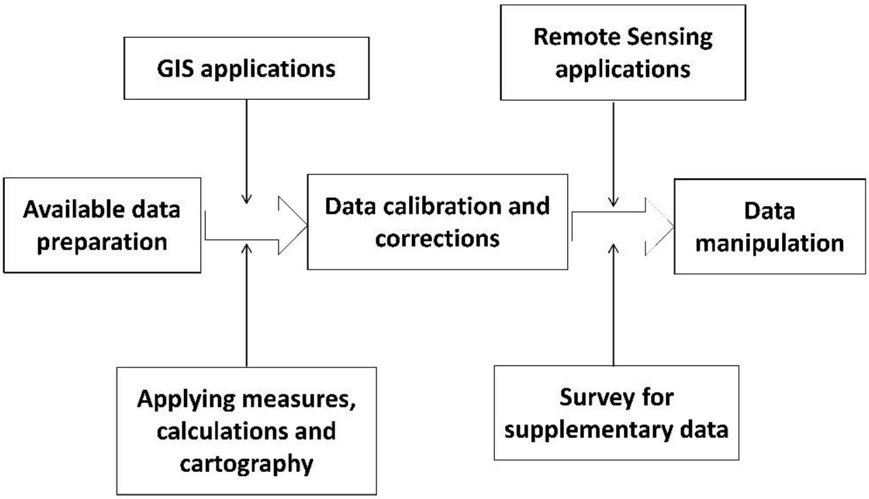

Figure 5.2. Schematic figure showing used approaches to study shared water.

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Chapter 6

SHARED SURFACE WATER OF LEBANON

In order to face challenges on water resources, different approaches can be undertaken by the management, especially being prepared for future changes. However, sharing water among different countries is one of the challenges that can be managed if there is no encroachment or occupation by a country on another. Otherwise, it would be a complicated issue to be resolved. Such is the case of Lebanon where its shared water resources are governed by the political conflicts due to the Israeli occupation.

Lebanon is bordered with Syria from the northern and eastern sides of the country, with the Palestinian Territory (PT) from the south. It is located along the Mediterranean Sea where its western border acts as a coastal line. About 74% of Lebanon's perimeter is shared with Syria and PT. Its natural setting, with its remarkable geomorphology and geology, allows surface and subsurface water to intermingle with the neighboring regions, which also seeps into the sea.

In fact, there are no precise volumetric estimates for the shared water resources of Lebanon except few applied estimates. Therefore, the budget of shared water has remained undetermined and unmanaged since a long time. There are two shared rivers between Lebanon and

Syria in the north and one river with the PT in the south. Moreover, aquiferous rock formations extend between Lebanon and these regions without any defined hydrogeological understanding. There are also large number of springs, streams, snowpack, and many other aspects of water bodies that extend between Lebanon and the neighboring regions.

The Middle Eastern countries, in particular, are witnessing the problem of shared water resources. This has been exacerbated due to many geo-political reasons, with a special impact by the presence of Israel in the region. It is not exaggeration to describe the current political dispute in the Middle Eastern region as a "Water War" (Shaban, 2010).

Therefore, security instability is well pronounced, which is reflected in the water resources management, as well as economics, agriculture, and the social status. Therefore, conflicts are occur often, and sometimes become a national dilemma, such as the event in 2002 when Israel prevented Lebanon from pumping water from the Wazzani spring, which is located in Lebanon (Figure 6.1).

Figure 6.1. Wazzani spring, a major source feeding the Hasbani–Wazzani River.

Amery (2002) stated that most international water disputes in the Middle East will be resolved peacefully. Besides, others are likely to trigger unstable political situation in the Middle East in the next few decades.

The recent borders in the region were drawn in 1916. It was separated once the united territories in accordance with a British–French–Italian–Russian arrangement worked out, and Palestine and Transjordan along with Iraq were put under the British mandate, while Lebanon and Syria were put under the French mandate (Haddadin, 2001). Therefore, most of the recent national borders were drawn in accordance with the topography and other distinguished physical features.

The national border between Lebanon and its surrounding regions is represented mainly by remarkable geographical localities and landmarks (crests, river courses, etc.). Hence, large segments of this border are now under political conflict, which makes it tedious to control the existing resources. Hence, it was estimated that between 25% and 30% of the Lebanese water resources are shared ones (Shaban and Douglas, 2008). Among them, about 90% is with Syria and 10% with PT (Figure 6.2).

Even though Lebanon has a small area (10,452 km^2), around 3/4 of its border is shared with the neighboring countries, and the rest 1/4 is situated adjacent to the Mediterranean Sea. In addition, the tremendous water resources of Lebanon, with widespread extent, whether on surface or subsurface, make these resources interfere with the neighboring regions. These resources are neither identified nor managed, and thus, large volumes of water are considered as loss (Shaban, 2014). Therefore, the total perimeter of Lebanon, which is about 803 km, is divided in the following way:

1) 562 km (70%) is shared with Syria in the north and the east (Figure 6.2).

2) 32 km (4%) is shared PT in the south and partly in the southeast.
3) 209 km (26%) faces the Mediterranean Sea to the west.

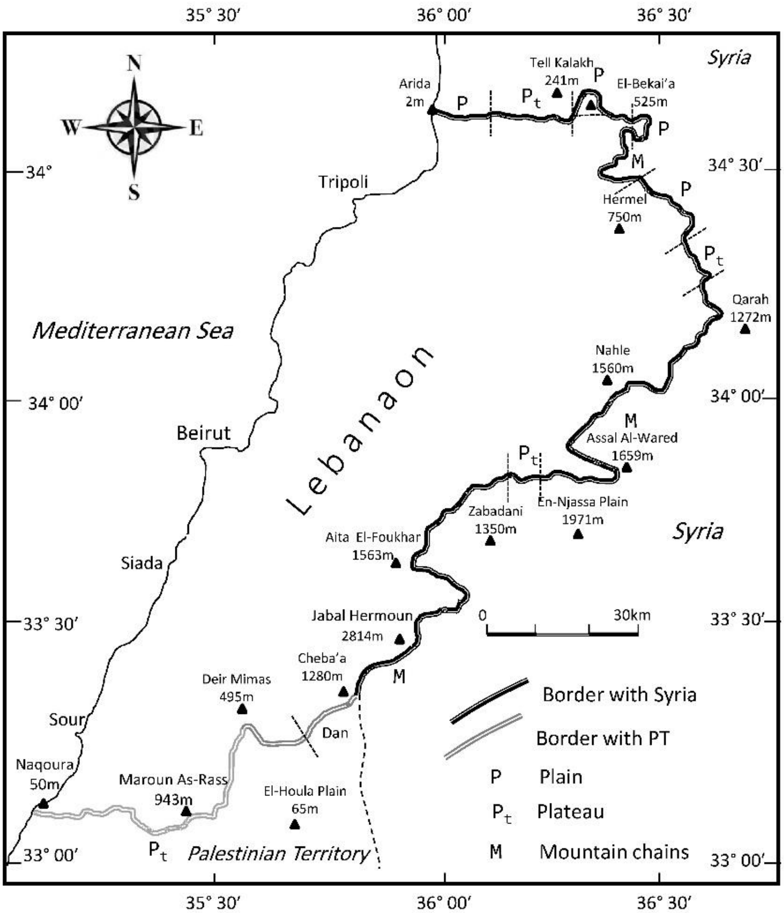

Figure 6.2. Lebanese national border with respect to its physical setting.

Generally, the majority of the visible shared water resources in Lebanon, as they are very well known, include only three rivers, namely El-Kabir River, Orontes River, and Hasbani–Wazzani River, and many other aspects, as illustrated in Figure 6.3. However, there are also other significant aspects of unidentified shared water in Lebanon, but most of them are unknown sources. They are expected to occupy water volumes larger than any one of the three visible rivers. For example, some extended carbonate rock aquifers and their related issuing springs between Lebanon and the neighboring regions have water volumes bigger than what is discharged from one of the three shared rivers.

Also, the large-scale snow patches, which are a major source of the water that feeds the surface and groundwater, and extend between Lebanon and the surrounding, are believed to produce water (in the liquid state) in large volumes. Thus, they also require attention as an aspect of shared water. Any existing human activity on this snow will affect water conveyed from the snowmelt to the neighboring regions.

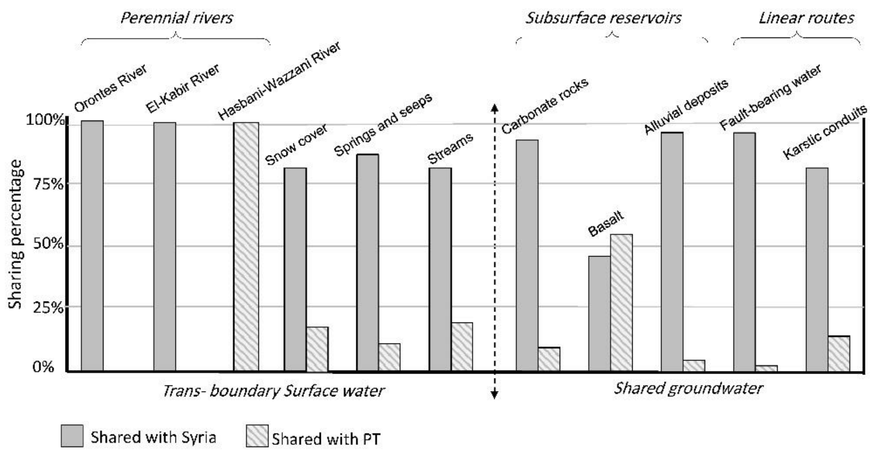

Figure 6.3. Major elements of shared water resources of Lebanon.

Even though they are poorly managed and unreachable in most cases, surface water resources in Lebanon have attracted much concern, as they can be identified, or at least observed. When compared with other Lebanese rivers, shared rivers in Lebanon can be considered as the most significant ones in terms of water volume/accessibility and continuity of discharge. Thus, three hydrological systems exist along the Lebanese border. They are located in the northern part of the country where two rivers flow along the Syrian border. One of them coincides with the Lebanese-Syrian border and is represented by the EL-Kabir River, and the other is located at the extreme north eastern side of Lebanon and is represented by the Orontes River, locally known as the AL-Assi River. Besides, the third system constitutes of the Hasbani–Wazzani River, which originates from Lebanon and runs south, joining the Jordan River in the PT (Figure 6.4).

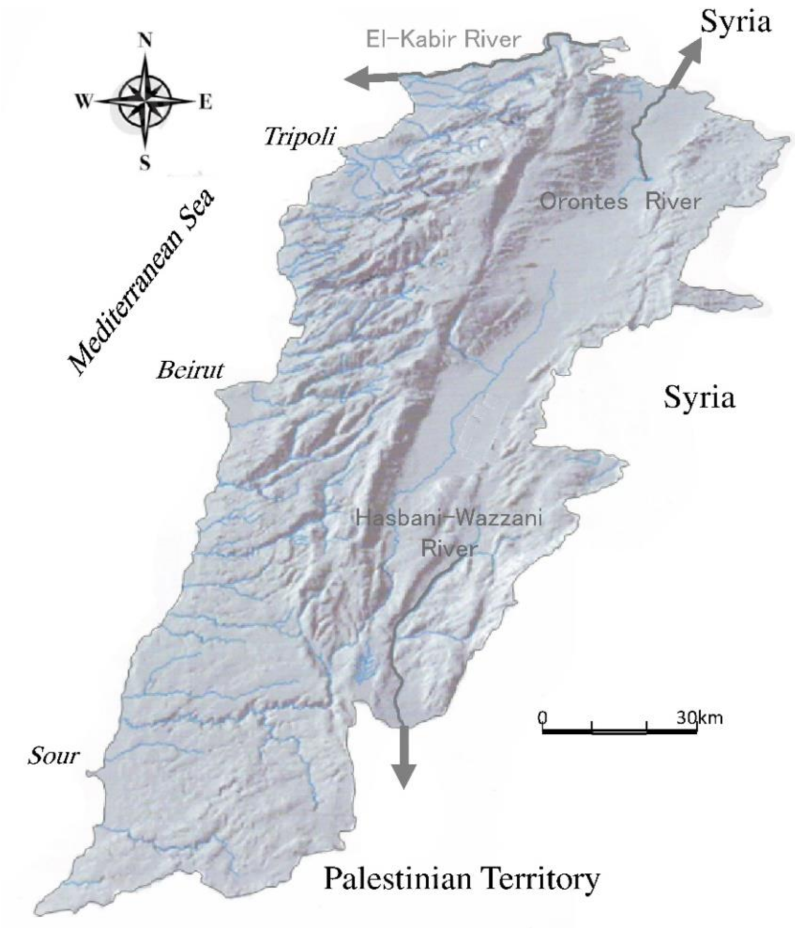

Figure 6.4. Shared rivers of Lebanon.

Except few estimates on some river tributaries, there are no creditable measures to estimate the volume of shared surface water in Lebanon. This results in unclear understanding about the volumetric measures of these rivers. In addition, the changing hydrologic trends cannot be illustrated. Moreover, it is not an exaggeration to say that the quota of Lebanon from this water is not satisfactory. In other words, the exploitation of water from the shared rivers of Lebanon is poor to moderate, moderate, and poor for El-Kabir, Orontes, and Hasbani–Wazzani rivers, respectively. This status is attributed to the following:

1) When compared with the domestic rivers, less concern is paid to the shared rivers by the water sector in Lebanon. This can be related to the relatively remote locations of these rivers as well as the lack of complete control on them.
2) There is an absence of effective conventions and treaties on water resources, notably with Israel, which is totally absent. While the treaties with Syria were obtained long time ago, which don’t comply with the current status. Thus, they need to be modified and must involve new considerations for the physical and anthropogenic changes.
3) Geopolitical conflicts, notably the military ones, have several aspects. This reduces the attention on the issue of shared water as a natural resource.
4) Denial of the international laws on shared water by Israel in order to exploit water from the Hasbani–Wazzani River.

The basins (i.e., watersheds) of the three shared rivers in Lebanon are totally different from each other in terms of area, orientation, and feeding sources from the Lebanese territory.

EL-KABIR RIVER

El-Kabir River (Figure 2.1, Table 2.1), locally known as Naher El-Kabir, is one of the coastal Lebanese rivers, located to the most northern Lebanese limit, which constitutes the Lebanese–Syrian border. The watershed of El-Kabir River extends between Lebanon and Syria, totaling about 972 km^2, where about 303 km^2 is located in Lebanon and 669 km^2 in Syria. Thus, in Lebanon, it constitutes about 31% of the entire basin (Figure 6.5). The orientation of the river basin is structurally controlled, including faulting, uplifting, and volcanic rock masses.

