Chapter

# Striking Challenges on Water Resources of Lebanon

*Amin Shaban*

## Abstract

Lebanon was described as the "water tower of the Middle East," but the current status is contradictory, and water supply/demand gap has become imbalanced. Even though, water is available, yet water shortage is a major challenge in Lebanon. This is attributed to the undefined hydrological cycle and the lack of sufficient hydrologic data to establish proper strategies and policies. This study investigates the existing physical and anthropogenic challenges and their impact on water resources. Hence, climate change is one major aspect of these challenges where the precipitation patterns have been abruptly changes to torrential rainfall, and this is accompanied with increased temperature estimated at 1.6°C. In addition, the exacerbated population rate (2%) with the doubled number of refugees makes Lebanon a country under water stress. The discharge in rivers and springs has declined by about 60% over the last four decades, while groundwater level has sharply lowered in the major aquifers and the pumping rate has decreased to about 35%. The problem on water resources in Lebanon should be resolved by promoting a national strategy that takes all hydrological components into account, as well as new adaptation measures must be proposed for better water management.

**Keywords:** water deficit, river discharge, pollution, mismanagement, water policy, Lebanon

## 1. Introduction

The topography of Lebanon is characterized mainly by mountainous ridges where two mountain chains extend parallel to the Mediterranean Sea, thus building a regional climatic barrier besides the cold air masses from the sea, and then falling considerable amounts of rainfall and snow in the elevated areas. The annual rainfall rate ranges between 700 and 1500 mm and snow remains for a couple of months on mountains and covers more than 2500 $km^2$ of the Lebanese territory. This is reflected on the hydrology of Lebanon where 12 permanent watercourses (i.e., small rivers) and more than 2000 major springs (>10 *l*/sec) occur. Moreover, there are a number of aquiferous formations and karstic conduits where considerable amount of groundwater is stored. This makes Lebanon a country with sufficient water resource. This status remained until the beginning of 1990s when the water sector in Lebanon started facing severe geo-environmental problems regarding water volume and quality.

Recently, water demand/supply has occupied a wide space of argument in Lebanon, and this has been raised mainly on the national level, notably that water per capita has been decreased to more than 60%. Hence, it is a paradox that

Lebanon became one of the countries under water stress since it was ranked as 149 on the wide world water availability list.

There are many challenges existing in the water sector of Lebanon, including physical and anthropogenic aspects. These have been exacerbated lately and their impact on water supply has been reaching intolerable levels. The majority of these challenges imply a change in climate, and more certainly increased temperatures and oscillating rainfall patterns. In addition, there is the population growth which has added to water demands as well as the issue of refugees who comprise more than 40% of Lebanon's population.

Complaining for water becomes a daily issue between different concerned institutions, and there is increased debate on the responsibility for the deterioration in the water sector of Lebanon, notably that the severe situation reached all surface and subsurface water resources and covering all Lebanese regions. Thus, every major water resource has come under dialog; and, many campaigns, committees, and even institutional frameworks were established to meet water demands, but no enhancement has been observed to date.

The Litani River, the largest of its type in Lebanon, is a typical example for the unfavorable status of water sector in Lebanon. The river is witnessing an extremely severe situation, and the streamflow has become minimal while the quality has ultimately deteriorated and exceeded hundreds of times the international norms. According to Shaban and Hamze, the river's situation was described as "Death of a River" [1].

For the Litani River, a business plan to identify the measures to alleviate pollution in the river and the belonging Qaraoun Reservoir, was framed in 2006 and followed by an updated plan in 2013. Meanwhile, a national multi-ministerial committee for the depollution of the river basin was also established in 2012, and consequently a national committee was created to follow up the implementations for the remediation of the Qaraoun Reservoir in 2014 [2]. In addition, loans from international entities (e.g., World Bank) were provided to support the implementation of the approved plans. Nevertheless, the river is still in its worst condition.

This chapter aims at clarifying the major existing challenges facing water resources of Lebanon whether these challenges are of the natural or anthropogenic aspects. This will help highlighting the fundamental elements of these challenges, which can, further, serve as clues for proposing management solutions. The analysis of these challenges is based on previous studies obtained by the author who used several tools for analysis including, mainly, hydrological tools, as well as remote sensing and geo-information systems.

## 2. Method of analysis

For studying the challenges of water needs to investigate the existing problems on water supply/demand, the main factors influencing water supply to consumers must be identified and then investigated accordingly. This can be elaborated by considering the two principal pillars of challenges in the water sector. The challenges are of time-related origin, and they can be classified as: (1) challenges that originally occurred long time ago in the past, and they belong to the physical origin of the area and the living people inside and (2) challenges that have recently interfered with and influenced water volume and quality. For both aspects of time-related origin, the method of analysis of water challenges can be elaborated by empirical assessment of the water resources under stress, and this can help to identify what actions should be taken to reduce the impact of these challenges.

