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Physical and Anthropogenic Challenges of Water Resources in Lebanon

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Author's contribution

This whole work was carried out by the author AS.

Original Research Article

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ABSTRACT

Challenges of water resources in Lebanon are well pronounced. Even though sufficient water resources exist and high precipitation is often recorded, Lebanon's water is threatened by several physical and anthropogenic challenges that make it a country under water stress. This issue has been exacerbated in the last few decades. There are several studies, projects and even donations to enhance the status of water resources in Lebanon, but no remarkable progress has been achieved yet. This is attributed, in a broad sense, to unidentified figure of the hydrologic cycle accompanied with the lack of sufficient data and information upon which strategies and policies can be built for better management approaches. This study highlights the key issues of water problem in Lebanon including the existing challenges and their impacts. The existing challenges are not well understood by the decision makers, and often water shortage is attributed to undefined reasons. The approach in this study followed a number of indicative elements for data and information analysis. It utilized available records and time series, new techniques of remote sensing, as well as diagnosed previous studies and projects by the author. It introduces a clear understanding of the problematic issues of water resources in Lebanon, and then proposed the most applicable solutions for better stable water balance.

Keywords: Per capita; contamination; rainfall; mismanagement; Lebanon.

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1. INTRODUCTION

Along the eastern coast of the Mediterranean Sea, Lebanon is located and characterized by a mountainous terrain that makes it remarkable from the surrounding regions. It encompasses three major geomorphologic units; two uplifted mountain ridges forming the so-called Mount Lebanon to the west and Anti-Lebanon to the east, and the Bekaa depression in-between. The three units are oriented in NNE-SSW direction (Fig. 1), and then they extend parallel to the Mediterranean. They form a meteorological shied that capture wet air masses pushed by wind from west, thus resulting high precipitation rate (rain and snow) on the Lebanese mountains.

Water scarcity is becoming a problem across the globe due to increasing populations, land-use changes, as well as climate change and meteorological variability [1]. However, growing concerns on water scarcity and the resultant poverty and other social impacts require new approaches to manage water resources and the related resources, such as forests, agricultural lands, etc. Currently there is little science-based guidance for resource managers and policy makers to adapt to the novel and ever changing environment in the 21st century [2].

Similar to the neighboring regions, Lebanon is witnessing a problem in its water resources due to the dramatic increase in population size, as well as the effect of the changing climatic conditions. These conditions represent a global phenomenon and the whole globe is expected to face meteorological changes within the next few decades.

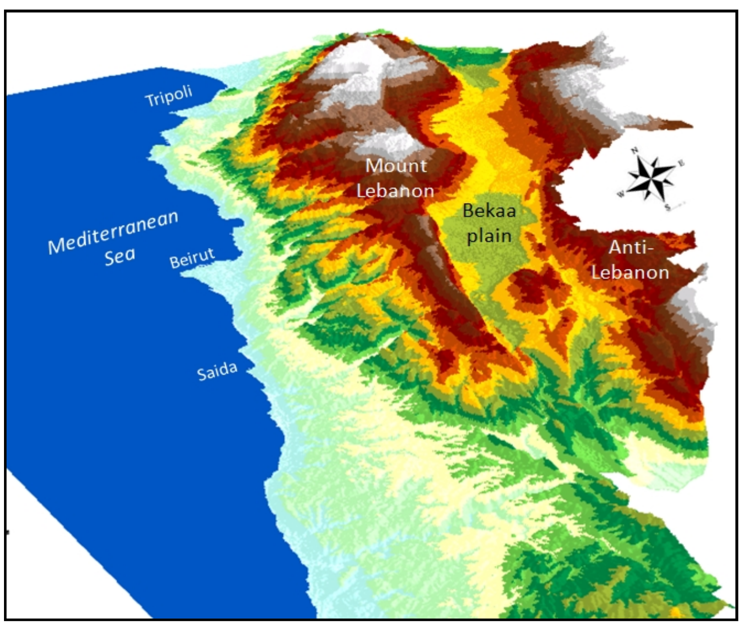

Fig. 1. The major geomorphologic slope units of Lebanon

Among the Middle East region, Lebanon is considered as water-rich country. This is a common criterion since the rainfall rate ranges between 700mm and 1500mm and there are several sources of surface and subsurface water. This is the reason why it was described as the "*Water Tower of the Middle East*". It is the only geographic location in the Middle East region where snow cover remains for several months on the mountain chains covering an average area of 2500km^2. In addition, Lebanon has 12 permanent water courses (rivers) that discharge about 3500 million m^3/year. There are also more than 2000 major springs with1250 million m^3/year, and the renewable groundwater reserve exceeds 1500 million m^3/year.

However, there is obvious water shortage which is still increasing in many regions in Lebanon. This is evident in decreased discharge in different water sources (surface and subsurface), which is mostly accompanied with quality deterioration. It has also reflected on decreased per capita, which was estimated at 40-50%. This conflicts with the fact that water availability in Lebanon is about 1350m^3/capita/year, while water demand is estimated at 220m^2/capita/year [1].

There are many challenges exist on water resources in Lebanon. These are either physical (natural) or anthropogenic (man-made), and both challenges are acting negatively on the volume and quality of water. Besides, there are no effective water management and adaptation measures applied to conserve water and to equilibrate water demand/supply. In this respect, there are several studies, projects, proposed plans and actions done. Nevertheless, the current status of water resources in Lebanon remains unsolved and it is still increasing, and thus it threatens water resources for the next few years; especially that the challenges are exacerbated lately.

This study shows a comprehensive view on the problematic aspects of water resources in Lebanon, including surface water and groundwater. The study discusses the elements of the physical and anthropogenic challenges. It relies on diagnosing the general status of the available datasets and information, either from previous records or from the newly advanced tools of analysis.

2. MATERIALS AND METHODS

The study employed empirical assessment and analysis of water resources in order to deduce the major water problems and explore what actions have been taken and their effectiveness. This established the basis for different solutions to be proposed. The following components of analysis were followed in this study (Table 1):

- Literature review and synthesis from previous studies and measures
- Data (records, measures, etc) analysis and interpretation
- Analyzing data from advanced techniques
- Field surveys on selective sites
- Comparing lessons learned in regions with similar water problems.

These components can also be used as templates in the assessment of scarce water resources. They join different aspects of data, information and applications in the trend of past, recent and future look at the water sector. Each component of analysis has several elements, thus, as much as these components are available, optimal outcomes can be reached (Table 1). Data and tools are the utmost significant in the assessment of water resources and in the identification of the fundamental water problems and their solutions.

2.1 Data Sources

Source of data and information on water is usually considered as the main constraint that often exists while making hydrological assessments. This can be attributed to several reasons. It is either due to the unavailability of data and measures, lack of sufficient instrumentations for measurement, or lack of coordination between different institutions which own data and records on water resources and the related disciplines.