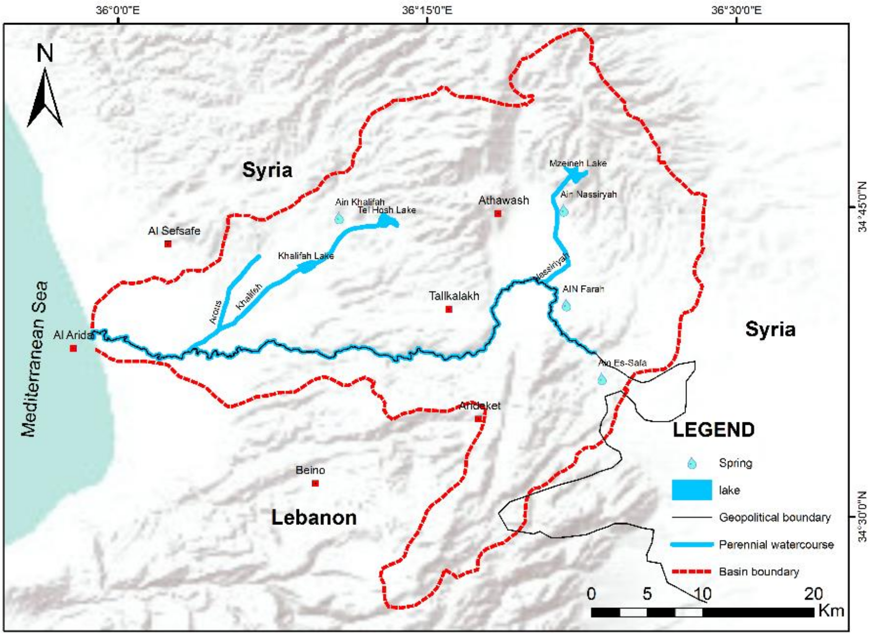

Figure 6.5. El-Kabir River, a shared river between Lebanon and Syria.

The El-Kabir River is fed by a number of springs and from the melting snow that accumulates on the elevated region (i.e., over 1000 m) to the east. The rainfall rate ranges from 800 mm and 900mm a year.

It also contributes significantly to the river flow during the period of highest rainfall.

The watershed of El-Kabir River is one of the largest basins in western Lebanon. The river is characterized by its water flow throughout the year. The characteristics of the river and its variable hydrologic properties are controlled by the abrupt changes in land physiography. Until recently, data on Lebanese rivers was inadequate, especially for the shared ones. Thus, the El-Kabir River watershed typifies this situation, particularly when the river has undergone many stresses, such as water pollution and decline in the discharge as a result of the changing climate and increased pollution (Shaban et al., 2005).

Generally, the El-Kabir River is considered as a short river, with respect to its basin area (i.e., 972 km^2), as its total length does not exceed 50 km. Even though it is relatively a small-scale drainage system, the hydrologic elements of the river and its basin are not well defined, due to the lack to sufficient studies.

The complicated geologic structures, including karstification, among the river basin resulted in an unclear hydrological regime. In addition, the situation of the river, as a shared resource, makes it difficult to be studied within an integrated scheme.

El-Kabir River receives a considerable amount of water, mainly along the tributaries, from the springs of Ain Essaqa, Ain Echrchara, and Ain Samawae, which are located in Syria; and from Nabaa Es-Saffa and other numerous issuing springs in Lebanon. Normally, the river is characterized by narrow floodplains in its western part, while it becomes wider in the plain area to the east (i.e., Sahel Bekiaa).

The outlet of El-Kabir River is in the Mediterranean Sea at Al Arida (Figure 6.5). While the average annual discharge from the river is about 222 Mm^3, with an average discharge of about 7.11 m^3/sec, this volume is distributed over the twelve months, where the maximum flow is between late December and end of April (Figure 6.6).

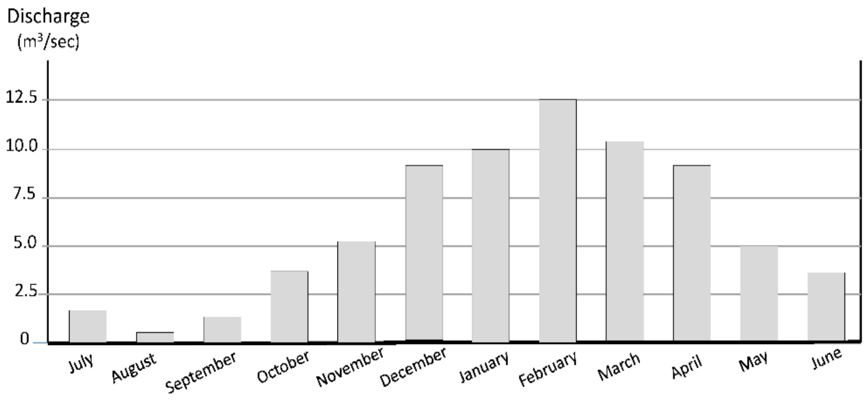

Figure 6.6. Average monthly discharge of El-Kabir River.

Even though the largest part of the El-Kabir River basin is located in Syria, the feeding from Lebanon is considerable, and specifically, from different crests at Jabal Akroum, Baidar El-Harf, Jabal Halabane, and Tell El-Hakim, which have altitudes of more than 1000 m. Over these mountain crests, snow accumulates and lasts for a couple of months, then melts and uniformly infiltrates among the carbonate rocks of the Cenomanian and Jurassic limestones, which are characterized by intensive fractures and karstification. This infiltration is rated at about 35%–40% of the precipitated water, forming high permeability and porosity.

It must be clear that there is a hydro-stratigraphic and hydro-structure interrelation between the rock masses in Jabal Akroum crests and the crests nearby Qurnet Es-Sawda (3088 m). The snow accumulation on the surrounding of Qurnet Es-Sawda remains for more than ten months a year. Thus, thick snowpack patches exist, and when they melt, water flows on surface and the subsurface in plenty amounts.

Table 6.1 shows the principal hydrologic characteristics of the El-Kabir River. They are elaborated from different sources including ground measures and remotely sensed applications. In addition, some variables in the table have been calculated from the following hydrological formula:

- Drainage density = $\frac{\Sigma L \text{ (Stream length)}}{A \text{ (Area of basin)}}$

- Meandering ratio = $\frac{L \text{ (straight)}}{L \text{ (curved)}}$

- Relief gradient = $\frac{\text{Mean Elevation–Minimum Elevation}}{\text{Maximum Elevation–Minimum Elevation}}$

(Pike and Wilson, 1971)

- Mean stream slope = $\frac{\text{Elevation at source–Elevation at outlet point}}{\text{Stream length}}$

- Mean catchment slope = $\frac{\text{(Elevation at 0.85 L)-(Elevation at 0.10 L)}}{\text{Elevation at 0.75 L}}$

(Morisawa, 1976)

Table 6.1. Principal hydrologic characteristics of El-Kabir River.

Hydrologic characteristics		Spatial areas of measurement	
		Lebanon	Syria
Average annual rainfall	862 mm	✓	-
Average volume of rainwater	840 million m^3/year	✓	✓
Length (straight)	46km	✓	-
Catchment area	972 km^2	✓	✓
Drainage density	0.88 km/km^2	✓	✓
Meandering ration	1.33	✓	✓
Relief gradient	0.34	✓	✓
Mean stream slope	17m/km	✓	✓
Mean catchment slope	25	✓	-

ORONTES RIVER

Orontes Rivers is a shared river that extends from Lebanon to Syria and then to Turkey, where it outlets in the Mediterranean Sea. It has several perennial watercourses that contribute to the river discharge. The most significant ones are Al-Assi River, as locally called in Lebanon, which is located in the northern part of the Bekaa Plain, near Hermel city. There are also Wadi Er-Rablah and Wadi Nefsah in Syria, and Karasu River and Afrin River in Turkey (Figure 6. 7).

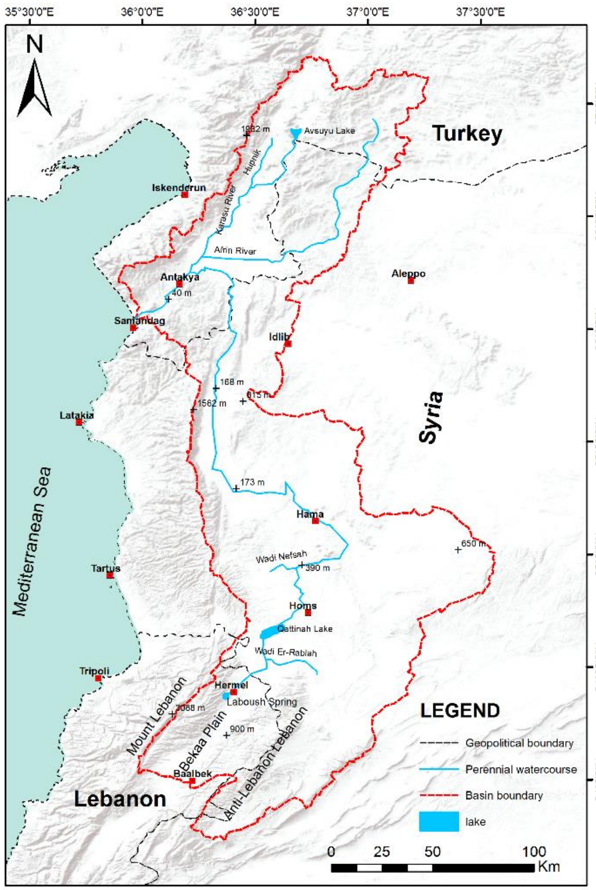

Figure 6.7. Orontes River, a shared river between Lebanon, Syria, and Turkey.

The catchment of Orontes River has been demonstrated by several studies with contradictory estimates, but the most reliable estimated area is 25300 km^2. Thus, about 1930 km^2 (7.5%) is located in Lebanon at the southern part of the river basin, then about 3456 km^2 (65%) in Syria, and the rest (27.5%) in Turkey (Figure 6.7).

There are a number of lakes along the primary watercourses of the Orontes River in the three shared countries. This includes mainly Hermel Lake (50 Mm^3) in Lebanon, Qattinah (or Homs) Lake is Syria (200 Mm^3), and Avsuyu Lake (450 Mm^3) in Turkey. There are also five dams in Syria totaling a capacity of about 736 Mm^3, which represents around 20% of total Syrian water use, thereby leaving 120 Mm^3 in Turkey out of 120 Bm^3 (Comair, 2008).

Orontes River is fed from a number of springs as well as from snowmelt and rainfall, where the latter is estimated in Lebanon between 350 mm and 1050 mm a year, and contributes significantly to the river flow during the period of highest rainfall.

Al-Assi River, the Lebanese tributary of Orontes River, runs in the northern segment of the Bekaa Plain. Its orientation is almost NE-SW, which conflicts with the apparent slope in the region. Thus, the basin boundary, within the Lebanese side, is represented by a number of mountain chains, namely Jabal Zaatar, Arid Souah, Jabal Haoueret, and Dohor El-Khanazir.

The outlet of Orontes River is in the Mediterranean Sea at Samandag in Turkey (Figure 6.7). While the average annual discharge from Lebanon is about 420 Mm^3, this volume is distributed over twelve months, averaging around 12.95 m^3/sec, where the maximum flow is between December and May (Figure 6.8).

The majority of feeding in Orontes River, as represented by the Al-Assi River in Lebanon, implies replenishment of water from snowmelt and rainfall, which are concentrated on the surrounding mountain chains from both facing flanks of the river basin. Therefore, the existence of think sequence of carbonate rocks of the Cenomanian age, with dominant faults and fracture systems in addition to subsurface karstification, makes it a potential recharge zone (i.e., 35%–40% of the precipitated water). Hence, water is derived mainly from precipitation, especially from snow, which accumulates on the top of mountains and remains for a couple of months. Therefore, this water infiltrates uniformly into the existing rock stratums, which are composed mainly of limestone and sometimes dolomitic limestone which compose the largest part of the exposed rock succession with dominant bed inclinations toward the Bekaa Plain where Al-Assi River flows.

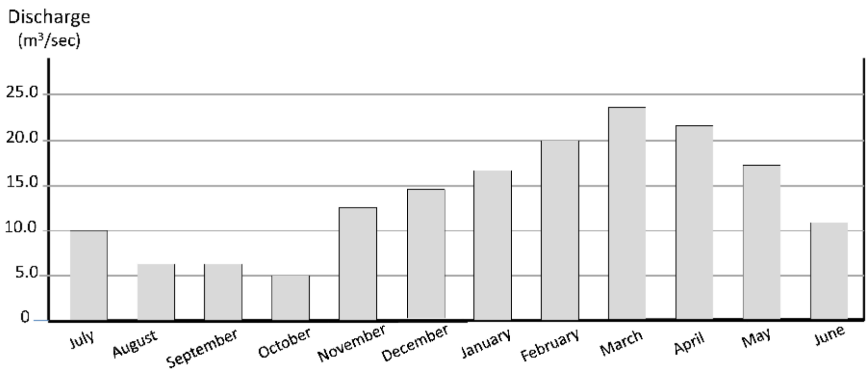

Figure 6.8. Average monthly discharge of Orontes River from Lebanon.

The hydrogeological setting of the Al-Assi River is significantly governed by the number of the issuing springs from its basin. These springs are similarly fed from snowmelt, and most of them are of the karstic and fault spring types. Therefore, a number of springs, like Labouh Spring (0.75 m^3/sec) and Ain Zarka (2.4 m^3/sec), are well pronounced. These are many other springs, such as Ain Flikah, Ras Baalbek, Eshawagheer, and Azeraa.

Table 6.2 shows the major hydrological characteristics of Orontes River, as classified per each sharing country. As in the case of the El-Kabir River, the hydrological data was elaborated from different sources, including ground measures and remote sensing data analysis from satellite products. Therefore, the illustrated variables in Table 6.2

were measured using similar hydrological formula mentioned for El-Kabir River.

Table 6.2. Principal hydrologic characteristics of Orontes River

Hydrologic characteristics		Spatial area of measurement		
		Lebanon	Syria	Turkey
Average annual rainfall	650mm	✓	-	-
Average volume of rainwater	1254 million m^3/year	✓	-	-
Length (straight)	571km	✓	✓	-
Catchment area	25300 km^2	✓	✓	✓
Drainage density	0.61 km/km^2	✓	✓	-
Meandering ration	1.85	✓	✓	✓
Relief gradient	0.21	✓	✓	-
Mean stream slope	9.5m/km	✓	✓	✓
Mean catchment slope	19	✓	✓	✓

HASBANI–WAZZANI RIVER

Hasbani–Wazzani River is the northern primary watercourse of Jordan River, in which the latter has an area of about 18425 km^2. Therefore, Jordan River straddles the territories of four countries, namely Lebanon, Syria, Jordan, and the PT. Hence, 645 km^2 is located in Lebanon, composing about 3.5% of the total basin area. The rest are distributed as 40% in Jordan, 36% in Syria, and 20.5% in PT (Figure 6.9).