According to Shaban [3], the principal phases for the methodology used in analyzing challenges in the water sector are illustrated in **Table 1**. They are five major phases

| Phase | Description | Expected outcomes |
|---|---|---|
| Data and information inventory | • Previous studies, researches, etc.<br>• Implemented plans and projects<br>• Existing strategies and policies<br>• Long-term climatic and hydrologic records | Preparing inventory on water resources in the country |
| Data analysis and interpretation | • Map analysis (including illustrators)<br>• Obtained case studies on water resources<br>• Statistical analysis of measures (e.g., water consumption population size, etc.) | Identifying the current measures and their trends |
| Use of advanced tools | • I*n-situ* measurements<br>• Advanced laboratory techniques<br>• Remote sensing and geo-spatial products | New tools and techniques will give accurate results |
| Field survey | • Field investigations (mainly those obtained by the author)<br>• Results of data from previous field observations and investigations | Verifying obtained results and adding filed measures |
| Benefit from lessons learned | • Benefit from successful studies and projects obtained regionally and globally<br>• Identifying useful tools used in water resources assessment<br>• Inducing reasons of failure in water sectors | Determining elements of success or failure in water sector and benefit from these element for better management approaches |

**Table 1.**
*Major phases of analyzing challenges on water resources (Adapted from Shaban [3]).*

that are integrating different aspects of data and information where the trends on water resources are viewed over long time period from past to recent. For each phase of data analysis, there are a number of measures and information sought (**Table 1**). In this respect, the availability of data and records is significant for the analysis.

## 2.1 Data sources

Constraints always exist while collecting data and information for further analysis in hydrological and meteorological studies. This is well pronounced in Lebanon where there is a lack of continuous time series data on elements of water assessment, which mainly includes the precipitation rate, discharge from rivers and springs, as well as volumetric measures on groundwater. There is also obvious contradiction between the measures obtained on water resources, and this is attributed to data unavailability, non-uniform distribution of measuring stations (meteorological and hydrological), and the complicated geomorphology of Lebanon.

For this research, the following data series was prepared:

- Precipitation and temperature datasets for the last four decades.
- Water flow rate for the major rivers and springs, as well as the two main artificial lakes in Lebanon.
- Water table depth and pumping rate from the major two aquifers in Lebanon and for selected areas.
- Results of water consumption surveys from pilot areas in Lebanon.

The collected data in this research were primarily organized; therefore, gaps were identified and filled either by statistical interpolation or from the remotely sensed data.

The majority of climate and hydrologic data sources, which are necessary for the assessment and for identifying the existing challenges, can be summarized as follows:

- Climatic Atlas of Lebanon—Atlas Climatique du Liban [4, 5].
- Tropical Rainfall Mapping Mission [6], which is a remotely sensed system based on radar data. It retrieves rainfall datasets on a daily basis.
- Department of Irrigation and Agro-meteorology (DIAM), Lebanese Agricultural Research Institute [7].
- Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) dataset. Its algorithm is built on ground-climatic measures incorporated with satellite information. It provides daily and monthly data [8].
- General Directorate of Civil Aviation—Direction Générale de l'Aviation Civile [9].
- NOAA climatic data system—National Oceanographic Data Center [10].
- Data and measures found in studies (e.g., theses, technical reports, etc.) conducted by different authors, all of them for pilot areas from Lebanon.
- Data and information measured in filed surveys whether on water resources or on the socioeconomic status, with a special emphasis on water consumption.
- Data from the projections and scenarios elaborated for the hydro-climate of Lebanon, such as those obtained by [11–13]

Thematic data were also used in this research in diagnosing the physical influencers on water resources. These mainly include a number of thematic maps and illustrations, such as topographic, geologic, hydrological, and hydrogeological maps with their attribute measures. They could be used for analyzing major water-related parameters.

### 2.2 Data analysis

The majority of data analysis follows a simplified approach for data investigation, comparison, and deduction. This represents a synthesis of the existing challenges on water resources. The followed approach is based on the data collected from all mentioned sources. Therefore, the method of analysis is as follows (**Figure 1**):

1. Review of the available documents and records on water resources and the related influencing factors (e.g., climate), and this focuses mainly on the volume and quality of the major water resources in Lebanon. Hence, notes were taken on the fundamental findings with a special emphasis on:
    - Water inputs into the hydrological systems (e.g., watersheds, aquifers, etc.).
    - Aspects of water loss (e.g., flow into the sea, evapotranspiration, etc.).