Table 1. Major components of analysis used in water resources assessment

Component of analysis	Manifest	Optimal outcomes
Literature reviews and synthesis	- Previous studies, researches, etc. - Obtained implements, plans, executed projects - Proposed strategies and policies	Preparing inventory on water resources in the country
Data analysis and interpretation	- Climatic data on time series - Hydrologic records and measures - Maps analysis (including illustrators) - Obtained case studies on water resources - Numeric measures (e.g. water consumption population size, etc)	Making inventory on available data and information in order to be investigated. This enables identifying the current measures and their trends
Use of advanced tools	- New *in-situ* devices and instruments - Newly used laboratory techniques - Remote sensing and geo-spatial applications - Lunched web-data sources (e.g. rainfall data, models, scenarios, etc)	Utilizing new tools and techniques for better, comprehensive and precise results
Field survey	- Field studies obtained by the author - Results from previous field observations and investigations	Reporting and identification of creditable information and data as induced on ground
Comparing lessons learned*	- Successful studies and projects obtained regionally and globally - Identifying useful tools used in water resources protection - 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

**It can be integrated with expertise exchange and cooperative works.*

In Lebanon, the institutes which are concerned with data, information and records on water resources are well defined. However, they are characterized by diverse approaches of data acquisition and data ownership. These institutes, with respect to data acquired from them can be classified as follows:

1. Major data source: This describes the institutes which apply measurements and then produce and store data on water resources. They are completely concerned with water sector in the country. These are: Ministry of Power and Water (MoPW) and the complementary authority, such as Litani River Authority (LRA)

2. Supplementary data source: This is related with the institutes which are not primarily concerned with water resources, but are concerned with disciplines and issues that are directly related to water, but also sometimes apply measurements on water. In Lebanon, these can be: Ministry of Agricultures (MoA) and the related scientific institute, such as the Lebanese Agricultural Research Institute (LARI), Ministry of Environment (MoE) and General Directorate of Civil Aviation (DGAC).

3. Supporting data source: This described the institutes and entities which work or search in specific discipline or topic on water resources according to their concern. It includes universities, research centres (i.e. with a special focus on the Lebanese National Council for Scientific Research, CNRS), international agencies (e.g. ESCWA, UNDP, etc) and private companies.

Data acquired (fully or partially) from these sources were directly related to water measures, certainly for water in rivers, springs and in groundwater reservoirs, as well as the meteorological conditions, with a special emphasis on rainfall, snow and temperature. For example, there is a large dataset on hydrologic measures, which are adopted mainly from the Litani River Authority (LRA), including stream flow for all Lebanese rivers and for the major springs [3,4]. Datasets for rivers and springs are available since 1950's, and some of them since 1931. However, there are a number of gaps which were filled by applying statistical interpolations to create continuous time series.

Several datasets on hydrologic and climatic measures, almost for limited time periods, were adopted from many other sources. These are fundamentally from: the Climate Atlas of Lebanon [5-7]. General Directorate of Civil Aviation [8] and the Lebanese Agriculture Research Institute [9]. Other than datasets from the above institutes, a considerable data and information were taken from individuals who worked on research studies and scientific investigations and produced valuable measures, explanations and new methods and tools for analysis [10-14].

There are also several thematic data which were also used in studying water resources. These include mainly thematic maps (e.g. topographic, geologic, etc), which can be used to determine some parameters linked to water resources. They can be helpful in positioning surface water sources (springs, lakes, etc), drainage system, groundwater reservoirs, rainfall and evapotranspiration; in addition they can be indicative to many other thematic data. Thus, in Lebanon, topographic and geologic maps are often used in studying water resources. This is also the case for some pluviometric and hydrologic maps which were obtained for selected regions in Lebanon.

2.2 Supporting Tools for Analysis

Insufficient and incomplete data series frequently exist in the assessment of water resources and there is a difficulty in exchanging data between different institutions. In addition, some aspects of data are still difficult to be acquired by conventional methods. This makes the use of new techniques and methodologies necessary for better investigation and results. Hence, in this study three major supporting tools were applied including statistical analysis, space observations, as well as models accommodating Lebanon as a geographic component.

2.3 Statistical Analysis of Records

Usually statistical analysis is applied to diagnose datasets and information on water and climate. This enables deducing the behavior of numeric values, which are mostly volumetric measures, such as the discharge of rivers, springs, or the amount of rainfall. Therefore, statistical analyses explored the trends (e.g. descending, ascending, oscillating, etc). This in turn helped in applications to future scenarios and filled many items required to run models.
In Lebanon, there are several studies which applied statistical methods, but all these methods represent ordinary illustrations of curves and diagrams. There are several studies obtained in this regard [1] and [14 -17]. However, there are new statistical data analyses applicable to several hydrologic and climatic measures in Lebanon. These are a part of cooperative work between the Istituto di metodologie per l'analisi ambientale (IMMA), which is related to the Italian National Council for Research (Consiglio Nazionale delle Ricerche - CNR) and the Lebanese National Council for Scientific Research (CNRS), through the Center for Remote Sensing.

In this cooperative work, however, advanced statistical methods for datasets analysis were applied; and more specifically the use of de-compositional datasets techniques for a non-stationary and aperiodic signals. Since observational datasets in Lebanon are generally characterized by noise, uneven sampling and spikes, efficient algorithms are necessary to get as much information as possible. In particular, Singular Spectrum Analysis (SSA) and Fisher-Shannon and Detrending Fluctuation Analysis (DFA) were the major statistical tools used. They are applied in:

- Investigating the time dynamics of monthly rainfall time series observed in northern Lebanon [18].
- Analysis of spring flow time series: an application to Anjar Spring, Lebanon [19].
- Long-term Stream Flow Trend Analysis of the Litani River, Lebanon [20].
- Singular Spectrum Analysis to Diagnose Snow Cover on Mountain Chains in Lebanon [21].

From the applied methods, time gaps in datasets were deduced and the major peaks (for rainfall, stream flow and snow cover area) precisely identified among the big number of oscillations in the established illustrations of hydrologic/ or climatic data. An example in Fig. 2 shows the application of DFA for the rainfall data in Baalbak area (Central Lebanon). DFA is a statistical method able to reveal the presence of scaling behavior in non-stationary time series. If the scaling, which is represented by alpha (ὰ) is larger than 0.5 then the time series is correlated.