The Hasbani–Wazzani River in Lebanon runs southward to Houle Lake in the PT, and then extends to Tiberius Lake, where it again flows from the lakes and joins with Yarmouk River, which originates from Syria. Therefore, the Jordan River drainage system originates, and it is connected with a number of valleys, mainly Naher Ez-Zarqa, Wadi El-

Hassa, and Wadi El-Mojeb. Jordan River's final outlet is into the Dead Sea (Figure 6.9).

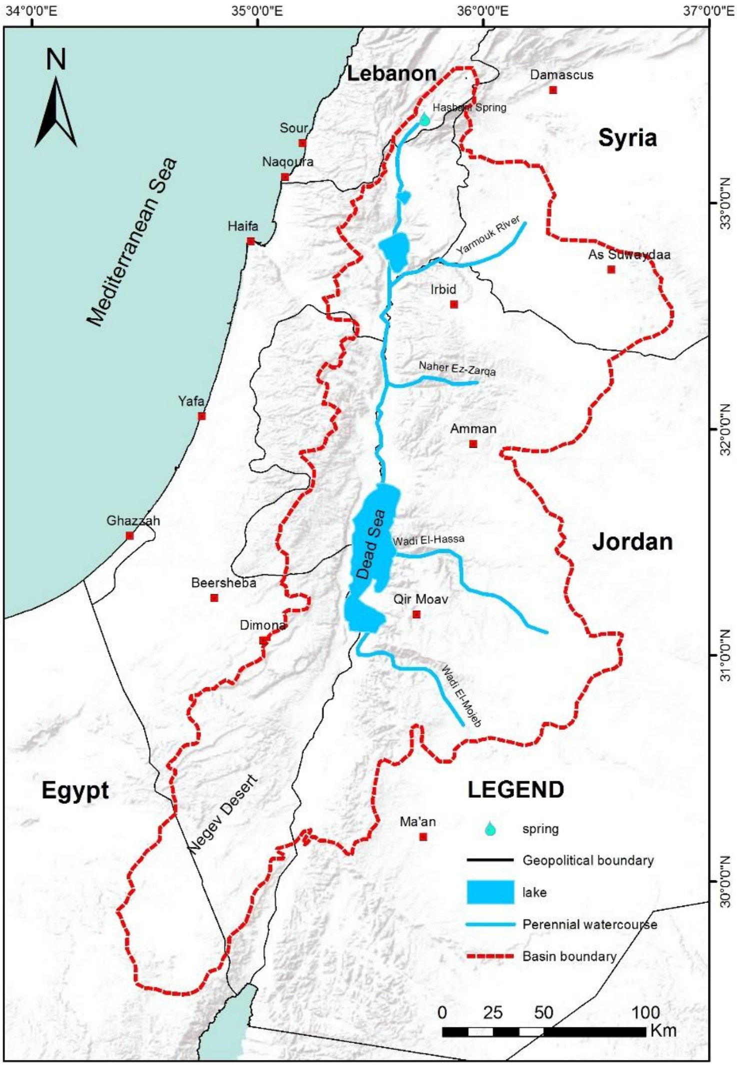

Figure 6.9. Hasbani–Wazzani River, the northern tributary of the shared Jordan River.

The Hasbani–Wazzani River is fed mainly from snowmelt in Jabal Hermoun (the so-called Jabal Ash-Sheikh), which has an average altitude of 1600 m, which replenishes many issuing springs in the river basin, particularly, the Wazzani Spring (3.45 m^3/sec) in the Ghajar region (Figure 6.1). The river discharges about 225 Mm^3 per year, with an average of about 7.23 m^3/sec where the maximum flow is between November and May (Figure 6.10). This discharge was estimated over 275 Mm^3 per year in the last 40 years.

According to UN-ESCWA and BGR (2013), the flow rate in the downstream part of the Jordan River has substantially decreased in the last 50 years due to the construction of a series of infrastructure and diversion schemes in the basin. For instance, the mean annual historic flow of the Yarmouk River was estimated at 450 Mm^3–500 Mm^3 in the 1950's, which has today decreased to 83 Mm^3–99 Mm^3, which accounts for about 70%. Thus, the current annual discharge of the Jordan River into the Dead Sea is estimated at 20 Mm^3–200 Mm^3 compared to the historic 1300 Mm^3.

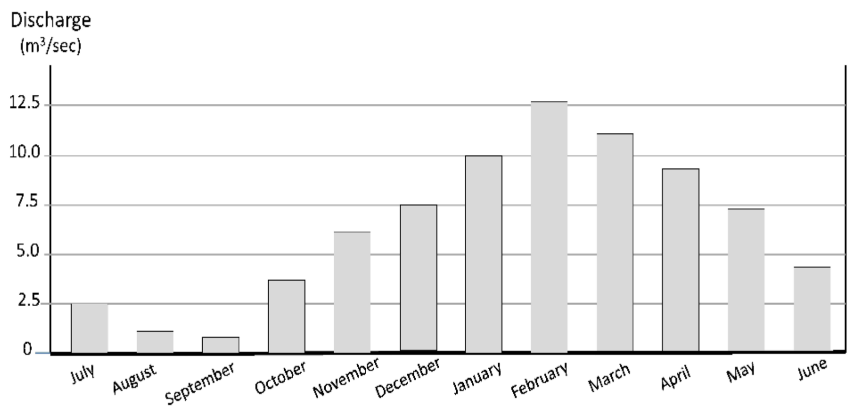

Figure 6.10. Average monthly discharge of Hasbani–Wazzani River from Lebanon.

Water use in the Jordan River basin is unevenly distributed. Thus, Palestine and Syria have no access to the Jordan River, and thus, their use of the river itself is nil. However, Syria has built several dams in the Yarmouk River sub-basin, which is part of the Jordan River basin (UN-ESCWA and BGR, 2013).

The geological setting of Jabal Hermoun, with highly fractured and karstified dolomitic limestone of the Jurassic age, makes it a potential zone for water recharge among the carbonate rock succession. Also, the fault systems are well pronounced along this mountain ridge and sever in transporting water for a considerable distance, vertically and laterally.

Table 6.3 reveals the principal hydrologic characteristics of Hasbani–Wazzani River, which is a major tributary of the Jordan River. These characteristics are classified according to each sharing country, with a special focus on the Lebanese part. The illustrated hydrological data was obtained from different sources, as in the case of the previous two shared rivers. This includes ground measures and remote sensing data, which were extracted from satellite products. Hence, the same hydrological formulas mentioned for El-Kabir River were also applied to Hasbani-Wazzani River and the results are shown in Table 6.3.

Table 6.3. Principal hydrologic characteristics of Hasbani–Wazzani River

Hydrologic characteristics		Spatial area of measurement			
		Lebanon	Syria	Jordan	PT
Average annual rainfall	980 mm	✓	-	-	-
Average volume of rainwater	613 million m^3/year	✓	-	-	-
Length (straight)	217km	✓	✓	✓	✓
Catchment area	18425 km^2	✓	✓	✓	✓
Drainage density	0.77 km/km^2	✓	-	-	-
Meandering ration	1.94	✓	-	-	✓
Relief gradient	0.78	✓	✓	✓	✓
Mean stream slope	21m/km	✓	✓	✓	✓
Mean catchment slope	24.5	✓	✓	✓	✓

SUPPLEMENTARY SHARED SURFACE WATER

As mentioned in Chapter V, a miscellany of surface water resources should be accounted for other than the shared rivers, which are often assessed when investigating water bodies and their routes between two or more countries. These are the snowpack, streams, and springs (as shown in Figure 6.3). However, the major springs were illustrated in this study, as they are the principal sources feeding the shared rivers. However, the snowpack and streams are to be considered.

Snow

According to Abd EL-Al (1953), water derived from snowmelt is considered as the main source feeding rivers, springs, and groundwater in Lebanon. For example, it was estimated that more than 60% of the Ibrahim River water is derived from snowmelt. Also, it was estimated that 1100 Mm^3 of water from snowmelt seeps into Mount-Lebanon (Shaban et al., 2004). Another study conducted by Shaban et al. (2014) showed that the average water volume derived from snow in Lebanon is about 2787 Mm^3, which is equivalent to about 58.5% of water volume in rivers and springs in Lebanon. This shows the significance of snow as a source of water that replenishes the main water bodies in Lebanon.

The concept behind considering snow in the assessment of shared water resources in Lebanon implies, in a broad sense, the human encroachments on the snowpack. In other words, several negative implements have been recently done by humans on snowpack, which disrupts the hydrologic regime of snowmelt (increasing the melting rate, changing flow directions of the melting snow, etc.) and even the quality of melted water. This is the case where a number of implements have been reported on snowpack in the riparian countries, especially between the shared snowpack between Lebanon and Syria, such as the following: 1) detaching snowpack from its residual place; especially for filling mountain lakes or disposal of snow masses, 2) expanding new urbanism, 3) draining melted water to remote localities other than its natural routes, and 4) not controlling waste disposal in areas of snowpack.

Snowpack interrelation to surface and groundwater is well pronounced in Lebanon. Therefore, it often extends between two or more countries and serves as feeding water sources to all of them. In some instances, it is located in one country and affects the hydrologic regime in the repairing countries. Hence, snowpack in Lebanon accumulates annually, covering more than 20% of the Lebanese territory for a couple of months (Figure 6.11). The thickest succession of this snow is mostly located in Lebanon, as it is governed by the altitude. Therefore, it can be classified as the following:

1) Snowpack located only in Lebanon, but it indirectly shares the hydrological regime with Syria, which is represented by zone (Snowpack zone 1) SPZ1, according to Figure 6.11, where snowmelt of Jabal Akroum contributes to the hydrological regime along the Syrian border in the north, especially to El-Kabir River.
2) Snowpack extends between Lebanon and the surrounding regions. It, in turn, feeds surface water and groundwater between Lebanon and the riparian regions, and this feeding is mainly controlled by the stratigraphic and structural controls. This is represented (as in Figure 6.11) by the following zones:
   - SPZ2, where it shares with Syria in the Anti-Lebanon Mountain ranges. The average geographic cover of snowpack in this zone is about 890 km^2, of which 58% is in Lebanon and the rest is in Syria.
   - SPZ3, which shares between Lebanon, Syria, and PT in Jabal Hermoun. The average snowpack distribution in this

zone is about 320 km^2, of which 54%, 33%, and 13% are located in Lebanon, Syria, and PT, respectively.

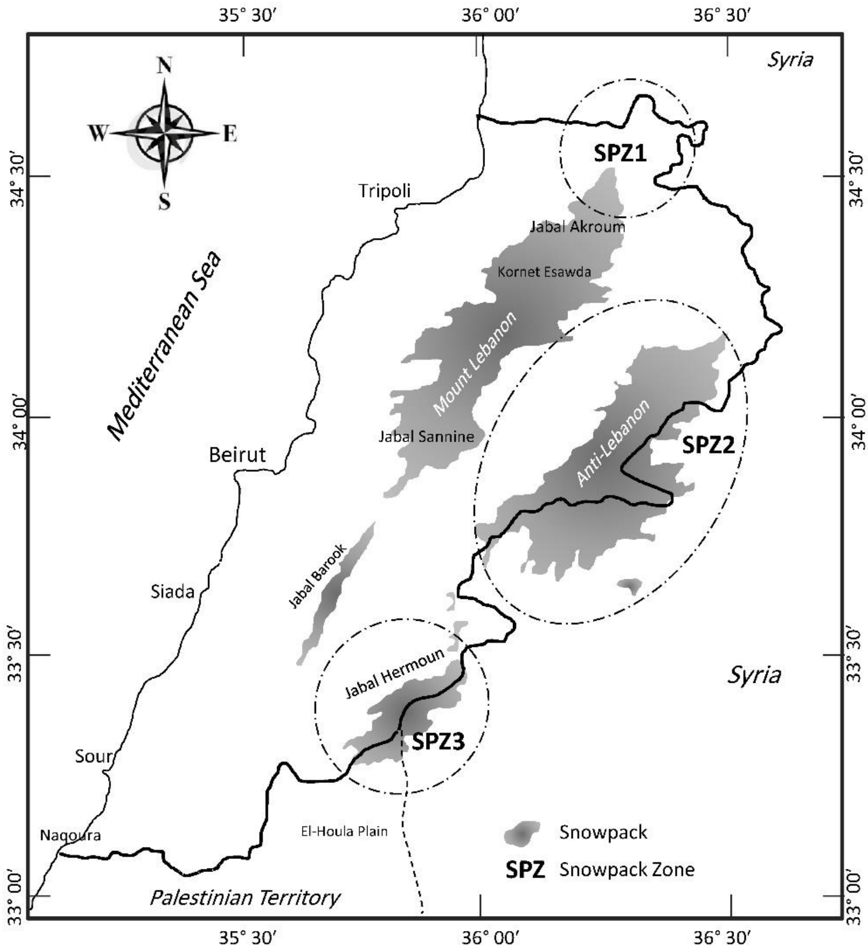

Figure 6.11. Snowpack in Lebanon and its geographic distribution.

Shared Streams

Recently, streams have attained great importance, in the view of the existing water shortage and the related implementations of adaption instruments for climate change and its impact on water resources. These topographic routes (valley systems) are localities that collect water in many arid and semiarid regions where they store run-off water in wet seasons for further use in the dry periods. In addition, most of these streams are dominated by a thick sequence of soil deposits. They then compose fertile lands with wet soil that can be used for different agricultural purposes.

Table 6.4. Major shared streams of Lebanon

Map* *(Sheet code)*	Number of major streams	Flow direction						
		L-S	*S-L*	*B*	*L-R*	***S-R***	***L-PT***	***PT-L***
Halba	26	-	-	-	14	12	-	-
Tell Kalakh	62	9	5	7	15	26	-	-
Jousse	21	6	8	7	-	-	-	-
Nabak	2	2	-	-	-	-	-	-
Assal Al-Wared	16	13	2	1	-	-	-	-
Rayak	23	4	13	6	-	-	-	-
Zabadani	12	9	3	-	-	-	-	-
Rachia	11	8	2	1	-	-	-	-
Hermoun	3	-	2	1	-	-	-	-
Marjayoun	2	-	-	-	-	-	-	2
Houle	14	-	-	4	-	-	10	-
BentJbeil	13	-	-	3	-	-	4	6
Naqura	3	-	-	1	-	-	1	1
Totals	208	51	35	31	29	38	15	9

*Topographic map (1:50.000); **Considerable dimension (e.g., length, cross-section, etc.).

L-S (from Lebanon to Syria); S-L (from Syria to Lebanon); B (along the geopolitical border);

L-R (from Lebanon to a shared river); S-R (from Syria to a tshared river);

L-PT (from Lebanon to PT); PT- L (from PT to Lebanon).

Therefore, if any activity takes place in the upstream of these valley systems, it will directly affect the downstream part. Hence, the geographic extent of these linear topographic features between different geopolitical boundaries often creates conflicts, even though these conflicts are created at individual levels. This is well pronounced, especially where these streams join different human settlements, agricultural lands, or they connect with springs.