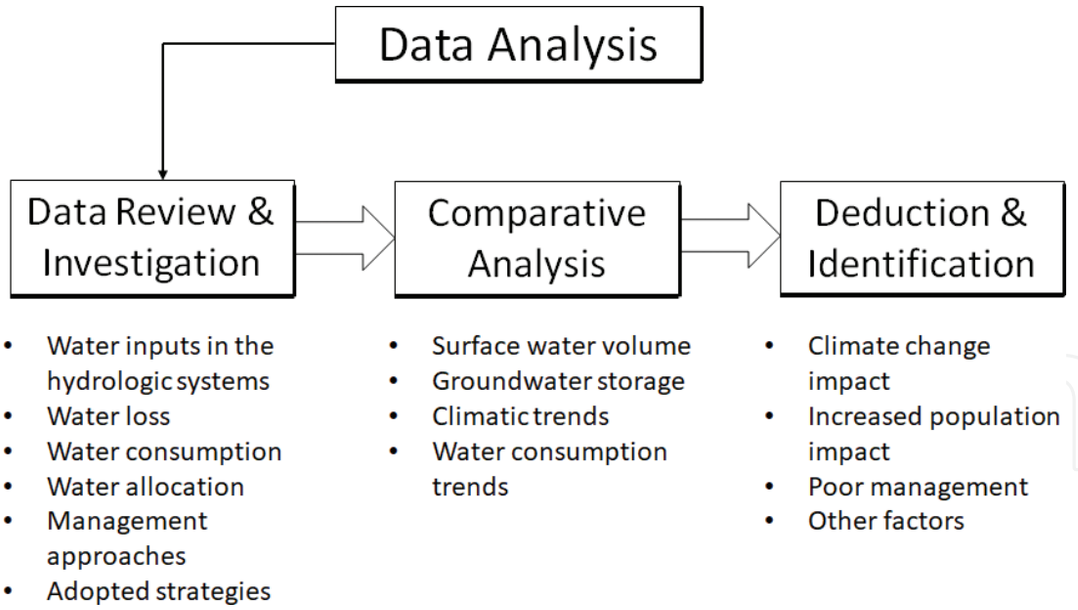


**Figure 1.**
*Major items for the method of analysis.*

- Water consumption by sector and allocation for different purposes.
- Existing aspects of water exploitation, notably for irrigation.
- The obtained management approaches whether taken by individuals or the government sector.
- The adopted strategies and plans for water conservation and management.

2. Applying comparative analysis on different water measures based on time series data analysis. This implies the use of advanced statistical methods to identify the behavior of the numerical values, which are mainly of hydrological and meteorological origin in addition to the consumption rates. In particular, singular spectrum analysis (SSA) and Fisher-Shannon and detrending fluctuation analysis (DFA) methods were applied to:
   - Water volume in rivers, springs, and lakes (artificial and man-made).
   - Groundwater depth, discharge, and number of boreholes.
   - Climatic trends mainly including the precipitation and temperature.
   - The changing trend in water consumption and water supply/demand over long times series.
3. Identifying major clues toward understanding existing challenges. In other words, it implies determining the influencing factors that result in challenges on water resources of Lebanon. This highlights:
   - The impact of climate changes (considering space and time dimensions).
   - The degree of influence caused by the increased population and refugees.

- Investigating the influence of poor management on water resources.
- Searching all other factors that directly or indirectly act on creating challenges on water resources.

## 3. Physical factors

Debate always occurs when talking about the responsibility of the existing challenges on water resources and the question is often raised: Are the existing challenges on water resources physical or man-made? Actually, both types of challenges occur in Lebanon and nobody has identified which is the most effective one, and even the degree of influence of each challenge is still obscure. However, there are many clear evidences to highlight the factors behind these challenges, and these evidences are declared even by the individuals who are directly touched by water deficit in all regions of Lebanon.

There are several natural factors that act on the hydrological regime of water resources. These are of different origins and act at different scales. They result in challenges that are represented mainly by shortage in water supplied to the consumers. Thus, some of these factors exist alone and sometimes are found combined with each other. Hence, physical factors are well known in Lebanon and they influence water regime from the source, through the entire water cycle including storage, consumption and loss into the sea.

The following are the major physical factors that act in developing challenges on water resources of Lebanon.

### 3.1 Geo-hydrological factors

The geo-hydrological factors have a significant role in creating and enhancing the impact of challenges on water resources of Lebanon, notably that Lebanon's territory encompasses all processes and features of the hydrologic cycle. This is highly influenced by the distinguished geomorphology of Lebanon, which possesses mountain ridges with sharp peaks that are detached by several valley systems and then carrying surface water directly to the sea.

The geo-hydrological setting of Lebanon implies different aspects of the elements influencing water flow/storage regime where the majority of this regime results in water seepages, inaccessibility, and water loss. This unfavorable flow/storage regime acts negatively on the exploitation of water resources whether those on surface or the subsurface. Therefore, the influencing elements on water resources in Lebanon include the following:

1. Lithological characteristics: The rock types that form the stratigraphic succession of Lebanon are characterized by diverse lithological aspects. This includes interbedded and intervening permeable and impermeable rock strata with relatively thin bedding planes, and this in turn enhances the seepage of water at the contact between the two diverse lithological types. This geo-hydrological phenomenon is well pronounced between the carbonate (e.g., limestone and dolomite) and argillaceous rocks in Lebanon.