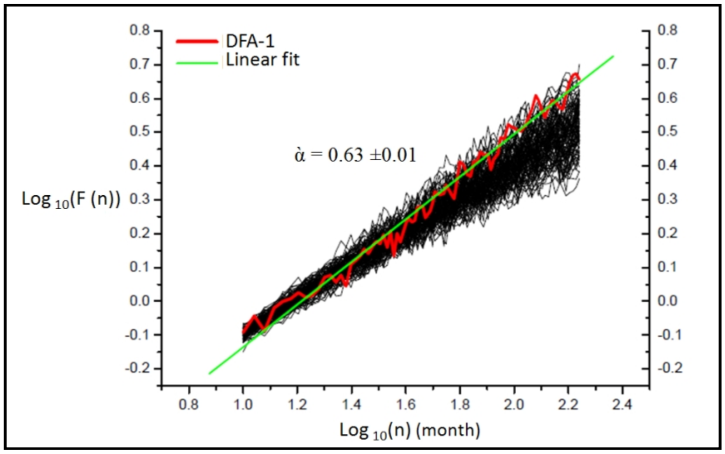

Fig. 2. Example for DFA-1 analysis performed on the Baalbak series [18]

For Baalbak, the time series is ὰ= 0.63, which is larger than 0.5; thus its scaling is significantly different from the randomness. So Baalbak time series is significantly correlated and this indicates the possibility of accurate prediction of rainfall behavior in the region as deduced from the datasets used.

2.4 Remotely Sensed Data

Space techniques in combination with different geo-information systems have become one of the most useful tools used in studying water resources and climatic measures. These techniques, which evidenced their power in many regions worldwide, can be used in several water disciplines including:

- Monitoring water bodies and determining their changing dimensions
- Land use changes and development in relation to water consumption
- Measuring land surface temperature and evapotranspiration
- Measuring precipitation including rainfall and snow cover
- Determining subsurface water flow direction and rate
- Groundwater exploration and subsurface reservoirs' identification
- Assessing water quality and contamination sources
- Studying natural hazards resulting from water, such as flood and erosion.

For this scope, satellite images of different optical and digital characteristics were commonly used. However, some specifications of the processed satellite images must be considered in retrieving meteorological and hydrological data as follows [2].

- Acquiring meteorological data needs satellites with short revisit time in order to have real-time or near real-time information, such as satellites of: WorldView-1 and Geostationary (once a day), AVHRR and MODIS (2 times per day), TIROS (4 times per day), Aster (16 days), etc.
- High frequency satellites are used in monitoring cloud masses distribution and rainfall amounts, such as TRMM (Tropical Rainfall Mapping Mission) system. This

satellite depends on Radar data acquisition and can capture meteorological data every three hours.

- Retrieve hydrologic data mostly needs high spatial resolution (capability to distinguish objects from space) satellites in order to identify water bodies. The commonly used satellites in this regard are of Landsat (30m), Aster (15m), SPOT (5m), Ikonos (1m), etc.

Usually, two principal characteristics (revisit-time and spatial resolution) are considered while selecting satellite images for further investigation on water resources. For example, MODIS and SPOT satellite images are used to monitor daily snow cover accumulation/melting [22]. In addition, some optical characteristics are needed for specific application on water resources assessment. For example, thermal differentiation may need to identify wetlands and this would be much useful if satellite images with a variety of thermal bands are processed, such as ASTER images which have five thermal bands.

Data provided from satellite images are also used to fill gaps that exist from ground records [2]. In addition, they can be utilized to integrate and compile data from different sources. Table 2 shows some examples of remote sensing applications on water resources and the related climatic parameters in Lebanon, which were accomplished by the author and they are found to be useful in providing valuable findings for better understanding.

2.5 Global Models

There are a number of hydrological and meteo-hydrological models applied to diagnose water balance, prediction and for understanding hydrologic processes. They are simplified, conceptual representations of a part of the hydrologic cycle. Two major types of hydrologic models can be distinguished:

- Stochastic hydrological models. These models are based on data and using mathematical and statistical concepts to link a certain input (e.g. rainfall) to the model output (e.g. discharge).
- Process-Based Models. They represent the physical processes observed in the reality (e.g. surface run-off, overland flow, evapotranspiration, etc). These models are known as deterministic hydrology models. Deterministic hydrology models can be subdivided into single-event models and continuous simulation models.

Outputs from General Circulation Models (GCMs) are often used in systematic methods for evaluating future available water resources. A distinction between hydrology and available water resources has been emphasized [23]. The former evaluates the total resource (naturalized river flow), whilst the latter requires the quantification of the exploitable amount.

Table 2. Selective studies on the application of remote sensing in water resources and the related disciplines in Lebanon

Title of the study*	Date	Reference
Investigating snow characteristics on mountain chains of Lebanon	2013	[22]
The Geological Controls of the Geothermal Groundwater Sources in Lebanon	2012	[24]
Analyzing climatic and hydrologic trends in Lebanon	2011	[2]
Support of Space Techniques for Groundwater Exploration in Lebanon	2010	[25]
Using MODIS Images and TRMM Data to Correlate Rainfall Peaks and Water Discharges from the Lebanese Coastal Rivers	2009	[26]
Use of Satellite images to identify marine pollution along the Lebanese coast	2008	[27]
The relation between water-wells productivity and lineaments morphometry: Selected zones from Lebanon	2007	[28]
Use of remote sensing and GIS to determine recharge potential zones: the case of occidental Lebanon	2006	[29]
Geologic controls of submarine groundwater discharge: application of remote sensing to north Lebanon	2005	[30]
Remote sensing application to estimate the volume of water in the form of snow on Mount Lebanon	2004	[31]

**These studies were obtained from the Lebanese National Council for Scientific Research, Remote Sensing Center*

Generally, most hydrological and climatic models are treated on continental or global scale rather the national (and local) scale, and this, in some instances, will not introduce much benefit for regions with small areas like Lebanon, which might be covered only by few pixels in a global model. However, in many cases downscaling is applied to convert large-scale data into small-scale ones, but this still does not fit the accuracy required from the results. The established models on hydrology and climate depend on digital programmes to develop a water database with hydrological modeling capability using remotely sensed data and Geographic Information System (GIS).

In Lebanon, hydrological modeling is either constituted as a part of applied global or regional models where Lebanon composes a small geographic unit, or they can be small-scale (local) models applied mostly on defined themes. They are obtained as statistical predications and future projections where hydrological processes are often linked with climatic parameters (Table 3).There are also a number of joint works between international and the Lebanese institutes on the application of models, scenarios and projections on water resources with respect to climatic changes and population growth. The majority of these applications are carried out with the CNRS, and more certainly with the Remote Sensing Center (Table 3).