In this respect, this study carried out a survey to investigate the major existing streams between Lebanon and the neighboring regions. It was based on the topographic maps (1:50000), which combine the Lebanon territory and the surroundings, as included in the fourteen topographic sheets (Table 6.4).

There are more than two hundred identified major streams with considerable length and cross-section dimensions. They represent shared intermittent water courses at the Lebanese border and they must be given attention. Out of these streams, eighty-six major ones connect Lebanon and Syria, and twenty-nine streams extend from Lebanon and outlet in the shared river (i.e., El-Kabir River). Besides, thirty-eight streams outlet in the El-Kabir River too from the Syrian side. Also, fifteen streams extend from Lebanon to PT and nine in the opposite direction. Moreover, thirty-one streams span along the geopolitical boundary between Lebanon, Syria, and the PT (Table 6.4).

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Chapter 7

SHARED GROUNDWATER RESOURCES OF LEBANON

As previously mentioned, Lebanon encompasses several aquiferous rock formations where carbonate rocks are the most dominant type with a special emphasis on limestone and dolomite rock types, which form more than 65% of the Lebanese terrain. These rock formations constitute different geographic localities from Lebanon. Hence, they occur along the coastal zone and in the mountainous regions, including Mount-Lebanon and Anti-Lebanon. The coastal aquifers mainly extend over the Lebanese territory, while the mountain aquifers are shared at different localities with Syria, and sometimes, with PT. Thus, a considerable volume of groundwater of Lebanon is shared with the neighboring countries and certainly with Syria.

SHARED ROCK FORMATIONS

Six rock formations extend along the Lebanese border, which are stratigraphically shared with the neighboring regions (Figure 7.1).

These formations are of different ages and lithologies. Chronologically, they can be illustrated as follows:

1) Quaternary deposits: These are composed of mixed soil and gavel, along with rock debris, which have been eroded by the flow of water. They are often composed of thin sequence of alluvial deposits (<10 m), and found to exist in three localities along the northern part of the country; one occurs at the coast near Telali, the second is in the Bekiaa region, and the third one is near Hermel (Figure 7.1).
2) Pliocene basalt: This formation is composed mainly of basalt and tuffaceous materials mixed with soil. It has a frequent thickness between 120 m–150 m, and exists in two localities along the Lebanese border; one in the north at the Syrian border in Tell Kalakh region and the other in the south, near Ghajar village along the PT (Figure 7.1).
3) Neogene conglomerates: It is composed mainly of mixed marly conglomerates and rock debris and marl, as well as alluvial deposits, which have been eroded from the adjacent mountain flanks. This is why it has been attributed to the Neogene age. This rock formation has a dominant thickness of less than 50 m in the area of concern, and it extends from the Bekaa Plain northward to Syria in the Hermel region.
4) Eocene Limestone: Even though this rock formation is widespread in South Lebanon, it extends to the PT within a limited area. It is composed of marly and chalky limestone with a thickness in the range of 4500 m–550 m.
5) Cenomanian dolomitic limestone: This is the most widespread rock formation along the border of Lebanon with the neighboring regions, as it occurs in several localities (Figure 7.1). It is composed mainly of limestone and dolomitic limestone, with a dominant thickness ranging from 550 m–600 m.

6) Jurassic dolomite and limestone: It also occurs along the Lebanese border and constitutes potential aquifers due to the fracture systems among dolomite and dolomitic limestone. It is exposed largely near the Rachaya region with an average thickness of about 150 m.

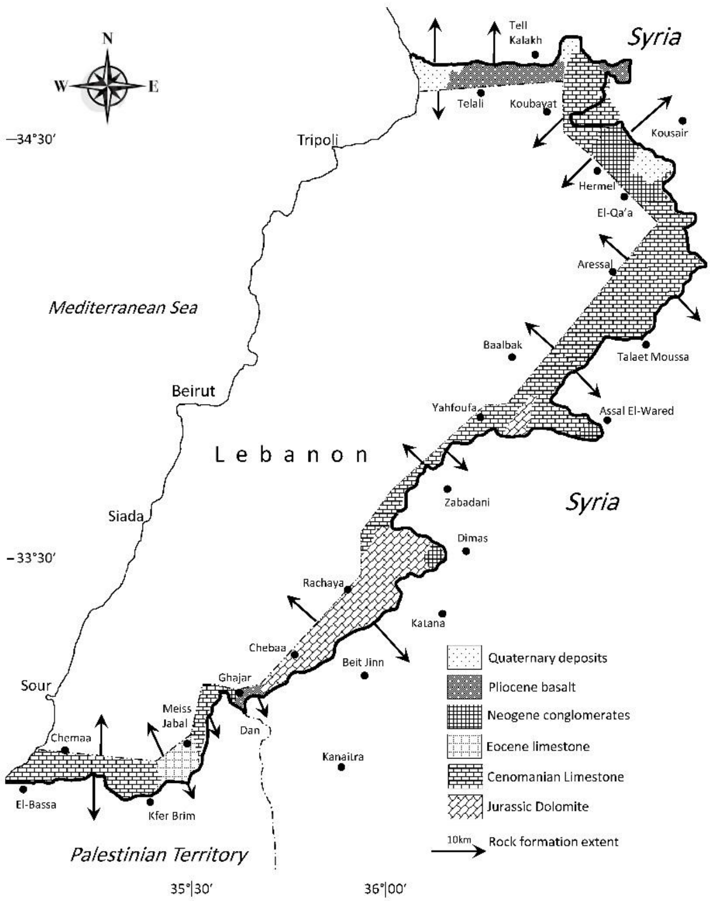

Figure 7.1. Shared rock formations between Lebanon and the neighboring regions.

The existing rock formations have different hydrogeological properties and varying capability for groundwater storage. Thus, the alluvial deposits and Neogene conglomerates represent an aquiclude formation. The Pliocene basalt is also aquiclude when it includes tuff, but sometimes, it is a semi-aquifer with limited extent when hard basalt masses occur. Nevertheless, perched aquifers and small-dimensioned groundwater basins are often found along the border, which are shared between Lebanon and its surrounding regions. Hence, groundwater flow and abstraction are governed by implementations that may be taken from any side at the border and this is common between Lebanon and Syria, notably along the northern border.

Three rock formations are considered potential for groundwater storage (i.e., aquifers) and they are tapped along the borderline without any control. These aquifers are distributed along the Lebanese border in five domains, which are classified as Eocene Limestone Domain, Cenomanian limestone Domains (I, II, and III), and the Jurassic Dolomite Domain.

SHARED EOCENE AQUIFER

This aquiferous rock domain is well exposed in the Lebanese side at the southern border with the PT (Figure 7.2). It has an area of about 322 km^2, and it is composed mainly of chalky and marly limestone with some marl lamina. Also, it includes tremendous chert nodules (Shaban 2003). The stratification of this rock formation in the studied domain constitutes moderate bedding planes that range from 50 cm to 80cm.

There is remarkable number of multiple sets joints, notably among the marly limestone where fracture systems are mostly found, which are often filled with calcite. In addition, there is a dominant development of karstification processes on the surface and subsurface. In the latter, the karstification occurs as cavities with considerable dimensions (i.e., few meters in diameter).

This domain as a whole represents an anticlinal structure where the hinge of this structure is principally constituted by the Eocene rock formation. Therefore, this rock formation plunges toward the PT where it is covered by the overlying rock stratum of the younger rock formations.

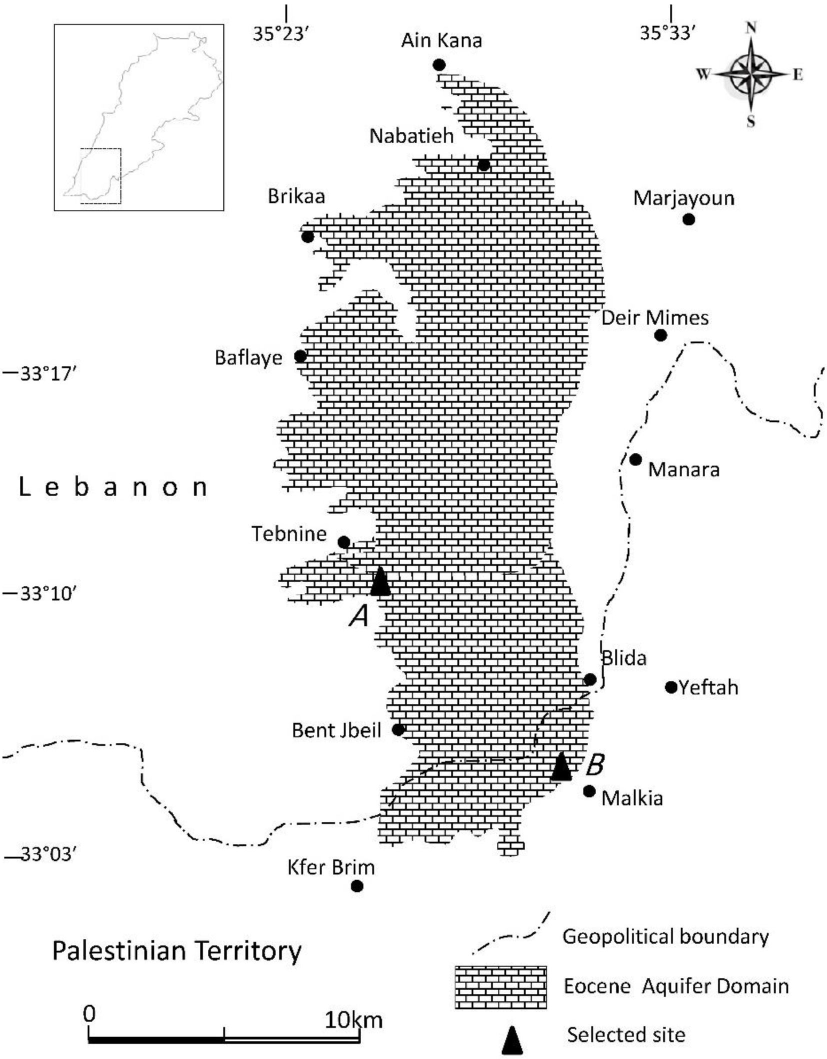

Figure 7.2. Shared Eocene Aquifer Domain of Lebanon.

A majority of the dip (i.e., bed inclination) is found consistent with the anticline limbs. In other words, the dominant dip is either E–W at the western side of the anticline or W–E in the eastern side. Therefore, groundwater flow is mainly governed by the dip direction where the average estimated dips in the Eocene Domain range from 10° to 28° (Figure 7.3). Therefore, large volumes of water are recharged in this rock domain, and then, groundwater seeps into the PT from the east.

Several faults span along this domain, constituting groundwater routes. However, these faults are mainly oriented in the NE–SW direction, and their alignment influences the groundwater flow.

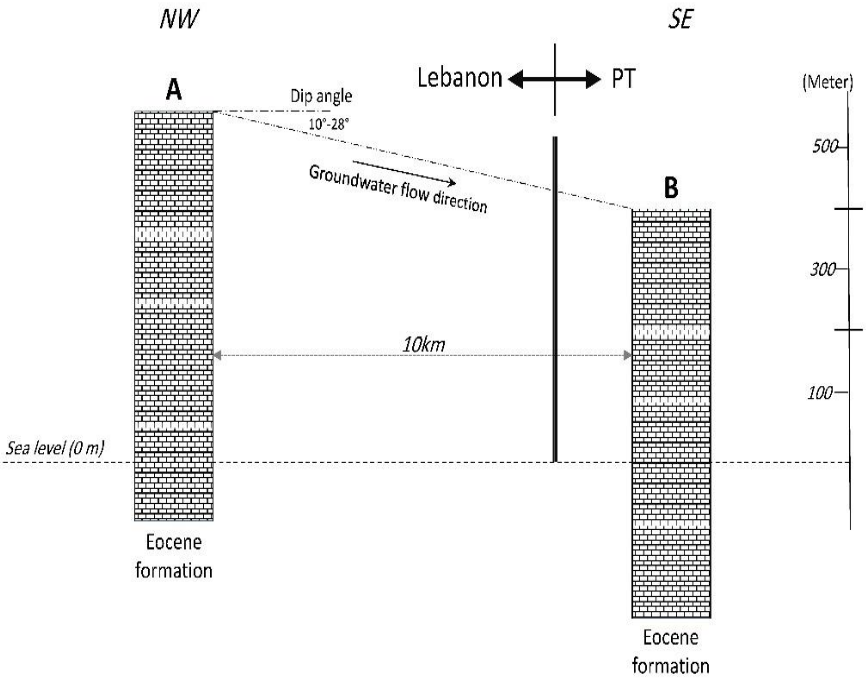

Figure 7.3. Schematic cross-section showing the general stratigraphy along sites A and B of the Eocene Domain (according to Figure 7.2).

The hydrogeological and hydrological characteristics of the shared Eocene Aquifer Domain of Lebanon can be summarized in Table 7.1.

Table 7.1. Hydrogeological/Hydrological characteristics of the Eocene Aquifer Domain

Hydrogeological/Hydrological Characteristics	
Area	322km^2
Area in shared regions	89% in Lebanon; 11% in PT
Dominant lithology	Marly and chalky lime stone, with chert nodules.
Fracture	Almost jointed and moderately fractures.
karstification	Cavities are well pronounced.
Water table depth	350-600m
Transmissivity	1.82 x10^{-6} - 2.14 x10^{-6} (m3/sec)*
Hydraulic conductivity	0.2- 0.4 m/day**
Estimated infiltration rate	28-40%[‼]
Estimated run-off	8-14%[†]

* Measured in 45 boreholes;** Measured in 38 boreholes; [‼] & [†] Estimates from different sources.

SHARED CENOMANIAN AQUIFER DOMAINS

The Cenomanian rock formation along the Lebanese border is exposed in three major domains, which are I, II, and III (Figure 7.1). They are assessed in this study separately because they mostly compose of isolated hydrogeological systems.

This rock formation, including the three domains, is the best aquiferous rock formation in Lebanon, as it is composed of dolomitic limestone and dolomite. The entire stratigraphic succession constitutes a thick rock column, which is about 700 m, where a marly unit is included in its middle with a thickness of about 60 m.

Cenomanian Aquifer Domain-I

This Cenomanian Domain is located at the northern border of Lebanon with Syria (Figure 7.5). It constitutes the rock mass of Jabal Akroum, and it is hydrogeologically separated by the Yammounah fault from the adjacent rock masses of the other Cenomanian domains in Lebanon, where it is represented mainly by Jabal Kammouah.

The exposed rock formation of Cenomanian Domain-I has an area of about 276 km^2, composed mainly of dolomites and limestone, with dolomitic limestone composing the main rock sequence. Thus, marl units also exist, where the middle part includes the 60 m marly unit. It owns moderate-to-thick bed rocks ranging from 50 cm to 150 cm.

