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Indicators and Aspects of Hydrological Drought in Lebanon

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Abstract Change in climate conditions has become a global issue that has given a serious concern by many researchers. However, the availability of data in this regard is considered as a major element for optimum comparative analysis. The Mediterranean region is influenced by climate change, which is reflected mainly by its impact on water sources supply and flow regime. In Lebanon, these water sources are witnessing obvious quantitative decrease, thus affected the supply side, the so-called "hydrologic drought". Therefore, many studies have been made to figure out a comprehensive understanding on water resources in Lebanon and their interrelation with climatic trends, but they often analyze one component of the water cycle. This study involves different indices of surface and subsurface water, thus, followed a comparative analysis of different hydrologic records. This was achieved by applying graphical illustrations of the numerical values adopted from available records. In this regard, different tools of analysis were used, and more certainly remotely sensed data were helpful for monitoring approaches. Therefore, results of the obtained comparative analysis revealed a clear regression in the amount of available water from different sources in Lebanon. These sources, which are under the impact of human like rivers and groundwater, showed a 23–29% decrease in the amounts of water since the last four decades. While sources, with less human interference, like snow cover and precipitation have been decreased by 12–16%. However, in both cases, the status is quite alarming and needs immediate water management plans to conserve water resources in Lebanon.

Keywords Climate change · Rivers · Drought · Remote sensing · Lebanon

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1 Introduction

In the last few years, the issue of climate change has been raised as a major global topic that has existed in many regions of the world. In this view, several human implements to assess and mitigate its impact have been applied, with particular concern to sensitive areas. However, a variety of models and scenarios have been made using different approaches of analysis to assess climatic trends in space and time. Such as those models obtained to prescribe sea surface temperature (SST) (Harvey 2004; Douville 2006) and CO2 and aerosol emissions (Douville 2005).

Likewise many regions in the world, the Mediterranean region is witnessing the impact of change in climatic components, which is mainly reflected by remarkable decrease in water availability. It is reported that in the Mediterranean, rainfall is now 20% less than at the end of the nineteenth century (Ragab 2005). Hence, rapid growth in population and industrialization are imposing rapidly growing demands and pressures on the water sources, thus the demand in the twentieth century has increased by 60% in the last 25 years. Also, in a short period of one generation, in a country after the other, the picture has changed from one of relative abundance to one relative sacristy (Hamdy and Lacirignola 2005). Thus, water shortage is essentially resulted and thus refereed as a “Drought” phenomenon. This phenomenon occurs in virtually all climatic zones, but its characteristics vary significantly from one region to another. Drought makes it difficult to determine its onset and end, hence, it is considered as a creeping phenomenon of natural hazards.

Similarly to the phenomenon of desertification, drought should not be viewed merely as a physical phenomenon; however, it is the result of interplay between a natural event and the demand placed on water supply by human-use systems. It works as a long-term natural hazard, and it is negatively reflected on significant economic, environmental, and social aspects. Thus, it is among the most complex and least understood of all natural hazards. If drought is considered as a part of desertification phenomenon, it is certainly an alarming geo-environmental issue since desertification occupies around 68% of the Arab World (Abahussain et al. 2002).

In general, climatic variability expresses the initial stage of drought, thus creates two major meteorological elements. These are: (1) precipitation decrease over an extended period of time including volume, intensity and timing, and (2) increase in temperature, wind velocity and sunshine, and decrease in relative humidity and cloud cover.

The phenomenon of drought is considered relative to some long-term average conditions of water productivity and balance between precipitation and evapotranspiration in a particular area. The frequency and severity of hydrologic drought is often defined on a watershed or river basin scale (Monacelli 2005). Timing is also another major component in a drought condition (i.e., principal season of occurrence, delays in the start of the rainy season, occurrence of rain periods in relation to principal crop growth stages) and the effectiveness (i.e., rainfall intensity, number of rainfall peaks) of the rains. Other climatic factors such as high temperature, wind, and low relative humidity are often effective and can significantly aggravate its severity.

Considering it at a national scale, water resources in Lebanon have more today than they are capable to manage through deficiencies. Other states such as Jordan and Palestine are presently consuming about 15% more than the annual renewable water (Amery and Wolf 2000).

Even though, they are limited; however, all obtained studies and scenarios on water and climate regimes indicate the drought condition in Lebanon. It is directly viewed from the change in climate trends and certainly in the decrease in the amount of water from different sources. Adding the rapid increase in population size to these conditions, the result is a shortage in water supply per capita. The built scenarios by UN (1994) showed that human quota of renewable freshwater water in Lebanon will be declined from 1,900 to 1,100 m^3/year between 1990 and 2025.