Table 3. Selective models, scenarios and projections on the hydrology and other parameters in Lebanon

Title of application	Date	Theme	Reference
Climate change and water resources in the Middle East: vulnerability, socio-economic impacts, and adaptation	2001	Scenario (climate/water)	[32]
Integration of remotely sensed data with hydrological modelling of Mount Lebanon	2003	Hydrologic modelling	[33]
Modelling snow/water equivalent on the karstic mountain chains in Lebanon	2004	Hydrologic modelling	[34]
Climate Change Projection, Water Supply-Demand	2005	Projection (climate/water)	[35]
Volumetric snow modelling on the Lebanese highest	2006	Hydrologic modelling	[36]
Indicators and aspects of hydrologic drought in Lebanon	2009	Hydrologic assessment	[37]
Automated cartography and interpolation for the average rainfall in Lebanon	2010	Prediction (climate)	[38]
Using LDAS (Land Data Assimilation System) which rovides land surface states and flux	1. On-going	Hydro-climatic modelling	CNRS, GEF, WB, NASA,
Combining GRACE Satellite Data with Modelling for Aquifer Monitoring			
Modelling Climate Change Impact on the Water Balance of a Coastal Watershed in Lebanon	2011 to date	Hydrologic modelling	CNRS and IRSA*
Monitoring snow cover dyanamic on the lebanese mountain chains using remotely sensed data	2010 to date		CNRS and CESBIO**

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*** Centre d'Etudes Spatiales de la Biosphère, France.*

Yet, there is contradiction in the numeric estimates and future predictions from models, scenarios and projections in Lebanon as observed in many applications. This created non-creditability in the applied programs, which is attributed mainly to the lack of sufficient data available to run the models as well as to the contradictory in the applied methods and tools used. In this respect, the use of remotely sensed data and geo-information systems is utmost significant in providing and the manipulation of geo-spatial data and information. They can play a major role in the application of hydrological and climatic models.

2.6 Physical Challenges

In many regions of the world, there are many natural factors existing as constraints in the preservation of water resources. These are considered as physical challenges that must be well identified and then treated properly to reduce the negative impact on water resources whether on their volume or quality. This is commonly known in Lebanon where number of physical challenges occur and influence water regime from the source, through its flow and storage or outlets into the sea.

2.7 Morphological Aspects

The morphologic setting of Lebanon has a remarkable aspect since it posses mountain ridges with sharp peaks. These ridges are detached by several valleys, forming complicated morphological systems. The majority of these systems control the flow regime from the high mountain chains towards the plain along the sloping terrain.
There are three major geomorphologic units of slope in Lebanon that control surface water flow regime. These are shown in Fig. 1.

- Ordinary sloping terrain unit, which exists from Mount Lebanon towards the sea. The average slope gradient in this unit ranges between 80-180m/km, with and averaging120m/km.
- Steep sloping terrain unit, which occurs from Mount Lebanon towards the Bekaa plain. This is mostly with an average slope gradient of about 150-170m/km.
- Moderately sloping terrain unit, which occurs on the two flanks of Anti-Lebanon mountain ridges? The average slope gradient in this unit ranges between 70-100m/km.

In general, the terrain surfaces along the Lebanese mountain ridges are considered as sloping with almost steep gradients. This creates a significant challenge in increased water flow energy either to the sea, the Bekaa plain or the neighboring countries. This in turn results water loss either to the sea or to the neighboring countries before any proper investment can be applied. The detaching valleys also water it into their routes and then divert it into different directions as water loss. Most of these valleys are incident ones and characterized by steep channel slope.

The accelerated water flow, due to slope and incident valley courses, retards the percolation of surface water into substratum, and thus a large volume of water is being lost without natural recharge to groundwater reservoirs [11] .This is one of the most challenging issues, when surface water is lost along the Lebanese rivers and the intermittent streams. However, such challenge can be managed if surface water restrictions (i.e. harvesting) are built, such as dams, channels, lakes, etc.

2.8 Hydrological Aspects

The hydrologic challenges are governed, in addition to the morphologic setting, by the terrain materials, and more certainly the rock types. For example, steep sloping surface with impermeable rocks results to more water loss than steep surface with permeable rocks.

The hydrologic challenges in Lebanon include a miscellany of aspects, and they are considered the most significant difficult natural problems in its management. Therefore, the hydrologic challenges in Lebanon are:

1. Fracture systems: The complicated tectonic setting of Lebanon along the Dead Sea Rift System makes it an active tectonic unit. Therefore, Lebanon has pronounced by dense fracture systems (e.g. faults, joints and fractures) that cut among different geological rock formations. There are many studies that utilized thermal remote sensing or DEMs to identify the fracture systems (i.e. lineaments) of different scale (Fig. 3). Even though, these fracture systems can be considered as hydro geological routes along which groundwater may flow or store [28], yet they usually play a negative role when:

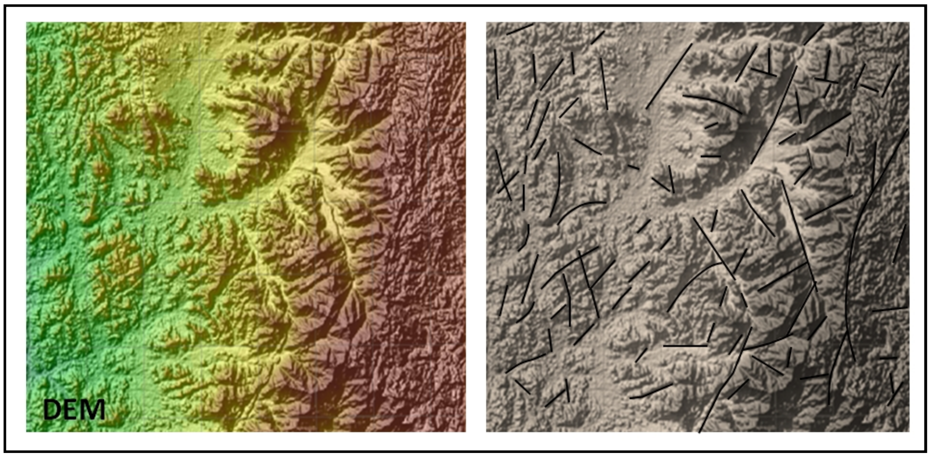

Fig. 3. Example of obtaining fracture map from DEMs (Fractures are show in black linears)

- They drain groundwater from the terrestrial aquifers into the sea, and then water loss occurs [25,30]
- Seeping groundwater to very deep (unreachable) aquifer.
- Leaking groundwater from the major aquifers into undefined systems.

Karstic galleries: These are well known hydrogeologic systems in Lebanon. They act in groundwater flow though subsurface routes, galleries, cavities and shafts of different dimensions, and then transport water several kilometers depth. In spite, these systems do not possess the same configuration as fractures, but they often play similar role in groundwater draining either to the sea (as invisible water routes) or into deep and very deep aquifers [11].

Karstic galleries usually encompass complicated an undefined systems, which makes it tedious to assess their routes and subsurface extent. This is a commonly known criterion by hydrogeologists. In Lebanon, studies on karstic systems are not adequate to present a clear hydrological concept about these systems, and this in turn composes a challenging issue, notably when management approaches for water conservation are proposed, such as in the case of artificial recharge or the tracing of groundwater alignments.