This domain is characterized by intensive fracture systems and fissures, which are dominant among different rock units, notably those with high dolomite content. In addition, karstification is well developed, whether on surface or subsurface (Dubertret 1953, 155). Thus, karns, lapis, and cylindrical holes are dominant on the terrain surface, while cavities, grottos, and conduits also occur, and most of them are water-bearing routes.

Structurally, this rock domain is totally controlled by the existing fault systems, which are considered as secondary rock deformations that exist parallel to the Yammounah fault. Therefore, the entire domain tilts westward as a result of the uplifting caused by the Yammounah fault. For this reason, this domain extends from Syria to a range in Lebanon. It is represented by Qurnet Mbayed (1900 m) near Wadi Zaouq, where a major fault cuts perpendicularly to the domain and then makes it a separate hydrogeological limit.

The geologic setting of the Cenomanian Domain-I controls the groundwater hydrology. Thus, the groundwater flow is mainly in the SE direction and more specifically toward the Bekaa Palin, where it feeds the Orontes River and the issuing springs. In addition, another groundwater flow system along the exiting faults span to the north toward the Syrian border. Table 7.2 illustrates the major hydrogeological and hydrological characteristics of the Cenomanian Domain-I.

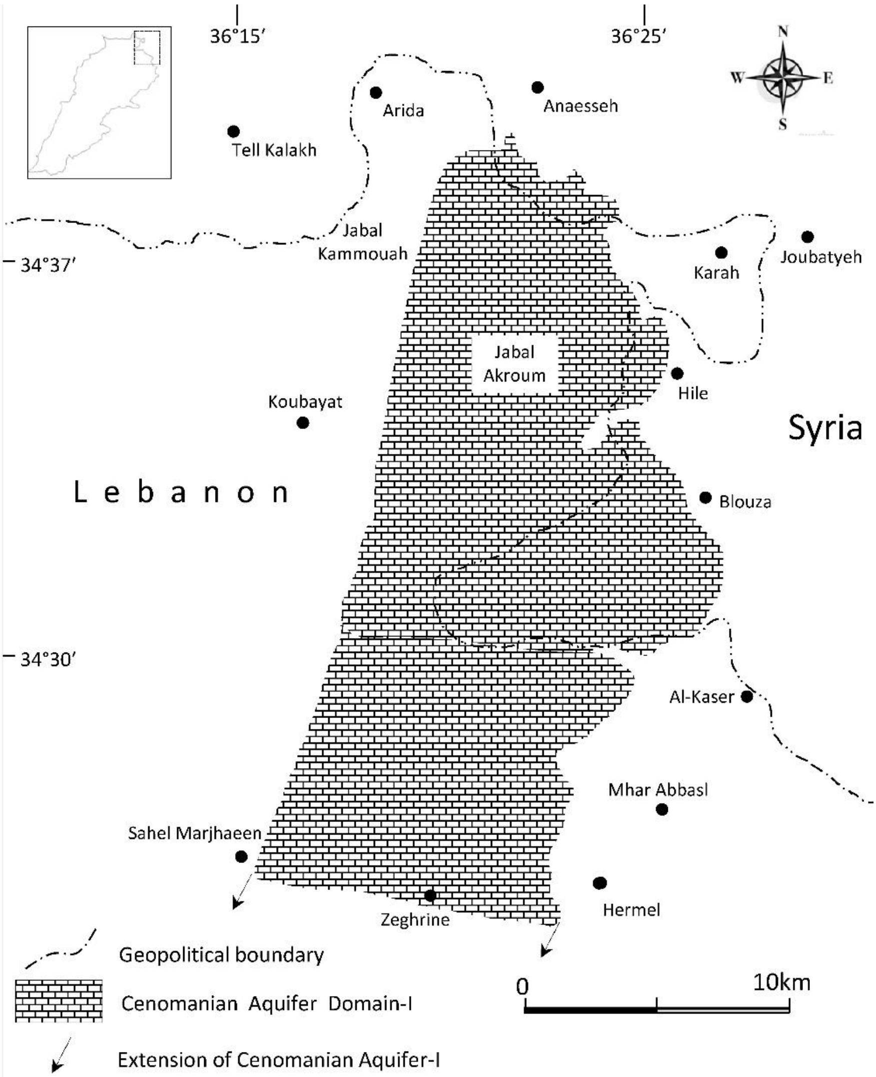

Figure 7.4. Shared Cenomanian Aquifer Domain-I of Lebanon.

Table 7.2. Hydrogeological/Hydrological characteristics of the Cenomanian Aquifer Domain-I

Hydrogeological/Hydrological Characteristics	
Area	276km^2
Area in shared regions	79% in Lebanon; 21% in Syria
Dominant lithology	Dolomitic limestone and dolomite with marl units
Fracture	high fractured with space between bedding planes
karstification	Cavities grottos and conduits are well developed.
Water table depth	425-675m
Transmissivity	2.55 x10^{-6} - 3.20 x10^{-6} (m3/sec)*
Hydraulic conductivity	0.8- 1.3 m/day**
Estimated infiltration rate	35-45%[‼]
Estimated run-off	4-8%[†]

* Measured in 32 boreholes; **Measured in 18 boreholes. [‼] & [†] Estimates from different sources.

Cenomanian Aquifer Domain-II

This rock formation constitutes the largest rock mass that shares Lebanon with the neighboring regions (Figure 7.5). It is located at the eastern border with a length exceeding to 150 km, forming the water divide between Lebanon and Syria. This formation encompasses an area of about 2160 km^2. Thus, it shapes the Anti-Lebanon ranges with a NE-SW orientation. It has several crests with remarkable altitudes, such as Jabal Haourette (1642 m), Jabal Younine (1864 m), Aared Al-Hamra (2128 m), and Haraf Habbouk (2191 m). Hence, this mountainous rock mass of the Cenomanian formation interferes at its southern side with the Jurassic formation in Jabal Hermoun.

The lithology of the exposed rock formation of the Cenomanian Domain-II is almost similar to that in Domain-I. Thus, it is composed of dolomitic limestone, limestone, and dolomite forming the majority of the rock sequence where the marl unit (about 60 m) is located in its middle part. Also, this sequence includes many laminas of marl and marly limestone. The existing strata constitute well bedding planes with a prevailing thickness ranging from 70 cm to 150 cm, while some massive rocks of reefal deposits exist with undefined thickness.

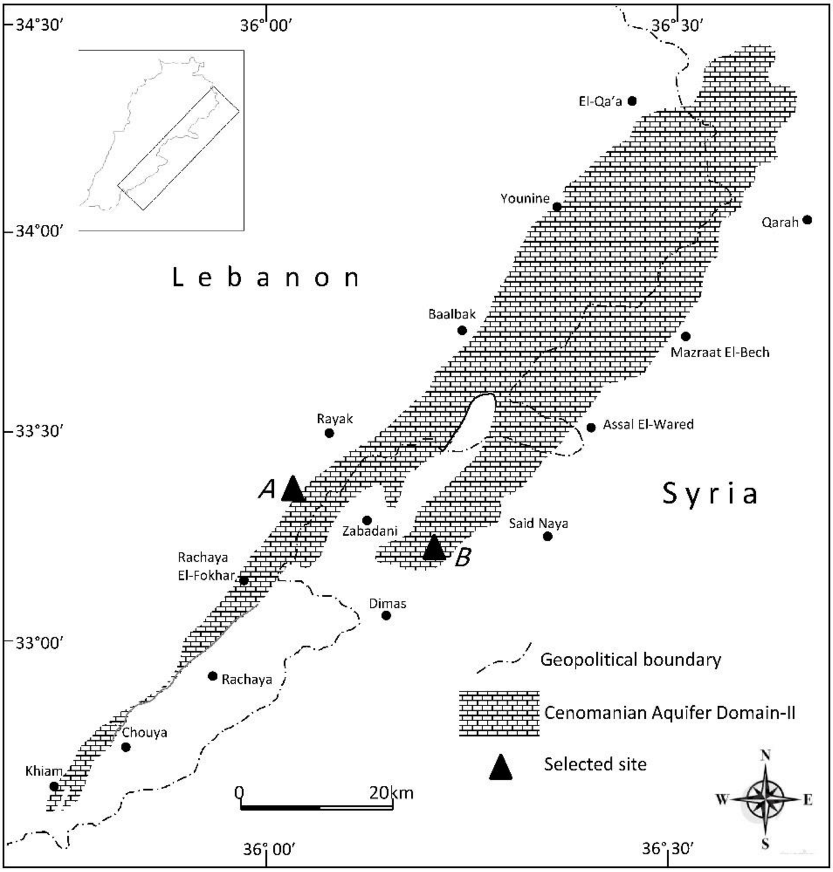

Figure 7.5. Shared Cenomanian Aquifer Domain-II of Lebanon.

Cenomanian Domain-II is characterized by tremendous fracture systems and fissures, which intensively occur among the rock layers with high dolomite content. In addition, mono-set joints exist and sometimes include calcite veins. However, karstification is dominant on the surface and on the subsurface; therefore, karns, lapis, and cylindrical holes are well developed. Hence, in the rock stratum, there are several cavities, conduits, shafts, galleries, and grottos, and most these voids are full of groundwater.

This rock domain is structurally controlled, because it represents the eastern flank of the Dead Sea Rift System that passes in Lebanon, forming the Bekaa Plain, and it faces the Yammounah fault to the west. Therefore, it represents the anticlinal structure where plunging anticlinal ridges are dominant along the eastern side of the Bekaa Plain (Figure 7.6). While the isolation of this domain from the Jurassic one is attributed mainly to the existence of the Serghaya fault, which is a large-scale fault, secondary faults result from the Yammounah fault.

The stratigraphy and structure of the Cenomanian Domain-II govern the regime of groundwater flow and storage. It is realized that the tilting of the bedding planes has two main directions, where the average dips are between 15° and 22° to the west and to the east, respectively (Figure 7.6). Thus, two major dip directions prevail in this domain and control the groundwater flow. One is to the west and the other is in the opposite to the east, following the limbs of the anticline.

The axial plan of the anticlinal structure is consistent with the water divide at the crests. Therefore, the groundwater flow regime follows two directions, which are follows:

1) Groundwater flows toward Lebanon, into the Bekaa Plain, from the western side of the anticline, and thus, contributes to feeding the Litani River and the issuing springs, such as Chamssine and Anjar.
2) Groundwater flows toward Syria, notably to Zabadani and Assal El-Wared regions, and then, replenishes the known karstic springs of Naba’a Barada and Ain Al-Figieh, which are a major source of water for the Damascus area.

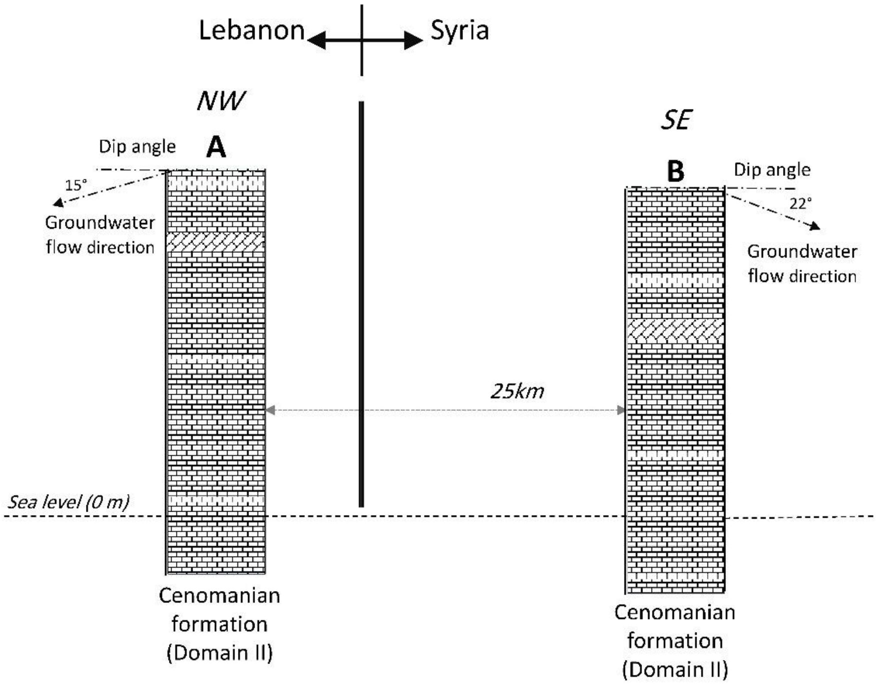

Figure 7.6. Schematic cross-section showing the general stratigraphy along sites A and B for the Cenomanian Domain II (according to Figure 7.5).

The existence of fault systems results in water seepage from this domain into different directions according to the fault alignments. However, the Serghaya fault makes it a groundwater route feeding Zabadani depression. In addition, most of the existing karstic conduits originate along the alignment of these faults.

The majority of the hydrogeological and hydrological characteristics of the Cenomanian Domain-II have been illustrated in Table 7.3, which represents the most dominant observations and measures applied.

Table 7.3. Hydrogeological/Hydrological characteristics of the Cenomanian Aquifer Domain-II

Hydrogeological/Hydrological Characteristics	
Area	2160km^2
Area in shared regions	68% in Lebanon; 32% in Syria
Dominant lithology	Dolomitic limestone and dolomite with marl units
Fracture	High fractured with spacing between bedding planes
karstification	Conduits, shafts and grottos are well developed.
Water table depth	310- 550m
Transmissivity	2.40 x10^{-6} - 3.65 x10^{-6} (m3/sec)*
Hydraulic conductivity	1.1- 1.8 m/day**
Estimated infiltration rate	35-45%[‼]
Estimated run-off	4-10%[†]

* Measured in 28 boreholes;** Measured in 25 boreholes. [‼] & [†] Estimates from different sources.

Cenomanian Aquifer Domain-III

This aquifers rock domain shares Lebanon with the PT in the south. It extends from the Mediterranean Sea to the east where it crosses the national border. It is composed of two major terrain masses that are separated by a distance of about 7 km, but they are geologically related (Figure 7.7). This rock domain has an area of about 642 km^2. Thus, the altitude of the domain with its two terrain masses does not exceed 900 m. Hence, major crests, such as Jabal Et-Tair Horme (66 8m), Jabal Beit Ed-Dowara (763 m), and Marj Ej-Jouani (824 m), exist.

The lithology of the exposed rock formation of the Cenomanian Domain-III is also similar to Cenomanian Domains I and II. Therefore, it is composed mainly of dolomitic limestone, limestone and dolomite with marl and marly to chalky limestone, where the 60 m-marl unit (as mentioned before) occurs in the middle part of the sequence. This rock formation is composed of well beds with a dominant bed thickness ranging from 50 cm to 120 cm, while some massive rocks of reefal deposits exist with undefined thickness.