2. Rock deformations: This is represented mainly by the dominant fracture systems, which characterize the rocks of Lebanon. Thus, Lebanon is known by its complicated and active tectonic setting along the Dead Sea Rift System; therefore, it is dominated by rock deformations mainly including dense fracture

systems (e.g., faults, joints, and fractures) that cut among different geological rock formations, as well as foldings of rock strata. Both aspects of rock deformations induce sharp bedding inclinations. The existing rock deformations often play a negative role when: (a) they transit groundwater from the coastal aquifers into the sea, and then water loss occurs [14, 15]; (b) groundwater seeps into very deep (unreachable) aquifers; and (c) groundwater leaks from the major aquifers into undefined systems [3].

3. Acute sloping terrain: It is one of the most acting factor on surface water flow regime, notably that the rugged topography of Lebanon makes it a terrain with less water retention. Therefore, the complicated geology of Lebanon is reflected by its topography and existence of acute slopes. In this respect, the slope gradient is often high and the average slope gradient exceeds 25 m/km over most of the Lebanese mountain chains (**Figure 2**). The steep sloping terrain negatively acts in enhancing water flow energy which can be to the sea or the neighboring countries and creates water loss before any proper investment for managing these resources.

   Also, the rapid water flow along the incident valley courses will act in retarding the percolation rate of surface water into substratum, and thus large amounts of surface water is lost before sufficient time for natural recharge to groundwater reservoirs [16]. However, such challenge can be managed if surface water restrictions (i.e., harvesting) are built, such as dams, channels, lakes, etc. [3].

4. Karstification: This is a very common hydrological phenomenon occurring in Lebanon and it is often given concern, notably because karstification has a significant influence on groundwater flow/storage regime though the subsurface routes, galleries, cavities, and shafts. The karstification features have different dimensions and occur on a large scale, and thus they are able to transport water for several kilometers vertically and laterally. Also, karstification features often

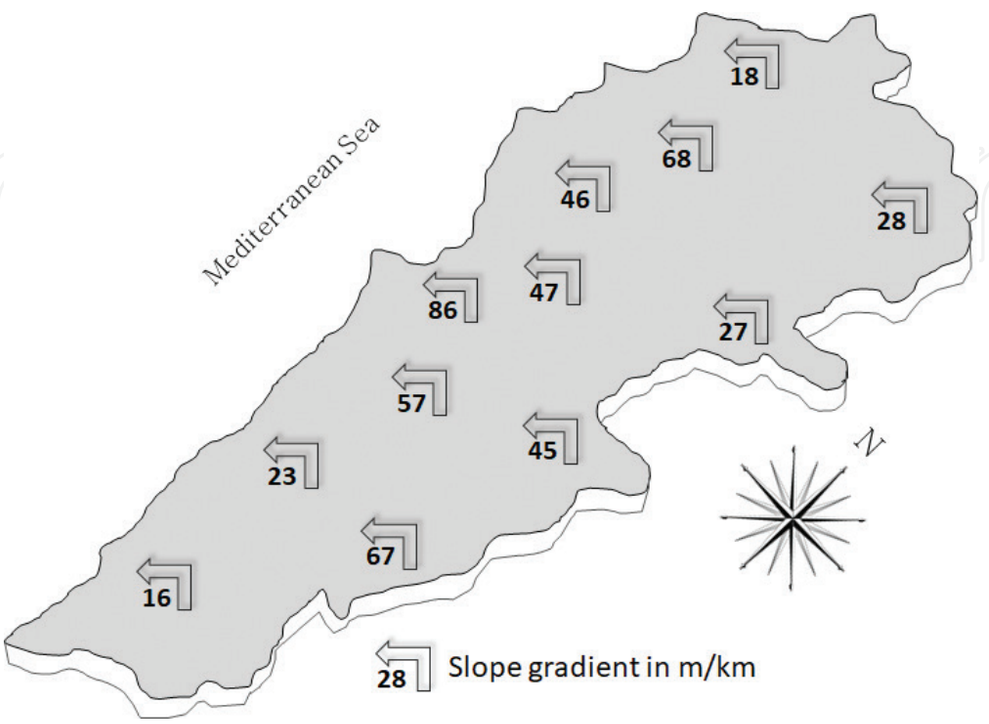


**Figure 2.**
*Simplified map showing selected slope gradients in Lebanon.*

play similar roles in transporting groundwater from the coastal aquifers into the sea (representing invisible water routes) or into deep and undefined aquifers [16].

Being of utmost importance to subsurface features, the karstic conduits and galleries are often found with large amounts of groundwater (e.g., Jeitta grotto), but there are many other aspects of conduits that are supposed to exist in Lebanon, and they are still uncovered. In fact, the karstic conduits usually form complicated hydrological systems, especially when exploration methods for groundwater are applied. Thus, these conduits do not have uniform or defined alignment, which makes them difficult to be identified. In addition, these conduits create problems while proposing artificial recharge into the coastal aquifers of Lebanon.