2.9 Climatic Oscillations

According to the GCM simulations, the Middle East region including Lebanon, is supposed to witness higher future temperatures resulting to increase in evapotranspiration and changes in climate patterns that might reduce rainfall in the region [39]. This is the current status in Lebanon where oscillations (or fluctuations) in the climatic behavior are well noticed, and thus create a problematic issue; especially when the meteorological parameters are not well defined.

Hence, climate modeling is still not fully understood, including cloud physics, aerosol effect, and atmosphere-ocean interaction among other processes [39]. However, if long-term data on rainfall-runoff correlation and basin water balance are not available, thus complex hydrologic models should be avoided [39,40].

Climate change assessment is often difficult due to data invariability, intermittent records, total lack of some effective meteorological measures (sunlight radiation, relative humidity, etc). This results to misunderstanding, and hence a difficulty in future water regime predictions. This is usually the case in Lebanon when projections, scenarios and models are applied.

There are many recent climatic concepts, such as the decreasing rainfall rate and increasing temperature [17]. This concept was not agreed by others who believe that rainfall rate in Lebanon is still constant, but there is a changing in the hydrologic regime [1].

2.10 Trans-boundary Water Resources

Even though Lebanon has a small land area of about 10,400 km^2; however, a large part of its water is shared with neighboring countries. Out of the total Lebanon's perimeter of 803 km, there is approximately 559km (67%) which is shared with Syria in the north and east; and 9km (11%) is shared with Israel in the south and partly in the southeast. The rest 235km extends adjacent to the Mediterranean Sea. In several localities; however, geographical landmarks such as mountains and valleys often coincide with political borders between the three countries [41].

The aspects of trans-boundary water resources in Lebanon can be summarized in Fig. 4. It shows the major surface and subsurface trans-boundary resources that shared with Syria and Israel. There are some hydrological aspects which are shared between Lebanon and only one of the two countries, such as Al-Kabir River; while other aspects extend further to other countries, such as the Orontes River and Wazzani Rivers, which originate from Lebanon to Syria and to Israel and then extend to turkey and Jordan, respectively.

It is clear that the three trans-boundary rivers originated from Lebanon, but they flow outside the country border. This is the case for the seasonal streams, which mostly originated from Lebanon and extend to the neighboring regions. This is due to the topographic setting of Lebanon.

It was estimated from the topographic maps (1:20,000) that more than 90% of the trans-boundary seasonal streams are shared with Syria and the rest with Israel, with almost similar percentage of shared springs with Syria (Fig. 4). While the average shared snowpack, as identified from satellite imageries (MODIS-Terra) is 81% and 19% with Syria and Israel; respectively.

The geological maps (1:50.000) in combination with high resolution satellite imageries (e.g. Aster, Landsat ETM, etc) provided information on the principal groundwater elements. Thus, the dimensions of groundwater reservoirs (aquifers) were estimated between Lebanon and the neighboring regions. This was also applied to linear geologic structures along which groundwater transport, and more certainly the fault systems and karstic conduits in which a major part is shared with Syria (Fig. 4).

From the above discussion on trans-boundary water resources of Lebanon, it is clear that large part of the Lebanese water resources is shared with the neighboring countries. It was estimated that between 25-30% of the Lebanese water resources are trans-boundary ones [42]. Among these shared resources, there are about 90% with Syria and 10% with Israel (Fig. 4).

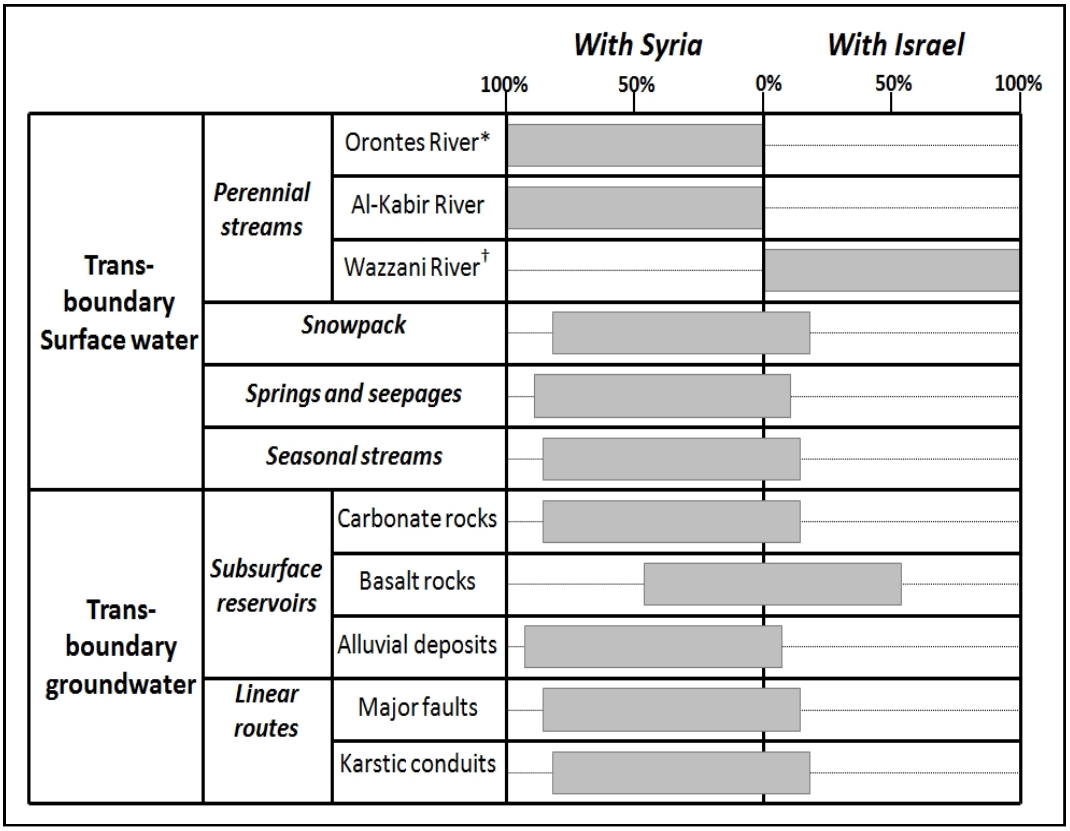

Fig. 4. Major trans-boundary water resources of Lebanon
**The river is shared between Lebanon, Syria and extends to Turkey.*
†The river is shared between Lebanon, Israel and extends to Jordan.

There is no convention or treaty for Lebanon's shared water resources, except one treaty between Lebanon and Syria, which was initiated in 1994 and concerned only the Orontes River, along which Syria executed five dams with total storage capacity of about 735m^3/year. In addition, there is still a clear ignorance on the Al-Kabir River, which extends along the northern border of Lebanon with Syria. This river remained uncontrolled, and therefore there is direct water pumping, sewage outlets into the river and many other aspects of water waste-use [41].