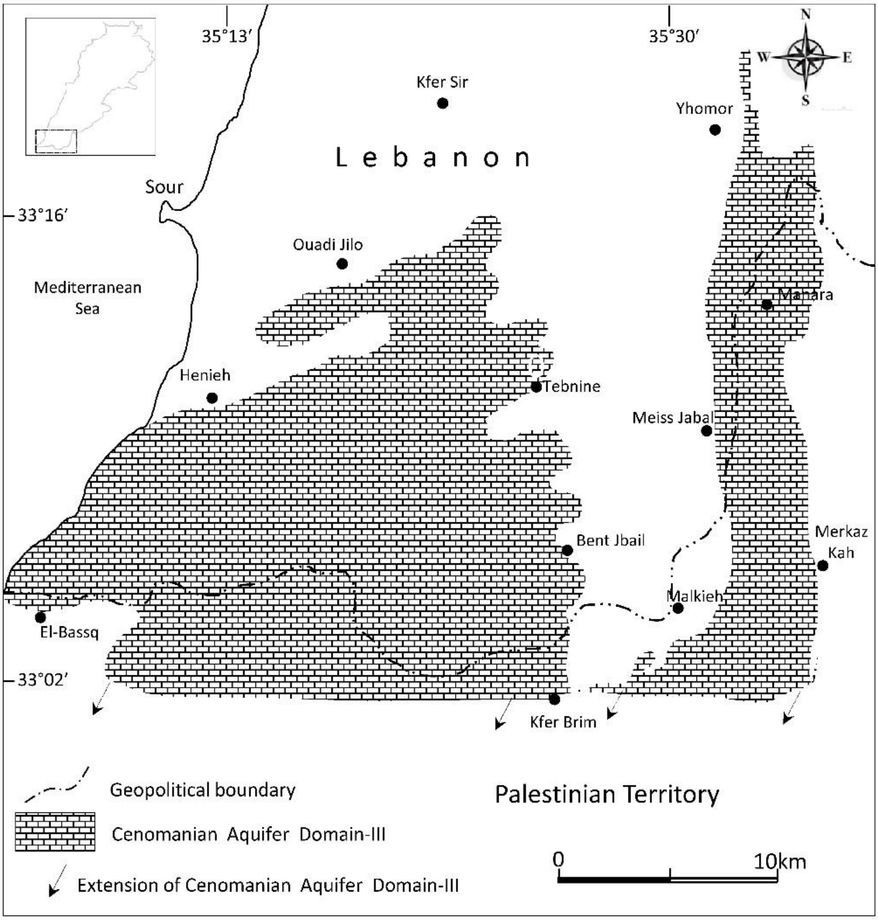

Figure 7.7. Shared Cenomanian Aquifer Domain-III of Lebanon.

The Cenomanian Domain-III is well pronounced by the fracture systems, fissures, and joints, which prevail in the largest part of the rock sequence, notably where hard lithologies exist, and these are represented mainly by dolomite. In addition, karstification is well developed among this rock formation, including both surface and subsurface karst. While cavities, conduits, shafts, and galleries are well known among the subsurface stratum of this formation, karns, pits, lapis, and cylindrical holes exist as surficial aspects of dissolution.

The western terrain mass of the Cenomanian Domain-III is cut by many faults that extend for several tens of kilometers, and are diagonally oriented to the north. These faults span from the Nabatieh plateau to the sea in a NE–SW direction, where most of them are of the wrench fault type with a dominant strike-slip movement (Shaban, 1987). Therefore, these faults help in transporting groundwater from the plateau (i.e., recharge zone) to the coastal zone (Shaban et al., 2016). In addition, groundwater flows along many of these faults to the southern region.

Table 7.4. Hydrogeological/Hydrological characteristics of the Cenomanian Aquifer Domain-III

Hydrogeological/Hydrological Characteristics	
Area	642km^2
Area in shared regions	59% in Lebanon; 41% in PT
Dominant lithology	Dolomitic limestone and dolomite with marl units
Fracture	Fractured are well developed
karstification	Cavities and conduits exist
Water table depth	380-570m
Transmissivity	2.04 x10^{-6} – 2.34 x10^{-6} (m3/sec)*
Hydraulic conductivity	1.2- 2.2 m/day**
Estimated infiltration rate	35-45%[‼]
Estimated run-off	4-8%[†]

* Measured in 44 boreholes; **Measured in 20 boreholes. [‼] & [†] Estimates from different sources.

The eastern mass of the Cenomanian Domain-III is totally controlled by the regional fault of the Dead Sea Rift System, which almost spans in the N–S direction and cuts to the north along the Bekaa Plain. Hence, it forms the morphology of the region, where the mountains composing of this domain occur adjacent to the Houle Plain. In this region, groundwater seeps into the southern regions, as it is controlled by this fault system and by the hydraulic gradient of the bedding planes.

The principal hydrogeological and hydrological characteristics of the Cenomanian Domain-III are shown in Table 7.4. The data illustrated in the table were adopted from the most dominant observations and ground measures applied in the boreholes dug in this rock formation.

SHARED JURASSIC DOMAIN

This Jurassic aquifer, including the middle and upper Jurassic ages, is well exposed at the eastern part of the Lebanon–Syria border, where it is composed of the Jabal Hermoun rock masses. Therefore, it constitutes largely the water divide between Lebanon and Syria in the south-eastern part of the Lebanese territory (Figure 7.8). It has an area of about 516 km^2. This aquifer domain it is composed largely of dolomitic limestone, dolomite, and limestone with some marly lamina. The bedding planes are almost separated by considerable spacing (few tens of centimeters). These planes represent thick rock masses that exceed, in many instances, by 2 m. Reefal deposition also exists and no obvious thickness can be observed.

Many fracture systems occur among the rock masses of this domain; therefore, fissures and joints are dominant and they are characterized by multiple sets fissuring, which are well developed where dolomite friction increases. This is well accompanied by water dissolution of the carbonate rocks (karstification) on surface and among the subsurface rocks. Hence, karns and lapis, plus many dissolution aspects (pits, furrows, etc.) are clearly observed on the surface of the exposed rock masses. In addition, subsurface karst prevails in this domain, and thus, large number of cavities, grottos, conduits, shafts, and galleries are dominant and mostly filled/transported with groundwater.

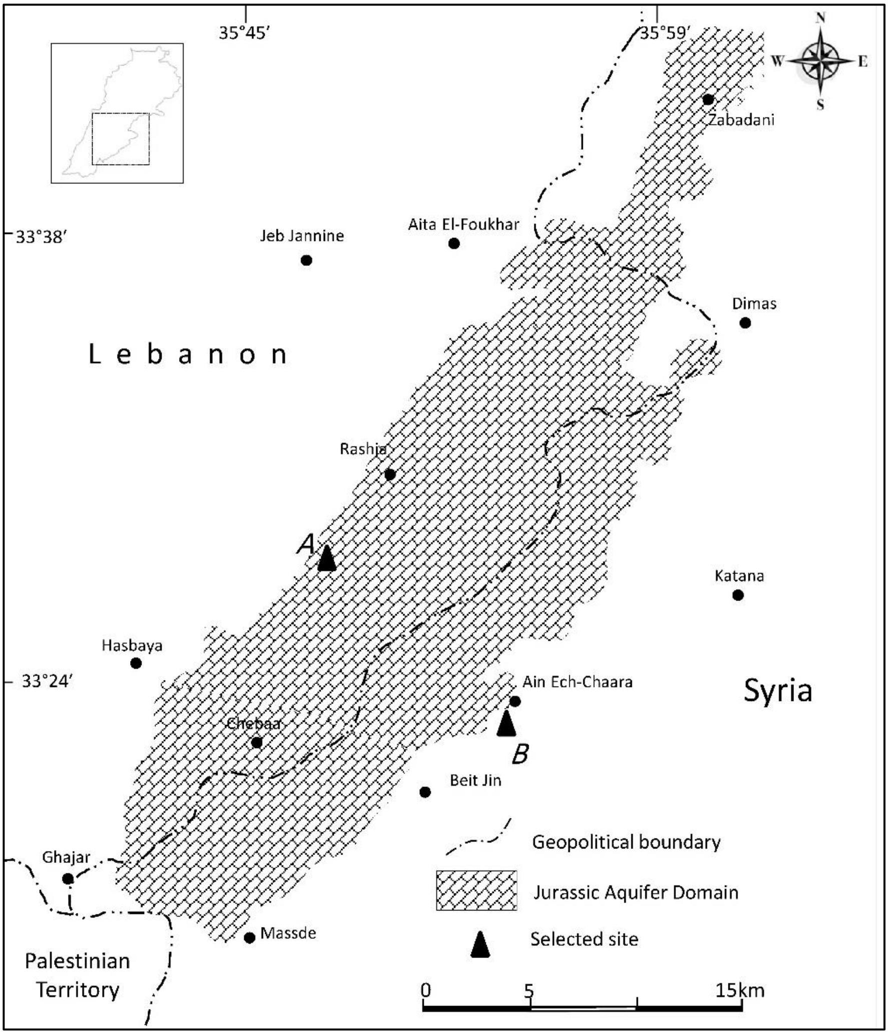

Figure 7.8. Shared Jurassic Aquifer of Lebanon.

The majority of the dip (i.e., bed inclination) is found to be consistent with the limbs of the anticlinal structure. Therefore, two major inclination directions were reported in this domain. First are the dominant dip measures ranging from 10° to 20° at the western side (Lebanese side) of the anticline and averaging around 12°. The second dips are at the Syrian side, which are much bigger than in that in the western limb, ranging from 15° to 30°and averaging around 21° (Figure 7.9).

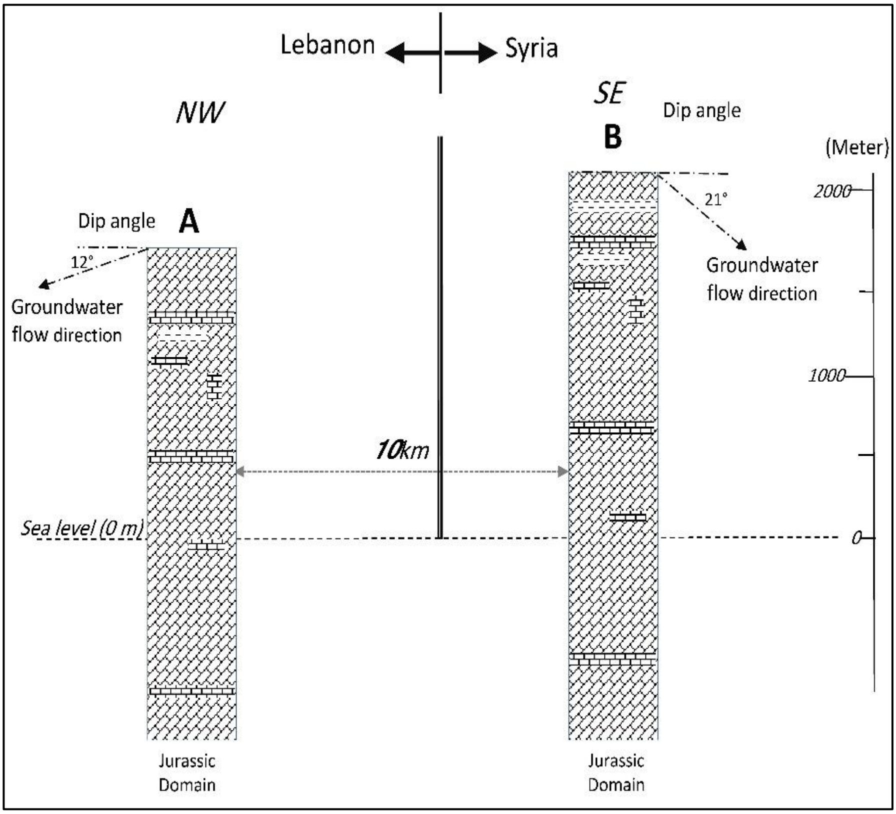

Figure 7.9. Schematic cross-section showing the general stratigraphy along sites A and B for the Jurassic Domain (according to Figure 7.9).

The entire body of this domain is composed of anticlinal structure where the axial plain represents the water divide all over the crests of the Jurassic rocks. Hence, folded and rugged mountain masses are dominant. In addition, this structure (anticline) is cut by one major fault system, which extends almost in the middle part of Jabal Hermoun, thereby shaping its topography.

The limbs of the anticlinal structure are almost included within the Lebanese territory where the slope gradationally occurs at the Lebanese side. The Jurassic rocks are mainly in contact with the overlying strata of the lower and middle Cretaceous. Besides, the slope is almost abrupt toward the Syrian side, where the Jurassic rocks, in most places, are adjacent to the Neogene and Pliocene rocks. This is well reflected by the inclination of the bedding planes.

The main hydrogeological and hydrological characteristics of the Jurassic are illustrated in Table 7.5. Data in this table were adopted from the available observations and ground measures applied in the boreholes dug in this rock formation.

Table 7.5. Hydrogeological/Hydrological characteristics of the Jurassic Aquifer Domain

Hydrogeological/Hydrological Characteristics	
Area	516km^2
Area in shared regions	54% in Lebanon; 46% in Syria
Dominant lithology	Dolomitic limestone and dolomite with marl units
Fracture	Fractured systems are well developed
karstification	Cavities, grottos and conduits are dominant
Water table depth	320-630m
Transmissivity	2.25 x10^{-6} – 2.80 x10^{-6} (m3/sec)*
Hydraulic conductivity	2.1- 3.6 m/day**
Estimated infiltration rate	30-45%[‼]
Estimated run-off	5-12%[†]

* Measured in 11boreholes; **Measured in 9 boreholes. [‼] & [†] Estimates from different sources.

The Jurassic Aquifer Domain represents a potential recharge zone of groundwater through the fractured and karstified rock masses, where this water is fed mainly from snowmelt and from rainfall. Therefore, groundwater flow in the shared Jurassic rock formation of Lebanon is governed by the dip direction and degree; hence, a substantial part of groundwater flows toward Lebanon along the Jurassic rocks where they face the impermeable layers of the lower Cretaceous rocks (Abbud and Aker, 1986). The amount of groundwater that flows into the Syrian side rapidly seeps into deep aquifers. In addition, there is a fundamental contribution for the karstic conduits and fault systems in transporting/storing of groundwater in this domain. However, these groundwater routes, sometimes, play a negative role in that water may flow into deep substratum and into undefined subsurface localities.

The entire body of this domain is composed of the anticlinal structure where the axial plain represents the water divide all over the crests of the Jurassic rocks. Hence, folded and rugged mountain masses are dominant. In addition, this structure (anticline) is cut by one major fault system, which extends almost to the middle part of Jabal Hermoun, thereby shaping its topography.

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The main hydrogeological and hydrological characteristics of the Jurassic are illustrated in Table 7.5. Data in this table were adopted from the most dominant observations and ground measures applied in the boreholes dug in this rock formation.