### 3.2 Meteorological factors

The meteorological factors have a significant role in creating challenges on water resources, and many people consider that the changing climate is the major reason behind water deficit in Lebanon. As a matter of fact, studies on this respect are tremendous, but they have contradicted results because of the lack of measuring records.

Generally, Lebanon is characterized by sub-humid to humid climate, but the country is still witnessing significant water shortage and imbalanced supply/demand. The annual rainfall rate in Lebanon ranges between 650 mm on the coast and 1500 mm on the adjacent mountains, while the average is about 910 mm. In addition, snow covers more than 2500 $km^2$ (25% of the Lebanese territory) and remains on mountain crests for a couple of months, while the average temperature in Lebanon changes between 21 and 23°C.

Over the last four decades, Lebanon has been under oscillating climatic conditions and this has reflected in its water availability; and, it can be said that the climatic oscillations play a role in determining the hydrological regime of many surface and sub-surface water resources, but this is not the only reason behind the water problem in Lebanon. The discharge in rivers and springs has decreased by about 60% over the last four decades. In addition, groundwater showed abrupt decrease in the pumped rate and water table has lowered in the main aquifers.

According to the most recent climatic data analysis, results showed that there are obvious periodicities in the climate regime of Lebanon, which is accompanied with meteorological oscillations [17], and the estimated rainfall rate was found to be fluctuating from one region to another in the range of ±200 mm over the last four decades [18], but no noticeable change has been reported in the volume of rainfall (**Figure 3**). However, there is a changing rainfall pattern and rain has been more torrential; in addition, there is clear shift in the beginning and ending of seasons. Besides, an obvious increase in the average temperatures has been reported over the last four decades (**Figure 4**), and it was calculated at about 1.8°C.

### 3.3 Water loss

Loss of water without any proper exploitation is one major problem that challenges the Lebanese water sector. Thus, many aspects of water loss occur in Lebanon, mainly including the seepage of groundwater to the sea along rock deformations and karstic conduits, flow of groundwater into deep karstic aquifers,