This is also the case in southern Lebanon, where El-Wazzani River, which originates in Lebanon, runs downstream without any volumetric or quality control. Therefore, conflicts often exist along this river between Lebanon and Israel, such as in 2002.

2.11 Anthropogenic Challenges

Usually the impact on water resources are directly linked to the changing climatic conditions and sometime to the other physical factors as previously mentioned. Nevertheless, the anthropogenic impact can be more influencing in changing the hydrologic regime, and thus in affecting the amount of available water and even its quality. Unfortunately, Lebanon became a typical example of negative human interference on water resources.

2.12 Increased Water Demand

Demand for water has been increased in Lebanon in the last few decades. There are several estimates for water demand in Lebanon. For example, the demand for water in Beirut was 30,50,84,112 and 200 l/day/capita for the years 1870,1912,1944,1959 and 2007; respectively [43]. While, the projections on water demand increase between 2000 and 2025 is estimated at 47% [40].

The available water per capita in Lebanon is about 1350m^3/year, while the need per capita is about 220m^3/year [2]. This reflects a surplus in the amount of water needed, but consumers are still complaining about water supply. Thus, increase in water demand in Lebanon can be attributed to a number of reasons as follows:

1. Population growth, which is known to be around 1% annually. This mean that about 9 million m^3 of water is additionally required every year. This is expected to increase in the future since some projections predicted an increase in the population of Lebanon from 6, to 8.1 and then to 12.1millions for the years 2015, 2030 and 2050; respectively.
2. Increased demand due to additional human requirements and this is attributed to new water requirements, such as increased car washing stations, touristic resorts, swimming pools, etc.
3. The existence of non-accounted-for-water, which has increased lately and attributed to water loss before any utilization, such as leakage of water due to old infrastructure.
4. Absence of legal controls on water supply (e.g. drilling boreholes, water meters, tariffs, etc) in Lebanon due to the political conflicts and instability; and this has several aspects. This results to lack of sufficient controls on the major natural water sources (Table 4).

Table 4. Major aspects of uncontrolled water sources in Lebanon

Source	Legal control	Implements	Impact*
River water	Locally controlled	Direct pumping and diverting water from upstream zones	High
Springs	Almost exists	Intensive exploiting of water directly from sources	
Mountain lakes		Direct pumping and diverting water from to lower lands	Moderate
Melting snow	Totally absent	Connecting tubes and thus diverting water to lower lands	
Snow packs		Excavation of snow to be collected in site for melting	Slightly high

*Estimated from field observations

2.13 Quality Deterioration

Water quality in Lebanon is a crucial and alarming issue that deserves concern. Thus, most of water sources in Lebanon are contaminated, notably the surface water sources. It is a major problem if the status quo on water quality in Lebanon remains without any rapid treatment. It is not exaggeration to say that more than 50% of the Lebanese water is contaminated.

There are many aspects of water quality deterioration in Lebanon, including mainly organic and chemical contaminations, as well as turbidity problems. This is well pronounced in river water, springs, lakes and reservoirs, as well as in well water.

There are many investigations on water quality of Lebanon, where most sources show unacceptable levels with respect to the international standards. For example, nitrate concentration in a number of wells located in the central part of the Bekaa plain exceeded 300 mg L^{-1} [43]. While the microbiological tests of the Litani River showed a Total Coliform (TC) exceeding 100000 c/ml and Faecal *Streptococcus* 7000c/ml in several localities. There is also the problem of heavy metals contamination in many river sediments, even though, the quality of snowpack was investigated and showed anomalous values (e.g., pH = 7.89; conductivity = 17.76 mS/cm; salinity = 11.22 ppm; 40300 ug/l).

Factors behind the quality deterioration in Lebanon's water are of two major aspects. These are the lack of awareness and the lack of appropriate management. This can be summarized as follows:

1. Lack to proper and new infrastructures to cope with new established human settlement.
2. Absence of waste disposal plans whether for liquid or solid wastes.
3. Let the replenishment areas of major springs unreserved.
4. Excessive use of fertilizers in cultivated lands.
5. There are tremendous solid wastes dumped on river banks and/or on rocks with high permeability property (i.e. fractured and karstified).
6. Lack of implementation of legislations and laws for environmental conservation.

2.14 Lack of Proper Management

Successful management of water resources has been witnessed in several regions worldwide even though these regions are characterized by unavailable water resources and they are located in arid and semi-arid zones. Thus, proper management can be the clue in solving many water problems and to face the existing challenges. Thus, problems of water resources are either due to the unavailability of these resources or due to mismanagement approaches used. Therefore, lack of proper management is considered as anthropogenic challenge since it is controlled by man.

Lebanon is considered as a region with available water resources, but complain about water still exists, and it is still increased. This status is always attributed to the political conflict in the country, but this is not very accurate concept. Yet, the applied management approaches are not effective enough. In this respect, several management plans and studies have been conducted in the water sector [44]. Nevertheless, implementations do not exist, because the responsibility, which must be a combined task between government and individuals, is not well determined.

There are several reasons behind the mismanagement in Lebanon. However, the main ones could be attributed to:

1. The lack of sufficient and updated hydrologic and climatic information and data.
2. Lack to sufficient financial resources dedicated for water sector and projects.
3. Fragmental responsibility and weak institutional cooperation.
4. Lack to confidence between the consumers and water sector, notably in the absence of legislations and governmental controls.
5. The political conflict in the country retards any progress in developing water plans or strategies.

3. RESULTS AND DISCUSSION

There are many challenges on water resources, and they differ according to the region where they exist. Some of these challenges are dealt properly and their impact could be reduced, but others are not and they remain as constraints on water supply. Thus, proper management approaches must be applied. Therefore, concerns for water resources raised as a global issue. The problem is exaggerated since water supply could not reach water demand. This is conflicting in a country like Lebanon where water resources must be plenty enough to cope with supply needs.

In Lebanon, several challenges exist and hindering water supply, and yet water supply shortage is increasing. d. They are not attributed only to the physical setting of Lebanon, as it is usually believed. For example, climate change exists everywhere in the Middle East region, but it is managed, and successful approaches are applied to reduce its impact on water resources, such as in the GCC (Gulf Cooperation Council) countries. This is also the case for groundwater reservoirs and many other water aspects which can play an integral role in the supply of sufficient water volume if they are correctly used.

There are many studies, projects and proposed plans and strategies applied on water resources in Lebanon. In addition, financial funds are often introduced by international and regional bodies and agencies to help Lebanon improve its water situation, but no remarkable improvement has been reported yet.

The challenges for water resources in Lebanon are still increasing. This study introduces a synthetic analysis of these challenges which are both of natural and anthropogenic origin. If these challenges are treated properly, thus water sector in Lebanon can be improved and better water supply can be attained.