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Chapter 8

Treaties and Agreements on Shared Water

The equitable allocation of water is of utmost significance in maintaining the ecological function of freshwater water sources for human beings. From a global view, water resources are under pressure due to the changing physical and anthropogenic challenges. Indisputably, the impact of changing climate on the hydrological cycle is well pronounced and it has exacerbated the water problem, which is further mangled by rapid population growth. However, these are not the only striking challenges on the sustainability of water. There are other challenges occurring and negatively affecting the water resources. Among these challenges is the sharing of water between two or more countries, which often creates many political conflicts between adjacent regions.

In this regard, there are several formal agreements, often named as treaties, pacts, covenants, and many other nomenclatures. These agreements have been obtained on different levels and they were attributed to different aspects of water sources that extend between the neighboring countries. Nevertheless, incongruity often exists, and in many instances, there can be unfavorable situations between the disagreed countries. This is anticipated, as there are 268 transboundary river basins and approximately 300 transboundary aquifer systems between two or more countries. Hence, examples in this view are many and certainly in the Middle East.

INTERNATIONAL LAW FOR SHARED WATER

The increasing water conflicts and the resulting tension between nations are catalytic factors to elaborate national agreements and laws to stabilize unfavorable situations between countries. Therefore, a number of international agreements were established by the international entities to regulate the sustainability and equity of exploitation of shared water resources between different countries. This highlights the obligations and responsibilities of each country. The most common laws are as follows:

Additional Protocol (AP I) to the Geneva Convention

The fourth Geneva Convention was adopted in 1949 to define humanitarian protections for civilians in a war zone. It covers “bill of fundamental rights which becomes applicable to the occupied territories and limits the authority of the occupying power.” However, the convention does not provide a systematic or an analytic protection of water resources during a war and in armed conflicts. Therefore, the AP I was elaborated in 1977 to protect water resources in armed conflict zones through a legal framework composed of articles 54, 55, 56, and 85 (Bassil, 2012).

Helsinki Rules

These rules were adopted by the International Law Association (ILA) in Helsinki in August 1966. It treats the uses of the waters of the international rivers. Thus, it introduced an international guideline regulating how rivers and their related groundwater that cross national boundaries may be used. Thus, Article IV states that each basin is entitled to a "reasonable and equitable share" in using water of an international basin within its own territory. While Article VII added relevant factors that might be useful to determine what an equitable and reasonable share of watercourse is. Moreover, Article VII illustrates that a basin state may not be deprived of the present reasonable use of water of an international basin to reserve the rights of such waters. Besides, it doesn't help states to settle their dispute over water use, which could end by being more problematic (Salman, 2007).

The 1997 UN Convention on Watercourses

In 1997, more than 100 nations gathered to adopt the UN Watercourses Convention, which represents a flexible and overarching global legal framework that establishes basic standards and rules for cooperation between watercourse states on the use, management, and protection of international watercourses. The convention re-calls many of the principles put forward by Helsinki Rules, but explains them in more detail. Thus, the convention stresses a newly maintainable development approach to the usage and management of international water resources.

Article 5 of the convention refers to the principle of reasonable and equal utilization of an international water resource, and adds that two constraints should be considered in doing so, i.e., the welfare of the watercourse states and the need for an acceptable defense to protect the watercourse itself. While Article 20 insists on maintaining “the ecosystems of the international watercourse,” Article 21 insists on controlling and reducing water pollution. Article 7 states that watercourse nations should “take all appropriate measures to prevent causing significant harm” to other watercourse states, in terms of exploitation and utilization. Finally, Article 8 imposes on watercourse states an obligation to cooperate on the basis of sovereign equality, territorial integrity, mutual benefit, and good faith to achieve “optimal utilization” and “protection” of any international watercourse (UN, 2005).

The 2008 Draft Articles on the Law of Transboundary Aquifers

In 2002, the UN International Law Commission (UNILC) added to its program of work the topic of Shared Natural Resources: transboundary groundwater, oil, and gas. In 2008, the UNILC completed its work on the first sub-topic by adopting, at the second reading, nineteen draft articles on the law of transboundary aquifers. The draft articles were then deferred to the UN General Assembly (UNGA). In the Resolution, the UNGA “encourages the States concerned to make appropriate bilateral or multi-lateral arrangements for the proper management of their transboundary aquifers, taking into account the provisions of these draft articles” (Stephan, 2001).

The ILC draft articles recall all the elementary rules and principles of the 1997 UN Convention on Watercourses, taking into account the specific physical and geological characteristics of groundwater. Article 4 states that aquifer states should utilize transboundary aquifers based on the principle of equitable and reasonable utilization, but differentiates between the nature of groundwater and surface water. Besides, Article 6 requires the aquifer states to take all necessary measures to stop causing noteworthy harm to other aquifer states. The ILC stresses that when significant harm is caused, the aquifer state is solely responsible for such harm. Article 7 provides a general obligation to cooperate, which is quite identical to the obligations stated by the UN Convention on Watercourses (UN, 2008).

SHARED WATER IN IWRM

IWRM (integrated water resources management) can be a useful tool for countries sharing water resources to begin the cooperation processes of planning, and then managing these resources on equitable basis. This can be well achieved once the obligations and rules extended by the international laws and conventions are respected. However, it is not deniable that the process of bringing together two or more countries with shared water resources is extraordinarily complex and challenging, but it is viewed as a must to regulate the supply from these resources in the view of the challenging conditions.

It is obvious that each shared water resource is unique, and each country has its own set of controlling factors on water management. This includes political, institutional, and legal frameworks, as well as the water supply/demand interrelation, water use efficiencies, institutional, economic, and management capabilities (Varis et al., 2008). Therefore, it is necessary for each country intending to apply IWRM to consider the shared water resources within the context of the controlling factors, and this can be harmonized on two levels, the national level within the country itself and the regional level including countries sharing the water resources. Therefore, sustainable regional cooperation between countries sharing water becomes a necessity for optimal IWRM; this can be achieved by identifying the benefits of participation in the development of joint visions and policies.

However, many countries apply IWRM and consider each water resources, within its territory, as a unique hydrological system without accounting for the shared water concept of these resources. This erroneous implementation is also applied when calculating the water balance in any country and ignoring the portion of water that might be shared or transported from/to other regions.

CHALLENGES OF SHARED WATER OF LEBANON

It is not an exaggeration to say that the transboundary water resources of Lebanon are poorly managed and their utility is minimal. These resources are totally ignored. This is applied to both surface and subsurface water resources. However, the status of water resources shared with Syria can be improved, as elements of cooperation exist between the two countries unlike that with Israel (the occupied Palestine Territory). Another factor responsible for the poor management of Lebanese shared water resources is that the geographic locations of these resources are mainly in areas with few/or no human settlements, and thus, the exploitation of water is not competitive.

Many challenges exist, which add to the exploitation of shared water resources of Lebanon. They can be summarized as follows:

1) Lack of abiding by the international rules issued by Israel. In this respect, the Helsinki Rules and the 1997 UN Convention endorsed the principle of "reasonable and equitable" sharing of the water of international rivers. However, this is not the case for the Hasbani–Wazzani River, where more than 92% (207 Mm^3/year) of water flows into Israel, while Lebanon is not allowed to pump its quota of water from the river. Thus, there is denial of the international laws on shared water by Israel, which sometimes uses military force to control uneven water supply.

2) Lack of integrated database and information that are essential to elaborate on the quantitative estimations of available water resources between Lebanon and the riparian countries. For this scope, there must be integrated systems for monitoring and measuring the hydrological data, especially between Lebanon and Syria where accordance can be done. However, this cannot be done between Lebanon and Israel.
3) Weak coordination and integration among institutions, notably on shared waters. This includes the lack of participatory management approaches and stakeholder involvement. There is also an overlap of functions between water-related institutions. This has been reflected on managing the shared water resources of Lebanon.
4) There is no enforcement mechanism for bilateral or multi-lateral agreements. Hence, the establishment of agreements, projects, and actions require more coordination.
5) There is limited financial resource to manage and develop shared water resources. Therefore, the weakness of financial resources and low investment opportunities, due to lack of effective economic instruments, impede the optimal management of these resources, which then remain with no investment.
6) Lack of consistent planning and follow-up procedures to cope with the changing physical and anthropogenic factors on the shared waters of Lebanon. Therefore, the need for harmonization of policies should increase with the expected intensified water stress in the coming years in the region.
7) Weak institutional and individual capacities and knowledge on shared water resources management. Thus, strengthening and capacity building for institutions and individual awareness on the management of shared waters should be considered as a priority.

8) Insufficient legal instruments, in areas of shared waters, to enable the establishment of regional cooperation mechanisms. This, in particular, affects water use rights, water quality standards, groundwater exploitation, supply/demand management, private sector participation, and institutional responsibilities.
9) Lack of scientifically-based assessment and data analysis. This is well pronounced in Lebanon where several studies and assessment approaches have been conducted without scientific basis, notably the hydrological and hydrogeological background.

LEGAL AND INSTITUTIONAL AGREEMENTS

The geographic setting of Lebanon makes it a country facing dispute regarding its water resources, which are shared with the riparian countries. In particular, its neighbor, Israel, exaggerated the problem, and represents a part of the political situation in the entire Middle East. Therefore, military conflicts often occur with Israel, which has tried many times to occupy the southern segment of the primary course of the Litani River, whose watershed is located in Lebanon. Hence, political instability occurs and legal systems are totally absent, and will never be formulated in the view of lacking international agreements.

As mentioned previously, about 74% of Lebanon is bordered with terrestrial lands of other countries, and between 25% and 30% of its water are shared resources (Shaban and Douglas, 2008). Among them, about 90% is with Syria and 10% with PT. There are legal arrangements with Syria, but they still need to be empowered and modified, notably with the existing demographic and political situation in the region. While no agreement can be done with Israel, which occupies many geographic parts of the neighboring Arab countries, shared water resources are out of control in this region.

Legal Arrangements of El-Kabir River

The hydrological sharing of the primary watercourse of El-Kabir River, between Lebanon and Syria, which makes it a national border, is not a common phenomenon, and thus, most shared rivers are found to extend from one country to another. Therefore, the existence of the El-Kabir River as a border line gives a chance for equitable water exploitation. Hence, each country directly abstracts water from its side without any conflict. In addition, the largest area of the river watershed is in Syria, which does not create any problems for either country.

Under the umbrella of the Syrian-Lebanese Higher Council, a cooperation and coordination treaty was signed in 1991 by Lebanon and Syria on the water sector. Thus, a Joint Committee for shared water was designated and represented by the Lebanese Ministry of Energy and Water and the Syrian Ministry of Irrigation. Therefore, both countries agreed in 2002 to share the El-Kabir River water for equitable and reasonable utilization of the water resource (60% of the annual flow to Syria and 40% to Lebanon according to Article 3 of the agreement). The agreement draws on the United Nations Convention on the Law of Non-Navigational Uses of International Watercourses (Comair 2003). Also, the agreement mentions the construction of a multi-purpose dam near Noura Et-Tahta with a planned storage capacity of 70 MCM for irrigation (about 10000 ha) and domestic use.

Both countries consider the agreement as a model for bilateral cooperation over shared water resources in the Arab region. According to Annex 3 of the agreement, the joint committee is to prepare an annual program for water use in the basin. However, these annual programs have yet to be drafted, along with the construction of the dam, which has not yet been started (UN-ESCWA and BGR, 2013).

Yet, there are several unfavorable issues regarding the river water between both countries. The most significant one is the water contamination in the river water and the feeding springs where the amount of phosphorus and nitrogen exceeds the normal standards (Hassan et al., 2005). This is also the case for sediments in the river bed where heavy metals (e.g., chromium and nickel) are intensive (Thomas et al., 2005). Thus, the uncontrolled border results in many problems, which harm the environment as well the humans. The problems include tremendous sewage outlets in the river course, smuggling and transporting of contaminated materials along the river (Figure 8.1).

Figure 8.1. Smuggling along the uncontrolled watercourse of El-Kabir River.

Legal Arrangements of Orontes River

Orontes River (AL-Assi) is a typical shared river, as it crosses three riparian countries. The river, with its tributaries, is connected at several confluences, and outlets into the Mediterranean Sea. From the Lebanese side, however, the river spans in a distinguished flow direction from south to north. Thus, the southern river tributary originates from Lebanon, as discussed previously, and then connects with other tributaries from Syria and Turkey.

Even though the Orontes River flows into three countries, there has not been any combined joint agreement between the three countries on the sharing of the river water. Besides, there are separate agreements between two adjacent countries (i.e., Lebanon and Syria; Syria and Turkey).

Due to its importance as a major source of water shared by three countries, the accordance on the Orontes River has been initiated since a long time between the riparian regions of the river. This can be attributed to 1939 when a protocol was agreed upon by Syria and Turkey. Later on, this protocol was developed at different time intervals till 2009 when the Turkish-Syrian Strategic Cooperation Council Agreement was initiated.

There are five agreements between Lebanon and Syria on the Orontes River. This has been elaborated on since 1972, when the first bilateral accordance between both countries was made, named as the "Agreement on Water Use." Hence, the formal basis for cooperation between the two countries in the water sector and the related sectors was considered, and thus, many joint committees were established, including the Lebanese-Syrian Joint Committee for shared water. The Fraternity, Cooperation and Coordination Treaty was established in 1991 because of this accordance (Comair, 2003).

Consequently, an adjoined bilateral agreement to regulate water distribution from the river was created in 1994 (Scheumann et al., 2011). It emphasized dividing the annual share of water as 80 Mm^3 (20%) for Lebanon when the volume of river water in Lebanon exceeds 400 Mm^3 and the rest flows to Syria. This was under the "Agreement on the Distribution of the Orontes River Water Originating in Lebanese Territory" (Act. No. 15 1994). Thus in 1997, this agreement was developed, following which it was complied with the annex identifying the four sub-basins and a main spring, which are to be excluded from Lebanon's annual share as agreed in the 1994 agreement.

Due to the increased population within the river basin in Lebanon, the Agreement on the Distribution of the Orontes River was amended in 2001 to allow Lebanon to establish some infrastructures on the river tributaries.

Yet, many issues conflict the status of the river and its flanks, notably in the absence of formal controls. This includes mainly the direct pumping from the river and the increased number of boreholes in its surrounding. In addition, contamination is well known in the river water at many sites.

Legal Arrangements of Hasbani–Wazzani River

The Jordan River, where the Hasbani–Wazzani River comprises one of its major tributaries, joins four countries including the occupied Palestinian Territory (PT) by Israel. Due to no combined agreement between all these riparian countries, conflicts often occur. There are bilateral agreements between Syria and Jordan, Jordan and Israel, and Israel and the PT (UN-ESCWA and BGR, 2013). Therefore, there is no accordance with Lebanon concerning the Hasbani–Wazzani River due to the political conflict in the region.