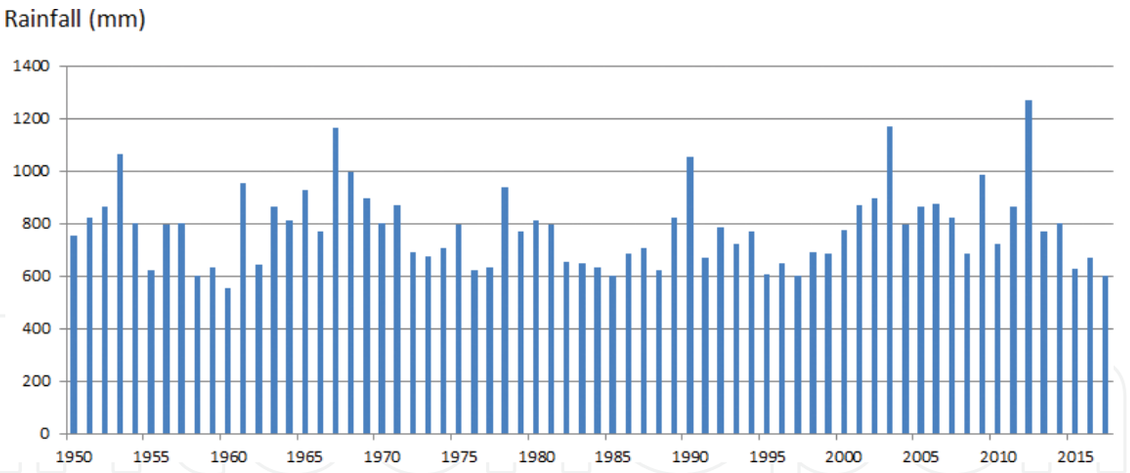


**Figure 3.**
*Annual average rainfall rate in Lebanon [18].*

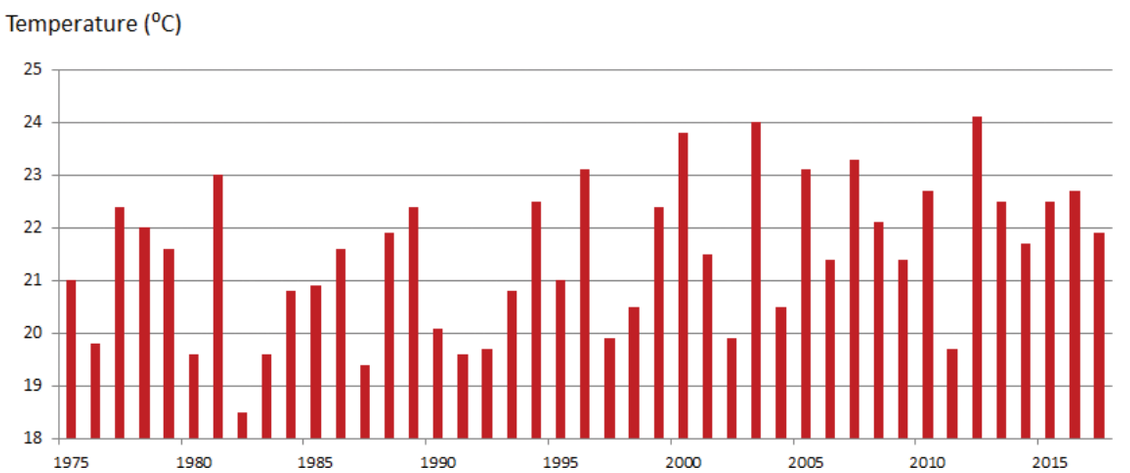


**Figure 4.**
*Annual average temperature in Lebanon [18].*

and the relatively high evapotranspiration rate (>55%). Also, there is a large part of surface water and groundwater in Lebanon shared with neighboring countries. Thus, of the 803-km perimeter of Lebanon's territory, about 559 km (67%) is shared with Syria in the north and east, and 9 km (11%) is shared with the Palestinian territory in the south and partly in the southeast.

About 27.5% of Lebanon's area is shared as transboundary river basins with the riparian regions, where Lebanon comprises one of the major tributaries for two international rivers; these are the Orontes and Jordan rivers (**Figure 5**). Therefore, water flows from the transboundary rivers of Lebanon's rivers with no/or very little utilization, while the estimated annual discharge from these rivers (from the Lebanese side) is about 867 million $m^3$ [17].

Shared groundwater with the neighboring regions for Lebanon occupies about 2631 $km^2$, which is equivalent to 25% of the Lebanese territory. The sharing reservoirs represent potential rock formations for groundwater storage. However, the geological setting of Lebanon makes groundwater flow along subsurface routes mainly from Lebanon to the neighboring regions. According to the applied hydrological calculations, the shared aquifers in Lebanon contain approximately 365 million $m^3$ of water [17].