Water resources in Lebanon have different aspects and they are tremendous. These are viewed from the volumetric measures, and more certainly from the precipitated water (rainfall and snow). Thus, the annual rainfall rate in Lebanon (950-1000mm) has not been remarkably affected by the changing climatic conditions, except a little decrease which does not exceed 40mm over the last four decades. Also, the snow, which is considered as a principal water-feeding source, still covers vast areas of the Lebanese mountains, and no significant decline in snow cover area reported according to by satellite images observations. Moreover, the last three years showed unusual snow cover that exceeded two/third of the Lebanese territory.

The assessment of physical and anthropogenic challenges needs to utilize advanced and creditable tools and methods. Each challenge is usually treated separately after analyzing its acting components. Therefore, there are new techniques applied in Lebanon with professional experts to diagnose different aspects of challenges of water resources. They could significantly be used, notably when they properly utilized, such as the new laboratory tools, new field devices, remote sensing and geo-information system (GIS). Nevertheless, non-professional experts in the field of water resources must not be involved in studies and investigations on water resources, as it happens, in order to avoid conflicts on the understandings and concepts.

Identifying the challenges of water resources and their impact, as well as their trends and the factors of influence will help introducing appropriate solutions. The treatment of the existing challenges is different between those resulted from natural regime and those from negative human interference. Therefore, it is obvious that the management of anthropogenic challenges is much easier than physical ones. This in turn needs awareness from the inhabitants and effectiveness from the decision makers on water sectors.

According to the synthesis obtained in this study and in previous studies done by the author; however, there must be rapid solutions and then implementations to be taken for the existing challenges. This in turn will help in introducing first-hand information for better water resources management in Lebanon (Table 5).

Table 5. Major water challenges in Lebanon and their proposed solutions

Challenge	Aspects	Major element of impact	Key problem	Proposed solution
Physical	Morphological aspects	High flow rate	Water loss to the sea	- Building dams and channels - Non-conventional method of rain water harvesting - Convey water between different basins
	Hydrological aspects	Fractures and karstic galleries	Water loss to deep aquifers and into the sea	- Exploring groundwater potential zones - Applying artificial recharge - Assessing fracture system orientations in relation to groundwater
			Missing hydrogeologic routes	- Emphasizing studies on karst hydrology - Applying tracing and isotope methods
	Climatic oscillations	Lack of data	Poor climatic assessment	- Applying new statistical interpolation methods
		Unidentified climatic regime	Obscure future implementation	- Use of remotely sensed techniques - Applying creditable and successful models and scenarios
	Trans-boundary water	Shared surface water Shared groundwater	Water loss to the neighboring regions	- Building up comprehensive assessment on shared water (volume and quality) - Establishing international treaties. - Applying international water conventions

Anthropogenic	Increased water demand	Population growth Increased requirements	Shortage in water supply	- Applying awareness campaigns - Wastewater treatment and reuse. - Following new policies in water sector, such as water-meters, supply control, tariffs, etc
	Quality deterioration	Contaminated water resources	Non-secured water quality	- Establishing environmental legislations - Following periodic water testing - Environmental ethics must be considered by individuals
	Lack of proper management	Lack of control and implementation	Absence of plans and strategies	- New water strategies should be implemented - Applying water projects according to successful applications worldwide - Benefit from new techniques on water resources and skills available

4. CONCLUSION

There are many challenges of water resources and, and they represent constraints for water supply management. In some countries, these challenges are well treated, but they are not so in others, especially the physical ones, which are not under direct human control.

The best approach is to treat (i.e. solve) each aspect of the challenging issues separately. This can be well obtained for the anthropogenic ones. For example, applying strategy for wastewater treatment or quality control will be a tangible solution to face water quality challenge. There are many successful stories in this respect. Consequently, all these solutions can be integrated to reach a comprehensive solution for water resources management.

In Lebanon, there is no complete solution applied for any aspect of the existing challenges. This makes the problem of water increasing and developed, notably that the physical challenges are out of control. Water shortage in Lebanon; therefore, is exaggerated since water supply could not reach water demand. This is conflicting in a country like Lebanon where water resources must be plenty enough to cope with supply needs. This is well evidenced since the required amount of water per capita in Lebanon is about 220m^3/year, while the available water amount is about six times this amount (i.e. 1350m^3/year). It is also clear the water availability in Lebanon is still above the water-stress threshold, which is estimated at 1000m^3/year.

This study differs from many other applied studies on water resources in Lebanon in that it discussed all the problematic issues facing the water sector, the so-described water challenges. It divided them according to their origin, and it represents an inventory that highlights the key issues on water resources in Lebanon.

It is therefore recommended to specify the challenges of water resources in Lebanon after utilizing from the current study as first-hand information. Consequently, outline for best solution of each challenge threatens water supply must be identified. This can be applied along two schemes; first, is the technical one, which can be empowered by using advanced techniques for analysis in water resources issues, such and new sophisticated devices and laboratories, as well as monitoring systems, like those of remotely sensed techniques. The second scheme implies the enhancement the human knowledge and understanding on water resources including consumption and conservation approaches. If these indicative points are well applied; therefore, optimal solution for water supply can be reached.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. IPCC. Climate Change: Synthesis Report - An Assessment of the Intergovernmental Panel on Climate Change; IPCC Plenary XXVII: Valencia, Spain; 2007.
2. Shaban A. Analyzing climatic and hydrologic trends in Lebanon. Journal of Environmental Science and Engineering. 2011;3(5).
3. LRA. Litani river authority. Unpublished Report. 1970;23p.
4. LRA. Litani river authority. Unpublished Report. 2012;29p.
5. CAL. Atlas Climatique du Liban. Tome 1. Service Météorologique, Ministère des Travaux publics et Transports. 1971;45p.
6. CAL. Atlas Climatique du Liban. Tome 1. Service Météorologique, Ministère des Travaux publics et Transports.1973;31p.
7. CAL. Atlas Climatique du Liban. Tome II. Service Météorologique, Ministère des publics et Transports. 1980;40p.
8. DGAC. Direction Générale de l’Aviation Civile. Rapport annuel, Beyrouth, Liban. 1999; 32p.
9. LARI (Lebanese Agricultural Research Center).Climatic Data. Monthly Bulletin;1965.
10. Ghaddar, N. Climatological data. Monthly Bulletin. American University of Beirut. Lebanon; 2003.
11. Shaban A. Etude de l’hydroélogie au Liban Occidental: Utilisation de la télédétection. Ph.D. dissertation. Bordeaux 1 Université. 2003; 202p.
12. Saadeh M, Semerjian L, Amacha N. Physicochemical Evaluation of the Upper Litani River Watershed, Lebanon. The Scientific World Journal. 2012;462-467.
13. Darwich T, Shaban A, Portoghese I, Vurro M, Khadra R, Saqllah S, Drapeau L, Gascoin S, Amacha N. Using remotely sensed data to induce snow cover dynamics and water productivity for sustainable water management in Ibrahim River Basin, Lebanon. First CIGR Inter-regional Conference on Land and Water Challenges, Bari, Italy. 2013;10-14 September.
14. Ramadan H, Beighley R, Ramamurthy A. Temperature and Precipitation Trends in Lebanon’s Largest River: The Litani Basin. J. Water Resour. Plann. Manage. 2013;139:86–95.
15. Abd EL-Al, I. Statics and dynamics of water in the Syro-Lebanese limestone massif. Ankara symposium on arid zone hydrology, Ankara, Turkey, UNESCO. 1953;60-76.
16. Karam F. Climate change and variability in Lebanon: Impact on land use and sustainable agriculture development. Unpublished Report; 2009, Available on: http://www.fao.org/sd/climagrimed/pdf/ws01_24.pdf
17. Bou Zeid E, El-Fadel M. Climate change and water resources in Lebanon and the Middle East. Journal of Water Resources Planning and Management. 2002;128:5(343),343-355.