The status quo can be described as instable, and it contradicts the international laws and conventions on shared waters. Thus, with the current encroachment of Israel, Lebanon is neither issuing its quota of water from the Hasbani–Wazzani River nor utilizing the riparian zones of the river (i.e., adjacent mountains springs). Therefore, frequent conflicts exist, and in many instances, Israel uses military force to postpone Lebanon's utilization from the river water, such as the event in 2002.

In the view of the current situation in the Middle East, no any initiative or multilateral or bilateral agreement can be taken with Israel.

Legal and Institutional Arrangement of Groundwater

Usually, concerns are given to surface water resources that are visible and can be measured or assessed. However, this is not the case for groundwater, which occupies an integral part of the shared water resources. In many instances, groundwater has a greater share of volume than that of surface water. However, the existence of groundwater in the subsurface media makes it attract less attention. From the hydrogeological point of view, the volume of shared groundwater resources of Lebanon is estimated to exceed the volume of shared surface resources. This is obvious from the hydro-stratigraphic and hydro-structure delineations between Lebanon and the neighboring regions, where the substantial flow of this water is derived from Lebanon outbound.

However, there is no convention or agreement dedicated to the sharing of groundwater, either between Lebanon and Syria or Lebanon and the PT. Most shared aquifers are subjected to obvious decline in water volume and lowering of the water table. This is well pronounced along the riparian zones with Syria and notably between El-Bekai'a and Tell Kalakh, Hermel and Kousair, as well as the riparian zones with the PT, and mostly along the stretch between Khiam-Markaba-Aytaroun and Yeftah-Malkieh-Kfer Brim, notably that Israel occupies many Lebanese villages, such as Malkieh, Dan, Hounine, etc.

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Chapter 9

CONCLUSION AND RECOMMENDATIONS

Striking challenges on water resources have been exacerbated due to many factors, mainly by the negative interference of humans, whether on the hydrological or/and meteorological systems. The increased population growth, accompanied by its rising water demands have also added to these challenges. From this point of view, there must be management and conservation approaches to protect water sources in terms of quantity and quality. Water should also be properly utilized as much as possible during its journey in the water cycle.

If water is not naturally available to cope with human demands in any region, it would be a key issue to think on the use of non-conventional water sources. In many arid and semiarid regions, water availability doesn't exceed 200 m^3/capita/year. Thus, several water production methods are followed, such as the desalination of seawater or water treatment and water re-use. Besides this figure, water is available in other regions, but supply/demand is poor and it always oscillates between different regions, even in the same country.

The most commonly raised questions are: Is Lebanon a country with available water resources? Is the interrelation between the supply and demand satisfactory? Are water sources in Lebanon well utilized? What are the major challenges on the water resources of Lebanon? All these questions imply one answer: Lebanon's water resources are not well managed and the country can be described as a water-poor country with inadequate water supply, which does not exceed even 30% of the water demand, which is estimated at 220 m^3/capita/year. Thus, Lebanon's water is under loss, and this loss has many aspects. Hence, "water loss" is the key issue of water resources in Lebanon, where these resources exist and can be adequate if they are well exploited.

One of the major aspects of water loss in Lebanon is the aspect of shared water, which is shared with the neighboring regions whether as rivers or groundwater or with any other aspect of sharing water. This is well pronounced when a reconnaissance on water supply/demand is applied in the border regions of Lebanon, whereby no obvious water control can be noticed.

About 2878 km^2 (27.5%) of Lebanon's area is shared as shared river basins with the riparian regions, where Lebanon comprises a major tributary for two international rivers, which are Orontes and Jordan. Hence, water flows from these rivers with no/or very little utilization. The estimated discharge from these rivers (from the Lebanese side) is about 867 Mm^3 per year.

In addition, about 2631 km^2 of Lebanon's area comprises shared groundwater reservoirs with the neighboring regions, which is equivalent to 25% of the Lebanese territory. These reservoirs (i.e., aquifers) represent potential rock formations for groundwater storage. If the hydrological formula is applied to these estimates, it can be seen that the shared aquifers in Lebanon contain approximately 365 Mm^3 of water.

Considering the volume of water pumped from the shared rivers in Lebanon, as well as the estimated water abstracted from dug boreholes (groundwater resources) in the border region, about 210 Mm^3 is the only volume of water that is utilized from the Lebanese shared water resources. This is equivalent only to about 15% of the total volume of these resources, which extend over more than one-quarter of the Lebanese territory.

If Lebanon applies better management approaches for its shared water resources, and work in the direction of utilizing around 50% of these resources, a water volume of about 700 Mm^3 can be added to Lebanon's water budget (Figure 9.1). If this amount is distributed among the existing population, there will be around 175 m^3 per capita (i.e., equivalent to about 80% of the water demand per capita) of additional water supply. Meanwhile, if 60% of the shared water is well tapped in Lebanon, the demand per capita will be completely supplied from this water, and any added percentage will provide surplus for the water demand (Figure 9.1). This is a promising motivation to account for the shared water resources in adopting water strategies and policies in Lebanon, which is almost absent in a time of water scarcity and imbalanced supply/demand.

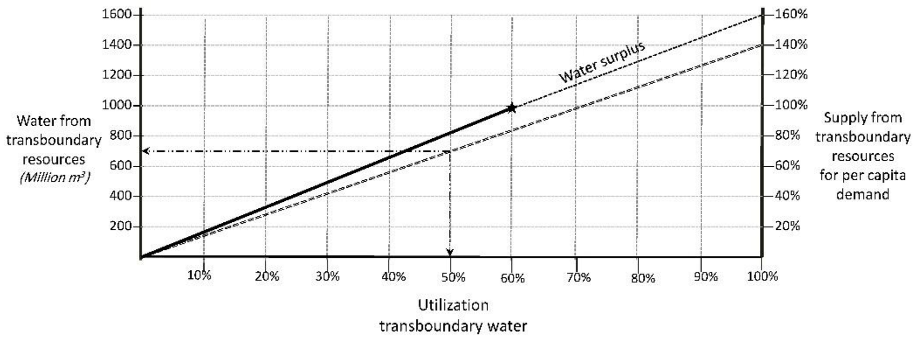

Figure 9.1. Water volume which can be utilized from shared resources and its contribution to the demand per capita in Lebanon.

However, the question remains: How can Lebanon benefit from its shared water resources? The answer can be viewed from two major pillars. The first pillar implies the reinforcement of the existing treaties with Syria and development of new accordance regarding the sharing of water between the two countries. Second, there must be recognition by international water laws, which should be abided by Israel.

Based on the detailed description and the discussion introduced in the previous chapters on the shared water resources in Lebanon, the following actions can be proposed for optimal investment of these resources.

SPECIFIC ACTIONS

These are actions proposed for Lebanon to be implemented on its major shared water resources. This includes the three shared rivers and the five sharing aquifer domains.

El-Kabir River

1) Water harvesting, including earth dams, should be done along the primary watercourse of the river. In addition, check dams can be also implemented along the river tributaries.
2) The catchment areas of the principal springs feeding the river should be conserved.
3) Quality control should be carried out, as the river water is totally contaminated. This implies river water and sediments (i.e., bed load).
4) Environmental legislations must be adopted for groundwater abstraction in the context of the river. This must also be applied to liquid and solid wastes disposal into the river water.

Orontes River

1) Many aspects of harvesting can be done along this river, with a special focus on dams of different dimensions, which can be built along the primary watercourse of the river. In addition, mountain

lakes should be constructed on the elevated regions surrounding the river.

2) The replenishment zones for the feeding springs in the river's proximity must be protected.
3) Quality control should be applied, notably in the areas where human settlements exist.
4) Environmental legislations must be adopted for water abstraction, whether from the river or from groundwater reservoirs. This must be also applied to wastes disposal into/or near the river.

Hasbani–Wazzani River

1) Water from the Wazzani Spring must be regulated and adopted as Lebanese water sources.
2) Check dams must be established along the primary course of the river as well as along some tributaries.
3) Water harvesting, notably mountain lakes, must be done in the catchment area of the river where snow cover is dominant.

Eocene Aquifer Domain

The Eocene Aquifer domain, which occurs at the border between Lebanon and the PT, has a thick succession and a good potential to store groundwater. As was mentioned, the largest part of this domain is located in Lebanon. Thus, this water must be tapped by digging boreholes where groundwater depth does not exceed 600 m. Therefore, the most potential sites for groundwater are located at the ends of the anticline limps, particularly, at the geographic stretches joining Beflaye-Tebnine-Bent Jbeil, as well as the stretch of Deir Mimes-Bilda (Figure 7.2).

Considering the hydrogeological parameters of this domain, a volume of about 25 Mm^3 of water is expected to be stored here. Hence, groundwater must be abstracted, followed by the development of water projects to supply water to the surrounding villages.

Cenomanian Aquifer Domain-I

The Cenomanian Aquifer Domain-I, which is shared with Syria, has its largest extent in Lebanon, where it extends to Mount Lebanon (Figure 7.4). The mountainous zone of this potential aquifer domain, with almost a deep water table (i.e., <550 m in average), is one of the most potential water recharge zones in Lebanon where water from melting snow and rainfall has the highest rate in the region (>1400 mm).

Even though the domain itself does not occupy a dense population, a considerable amount of groundwater (estimated at about 60 Mm^3) is available, which should be exploited. This water can be delivered toward the Hermel region, notably to the agricultural lands. In addition, a portion of the abstracted groundwater can be supplied to the Aadakit and Koubayat regions.

Cenomanian Aquifer Domain-II

The exposure of this domain is well developed to the north-eastern part of the Baalbek region and extends to Syria (Figure 7.5). It comprises significant recharge zone among the carbonate rocks where water from snow melt and rainfall seeps into fractures. The water table in this domain is almost deep, averaging around 450 m.

As the northern part of this domain represents mainly an anticline structure, groundwater flows into two directions, and usually, in equal volumes between Lebanon and Syria. Besides, the southern part of this domain comprises mainly a plunged structure where groundwater flows into a deep stratum.

Based on the hydrogeological characteristics of the Cenomanian Aquifer Domain-II, the estimated groundwater volume is about 300 Mm^3 where more than 90% of this water is allocated in the northern part of it. Thus, groundwater can be tapped by drilling boreholes, and consequently, water supply projects can be carried out to replenish the northern Bekaa region, between the El-Qa'a and Rayak geographic stretch.

Cenomanian Aquifer Domain-III

The Cenomanian Aquifer Domain-III, which is shared with the PT and its exposure is separated into two parts (Figure 7.6), is a potential aquifer with a relatively large recharge zone from rainfall. It is characterized by a relatively deep water table (i.e., 500 m in average). Therefore, large portions of groundwater are stored in this domain, which consequently flows into the southern regions, and a part of this water seeps into the sea along the inclined rock beds and the existing fault systems and karstic conduits. Hence, water loss is well pronounced in this domain.

The estimated groundwater volume in this domain is about 100 Mm^3, which can be substantially exploited by Lebanon. This water volume can be supplied to the villages located on the domain itself, such as El-Bayada, Kafra, Bent Jbeil, Rmaysh, Naqoura, as well as to the surrounding villages.

Jurassic Aquifer Domain

Even though this domain has a diverse age than the previous ones, the presence of carbonate rock facies as well as the geographic orientation of this domain places it under similar hydrological and hydrogeological characteristics with the Cenomanian Aquifer. While this domain apparently shares Lebanon and Syria, geologically, it extends to the PT (Figure 7.8).

The Jurassic Aquifer Domain is structurally similar to the Eocene and Cenomanian Domains-II and III, where anticline structures exist and deliver groundwater in opposite directions along the anticline limbs. However, this domain, which is fed from snowmelt and rainfall, there is also a substantial amount of groundwater seepage to the southern region (i.e., to the PT).

From the hydrogeological point of view, the estimated groundwater volume in this domain is about 55 Mm^3. Even though the domain itself has very few urban areas, the existing groundwater can be tapped at the foot slope of the domain to the west, and thus, water may be delivered to several localities in the surrounding regions, such as Hasbaya and Rashia.

GENERAL ACTIONS

Other than the specific actions to be implemented for each of the major shared water resources of Lebanon, there are general actions or considerations that should be also undertaken to benefit from these resources. These actions, which can be taken at the individual and institutional levels, are as follows:

1) Carry out detailed hydrological and hydrogeological studies on the shared water resources of Lebanon, including volumetric estimates, whether on surface or subsurface water sources. The subject matter of this document can be considered as first-hand information for the proposed studies.
2) Reinforce the treaties obtained with Syria and develop new accordance with respect to the sharing of water between the two countries.

3) Reactivate the roles of the technical committees, commissions, and institutions on the water sector with Syria.
4) Elaborate joint projects and studies with Syria to assess the shared water resources between the two countries.
5) Strengthen legal settings to adjust the existing national conventions and laws aiming to facilitate the development of the regional legal status, such as the negotiations, international laws and agreements, conflict resolution, etc.
6) Enhance coordination and harmonization between the concerned institutions in Lebanon with respect to the water management, with special emphasis on shared water resources.
7) Develop economic and financial instruments to ensure sufficient funding, and motivate donors to elaborate on projects on shared waters.
8) Motivate international entities to oblige by the Israel ratification and respect the conventions on shared water resources, notably for the Hasbani–Wazzani River.

About the Authors

Prof. Amin Shaban PhD - Applied Geology, France. Researcher in water resources management, geological processes and Remote Sensing at the National Council for Scientific Research (CNRS-L), Beirut, Lebanon (1997 to date).

Since 1997, A, Shaban, as a Director of Research, joined the Remote Sensing Center belongs CNRS-L, where he coordinated and contributed several research projects and published works and studies on natural resources management with a special emphasis to water assessment and exploration.

Dr. Shaban has been involved in many training courses and researches in different regions worldwide. He enrolled in the Fulbright Program (2005-2006) at Boston University where he produced several joint studies and projects. He is also member in many local and international scientific committees, as well as he is the IHP-Focal Point of the National Committee of Lebanon.

Dr. Shaban has been given many scientific awards. He has been three times honorably mentioned by CNRS-L, the Award for *Career Excellence in Scientific Research (2010), Award of Distinguished Researchers (2012)*. His scientific productivity implies publishing more than 50 researches in Peer Reviewed International Journals; and more than 100 publications in International Proceedings and seminars worldwide.

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Since 1998, M. Hamzé as Secretary General of the National Council for Scientific Research – Lebanon (CNRS-L) has given special attention to developing the Scholarship Program, the Grant Research Program, and The Science Technology & Innovation Policy (STIP). He also enhanced cooperation with numerous countries and organizations culminating in the implementation of bi-lateral and multi-lateral projects and programmes, including those with the EU (FP7, H2020, PRIMA).

He has authored several books, reports and scientific papers; chaired numerous international and regional meetings and symposia; and has been actively involved in international organizations, including: CIHEAM, IAEA, ICARDA, CEDRE, ESCWA Technology Centre, AUF, IOOC.

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