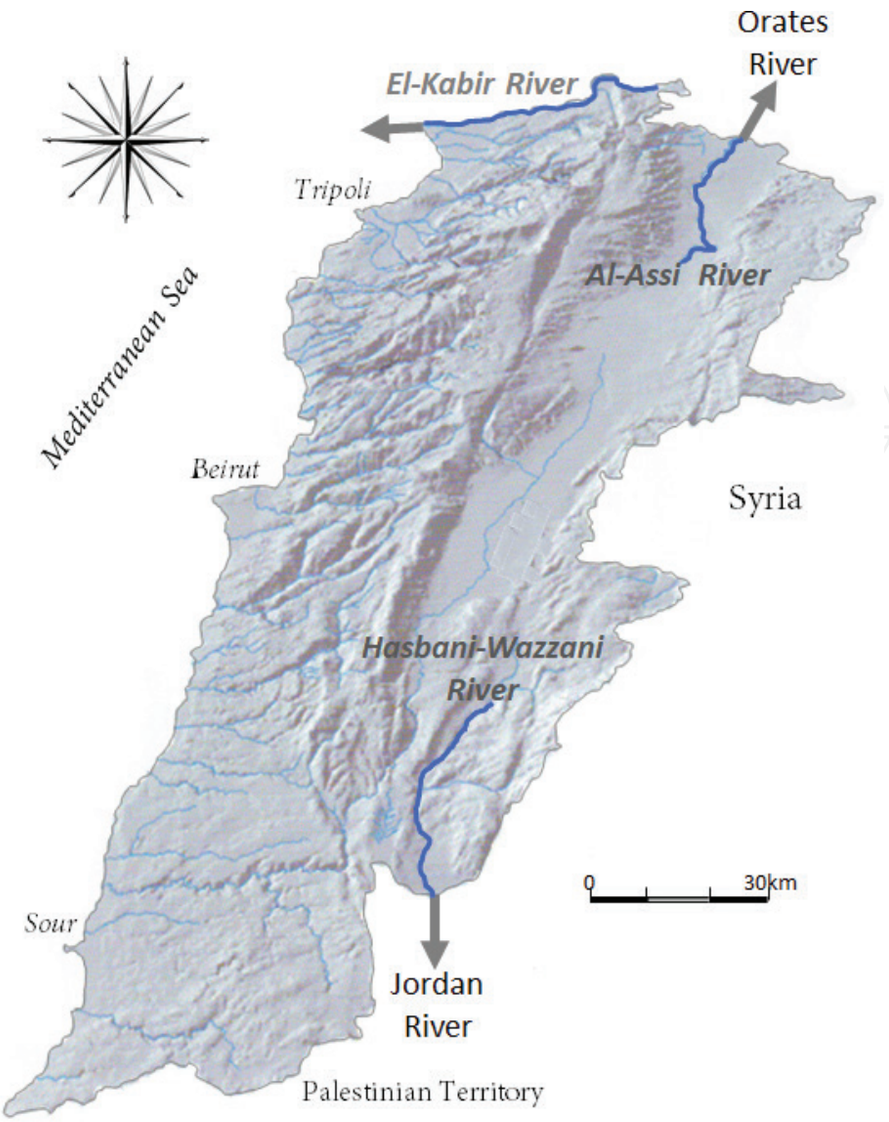


**Figure 5.**
*Transboundary rivers of Lebanon.*

## 4. Anthropogenic factors

There are several anthropogenic factors that play a significant role in increasing the impact of challenges on water resources, and these factors occur in Lebanon and remained untreated. However, the majority of anthropogenic challenges on water resources are represented mainly by the increased population and the related increase in water demands. This also results in many aspects of water deterioration (quantity and quality) and water loss due to the unwise use of these resources. Nevertheless, the anthropogenic factors that influence water resources can be resolved if consumers regulate their use of water and this in turn needs awareness and economic controls on water use.

### 4.1 Increased population

Normally, population size increases, but it would be wisdom to adapt the water use with the existing population size. In other words, the ratio of increase in population should be accompanied with more management approaches to have steady state of supply/demand. However, this is not the case in Lebanon where the increased population adds more stress on water supply.

The population growth rate in Lebanon is estimated at 1.1% [19]. This means that there is about 1.1% annual increase in demand for water and this also will be joined by additional human requirements. Of course, this will result in more water demand for different purposes, which is estimated at 12.8 million $m^3$/year for the whole country.

According to the estimated water demand in Lebanon, which is about 220 $m^3$/year/capita [20], this estimate will increase by about 2.5 $m^3$/year/capita. **Figure 6** reveals an example of the increased water demand integrated with the population density.

### 4.2 Unwise use of water resources

Due to the lack of awareness for wise-use of water resources in Lebanon, the existed water supply deficit often results negative behaviours of consumers. This is well pronounced in the agricultural sector (which accounts for about 70% of water use) where farmers often follow chaotic irrigation approaches. Therefore, uncontrolled digging for boreholes followed with extensive pumping has become a common observation. Pumping of water directly form rivers and springs is also widespread, and this has reflected in the loss of volume of water in surface water bodies and in groundwater reservoirs.

The unwise use of water resources in Lebanon accompanied with the lack of governmental controls have reflected in poor water quality and quantity, and thus several examples on water deterioration have been witnessed. The Litani River is one example where the water quality has been totally deteriorated and water volume has become minimal and therefore, the river is in jeopardy.

### 4.3 Lack of governmental controls

There is still a debate on the management status of water sector in Lebanon, notably that the country has witnessed several geo-political conflicts that have resulted in negative impact on water resources and the related sectors (e.g., agriculture, energy, and food). These conflicts have created distortion in most of the gauge stations (hydrological and meteorological), break down in the institutional framework, and ignorance of legislations to mitigate the encroachments on water resources, plus the lack of adaptation instruments to face the physical and man-made

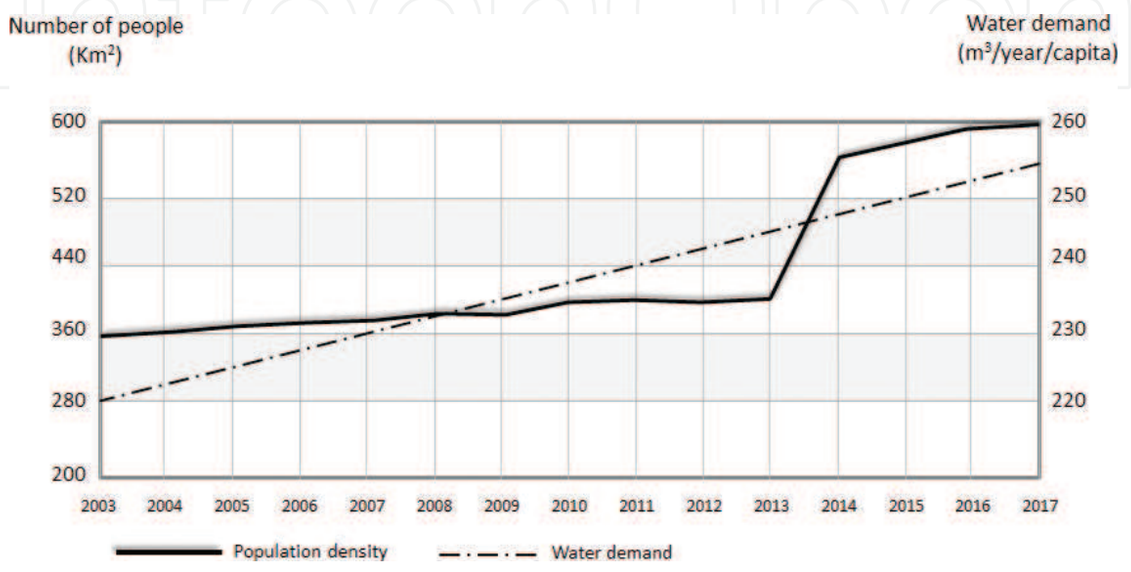


**Figure 6.**
*Population density and water demand in Lebanon between 2003 and 2017.*

changes, and certainly change in climate and new water demands. The unfavorable situation has made it difficult to implement any economic policy in order to regulate water consumption and collect financial resource to develop the water sector.