18. Lovallo M, Shaban A, Darwich T, Telesca L. Investigating the time dynamics of monthly rainfall time series observed in northern Lebanon by means of the t detrended fluctuation analysis and the Fisher-Shannon method. Acta Geopysica; 2013; DOI: 10.2478/s11600-012-0094-9.
19. Telesca L, Lovallo M. Shaban A, Darwich T, Amacha N. Singular spectrum analysis and Fisher–Shannon analysis of spring flow time series: An application to Anjar Spring, Lebanon. Physica A. 2013;392,(17)17,3789-3797.
20. Shaban A, Telesca L, Darwich T, Amacha N. Long-term fluctuations in stream flow time series: an application to the Litani River, Lebanon. 2013, Accepted to Acta Geophysica.
21. Telesca L, Shaban A, Drapea[3] L, Darwich T, El Hage M, Faour G. Use of Singular Spectrum Analysis to diagnose snow cover on mountain chains in Lebanon. submitted to Hydrology Science Journal. 2013;(b)
22. Shaban A, Darwich T. Investigating snow characteristics on mountain chains of Lebanon. First CIGR Inter-regional Conference on Land and Water Challenges, Bari, Italy. 20013;10-14 September.
23. Beran MA. The water resources impact of future climatic change and variability. In: Effects of Changes in Stratospheric Ozone and Global Climate. Vol. 1. J.G. Titus (ed.). US EPA/UNEP, Washington DC. 1986;299-328.
24. Shaban A, Kayrouz-Khalf L. The Geological Controls of the Geothermal Groundwater Sources in Lebanon. International Journal of Energy and Environment (IJEE). 2012; (Accepted).
25. Shaban A. Support of Space Techniques for Groundwater Exploration in Lebanon. Journal of Water Resource and Protection. 2010;(5):354-368.
26. Shaban A, Robinson C, El-Baz F. Using MODIS Images and TRMM Data to Correlate Rainfall Peaks and Water Discharges from the Lebanese Coastal Rivers. Journal of Water Resource and Protection. 2009;(4):227-236.
27. Shaban A. Use of Satellite images to identify marine pollution along the Lebanese coast. Environmental Forensics Journal. 2008;9:205-214.
28. Shaban A, Farouk El-Baz and Khawlie, M. The relation between water-wells productivity and lineaments morphometry: Selected zones from Lebanon. Nordic Hydrology. 2007;38(2):178-201.
29. Shaban A, Khawlie M, Abdallah C. Use of remote sensing and GIS to determine recharge potential zones: the case of occidental Lebanon. Hydrogeology Journal. 2006;14(4),433-443.
30. Shaban, A., Khawlie, M., Abdallah, C., and Faour G. Geologic controls of submarine groundwater discharge: application of remote sensing to north Lebanon. Environmental Geology. 2005;47(4):512-522.
31. Shaban A, Faour G, Khawlie M, Abdallah C. Remote sensing application to estimate the volume of water in the form of snow on Mount Lebanon. Hydrological Sciences Journal. 2004;49(4):643-653.
32. El-Fadel M, Bou Zeid E. Climate change and water resources in the Middle East: vulnerability, socio-economic impacts, and adaptation. The Fondazione Eni Enrico Mattei Note di Lavoro Series Index ; 2001.
    Available at: http://www.feem.it/web/activ/_activ.html
33. Corbane C, Somma J, Bernier M, Fortin P, Dedieu P, Gauthier Y. Application d'un modèle d'estimation de l'équivalent en eau du couvert nival à partir d'images RSO de radarsat-1 en montagne libanaise. Télédétection. 2004;4(1):481–498.
34. Khawlie M, Shaban A. Applicability of climate research and information for water resources management in semi-arid and arid regions. UNESCO-WCRP. 2005;Cairo, April18-20.

35. Somma J, Luxey P. Modélisation volumique des névés sur les hauts plateaux karstiques du Mont Liban. Actes de la conférence WATMED3. 2006;1-3Nov. 06, Tripoli, 11p.
36. Shaban A. Indicators and aspects of hydrological drought in Lebanon. Water Resources Management Journal. 2009;23:1875-1891.
37. Makké TM, La pluviometrie moyenne annuelle au Liban, Interpolation et cartographie automatique, Lebanese Science Journal. 2010;11(2),2010,11-15p.
38. Intergovernmental Panel for Climate Change, Working Group I (IPCC-WGI). Climate change 1995: The science of climate change, Cambridge University Press, Cambridge, UK; 1996 (a).
39. Economic and Social Commission for Western Asia (ESCWA). Updating the assessment of water resources in ESCWA member states. Report E/ESCWA/ENR/1999/WG.1/WP.3, Beirut, Lebanon;1999.
40. Shaban A, Darwich T, Hamze M. Assessment of Lebanon's shared water resources and the need for effective cooperation. International Year of Water Cooperation; 2013.
41. Shaban A, Douglas E. Trans-boundary Water Resources of Lebanon: Monitoring and Assessment. The Regional Meeting on Water in the Mediterranean. Near East University, North Cyprus, 9-11 October; 2008.
42. Fawaz M. Towards a water policy in Lebanon. A book published by ESIB (In Arabic), Beirut, Lebanon. 2007;259p.
43. Darwish T, Atallah T, Baydoun S, Jomaa I, Kassem M. Environmental risk of nitrate accumulation in the soil-groundwater system in Central Bekaa Valley, Lebanon;2008.
44. Zdruli P, Costantini E. Moving ahead from assessments to actions: Could we win the struggle with land degradation?. Book of Abstracts. 5th International Conference on Land Degradation. Bari-Italy 18-22 September: 2008;499-503.

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