## 5. Conclusion and discussion

It is a paradox that the estimated water availability in Lebanon is about 1350 $m^3$/year, while the demand does not exceed 220 $m^3$/capita/year. Besides, water supplied by the government sector does not exceed 35–40% of the total demand, which is equivalent to about 83 $m^3$/capita/year [21]. The rest needed amount of water is often managed by the consumers, and this adds more financial commitments notably for the people with limited income.

The country is witnessing one of the most severe conditions in the water sector and challenges on water resources have been exacerbated day after day. The majority of challenges include: limited water supply and water impurity. Therefore, people in Lebanon are always complaining about water shortage as well as its quality.

Based on the analyzed data, the following is a summary on the challenges of water resources in Lebanon.

1. Challenges on water volume:

   - The decreased volume of discharge from rivers and springs (about 55–60%) and the lowering of lakes' capacity (up to about 65%) have resulted in shortage in water supply, which is estimated at 50–55%. This has obligated consumers to look for new supply sources (i.e., buying water) costing them 120–150$/month on average.

   - Groundwater volume in the major aquifers of Lebanon has declined by 35–40%. This implies lowering of water table (30–35 m) and decrease in its pumping rate. This makes it necessary to increase the depth of drilled boreholes in order to attain sufficient amount of water. Therefore, a cost of about 1500–2000$ has been added.

   - Most wetlands in Lebanon are dried or have lost their unique ecosystems to water deficit and climatic variability. This leads to loss of the economic value of these lands, especially most of them have become abandoned.

   - Water supply by the government sector is less than 35% of water demand and this has resulted in several financial and socioeconomic problems.

   - The decreased water level in the Qaraoun Reservoir, the largest artificial water body in Lebanon, by about 45–48% has affected the hydropower generation from the reservoir, estimated at 238 megawatt, which is equivalent to about 10.5% of electricity needs of Lebanon [1].

2. Challenges on water quality:

   - It can be said that water from all rivers in Lebanon is polluted. For example, heavy metals content is very high in the river where Cr is 5 times above the norms and Cu level 800 times than the norms [22]. The existing pollution makes it difficult to use river water for domestic use, and this was also compensated by looking for alternative sources of pure water.

- Groundwater contamination (biologicallyor chemically) is well pronounced, notably in shallow aquifers. Thus, most people fixed water filters, which has been lately become commercial issue.

- Surface water bodies are also contaminated. The Qaraoun Reservoir, the largest of its type in Lebanon, is witnessing severe quality deterioration, and thus toxic bacteria have been reported in the Qaraoun Reservoir [23].

3. Challenges in water-agricultural-food nexus:

   - There is a change in agricultural practices, mainly including planting of new crops that are tolerant to dryness, and this resulted problems in the agronomical marketing. The cost of many filed crops has been lately doubled.

   - Insufficient water motivated farmers to use excessive amounts of fertilizers and chemicals and this in turn added contamination to the shallow groundwater and then to crops. This influences the food security in Lebanon since 10–15% of these crops contain heavy metals [24].

   - Water deficit for irrigation, by about 30–40%, created unfavorable socioeconomic and demographic changes from the rural to urbanized areas, notably to the coastal zone which comprises more than 70% of Lebanon's population.

   - Insufficient water supply postponed several hydro-power stations in Lebanon.

Based on the existing challenges, however, the following recommendations can be suggested:

1. Awareness and advises for better use of water should be introduced to consumers.

2. The existing strategies (i.e., The National Water Strategy of Lebanon) and policies should be adopted.

3. Promoting alternative water sources with a special emphasis on water harvesting and the use of non-conventional water sources.

4. Coordination between different intuitions and government bodies related to water sector.

5. Adopting systematic water quality investigation on the major water sources and combating water pollution, notably in surface water.

6. Applying economic water policies (e.g., tariffs, water metering, etc.) to mitigate the chaotic and irresponsible use of water.

7. Adaptation instruments must be implemented for the changing climatic conditions and their impact on water resources.

8. Applying efficient irrigation system to reduce the amount of water used for irrigation.

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## Author details

Amin Shaban
Lebanese National Council for Scientific Research, Beirut, Lebanon

*Address all correspondence to: geoamin@gmail.com

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