The present study aims to analyze the trends of climatic and hydrological elements and thus to figure out the indicators of hydrologic drought in Lebanon. These trends will be established depending on the available data records. The development of remotely sensed techniques added an essential role in data sampling. Therefore, they were utilized in this study and proved their benefit in this application.

1.1 Concept and Indices of Hydrologic Drought

Drought has given many classifications to categorize it into different types. Thus, four major ones were resulted. These are: hydrological, meteorological, agricultural and socioeconomic. However, all these types are tightly related with water and attributed in a broad sense to climate change. It is agreed that the initial process of climate change is created as a result of negative human activities. These activities are represented mainly by gases from different industries, wood cut (forest logging), smoke from engines, etc. Thus, they influenced the ozone layer and cause severe ozone depletion.

The change in climatic conditions is reflected mainly by the decrease in precipitation rate and increase in temperature, thus followed by shortage in water supply. These types exist in a sequential physical processes that often perquisite each other (Fig. 1).

Several definitions existed to describe the hydrologic drought. However, the most precise one was stated by Tallaksen and van Lanen (2004). They described the hydrological drought as a sustained and regionally extensive occurrence of

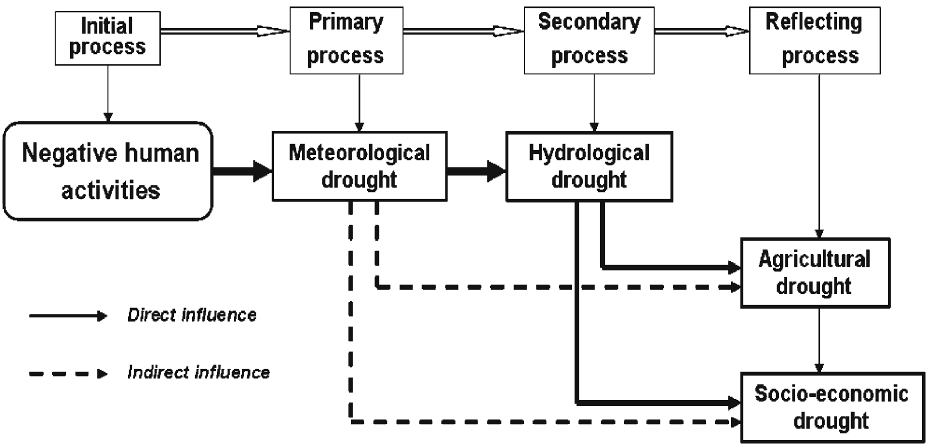

Fig. 1 The sequence of drought processes and its major types

below average natural water availability. Whilst, Yevjevich et al. (1977) defined the hydrological drought as a period of time below the average water content in streams, reservoirs, ground-water aquifers, lakes and soils. This period is associated with effects of precipitation (including snowfall) shortfall on surface and subsurface water supply, rather than with direct shortfalls in precipitation. This made hydrologists are more concerned with how this deficiency plays out through the hydrologic system.

Monitoring hydrologic drought mainly needs controlling indices of change in water storage among different hydrologic systems. A variety of indices for characterizing hydrological drought have been devised (Nalbantis and Tsakiris 2008). These indices can be viewed from the volumetric estimates in both surface and subsurface water sources, which are directly influenced by climatic conditions and human exploitation. Identification of these indices helps characterizing drought condition spatially and temporally as well as its intensity, duration, and severity (Redmond 1991). Each of the indices has different description with respect to water shortage.

There are seven major hydrologic drought indices (Table 1). Among these indices precipitation often included as a major component, though it is attributed, by some researchers, to meteorological indices. However, it is referred in study to hydrologic indices because it is an integral component the hydrologic cycle and has a major

Table 1 Major indices of hydrologic drought

Index	Elements	Criteria
Precipitation	Volume	Long-term decrease in rate
	Intensity	Intensive rainfall peaks
Rivers and stream	Stream course	Shallow water level
		High chlorophyll (and pollutants) content
		Low transported bed load
	Discharge	Decrease in discharge at outlets
		Low water velocity
	Length	Decrease in total tributaries length
		Intermittency in water flow in some courses
Spring	Discharge	Decrease in discharge
		Quality deterioration
	Permanency	Total disappearance of some springs
		Discharge intermittency
Lake and reservoirs	Water level and quality	Lowering in water level
		Surrounded by mud cracks and sediments
		Quality deterioration
Snow	Areal coverage	Decrease in areal coverage
		Low geographic distribution
		Lower snowfall frequency
	Thickness & density	Lowering in thickness
		Lowering in density
Groundwater	Pumping	Decrease in yield from wells
		Flow intermittency
		Quality deterioration
	Water table	High depletion in water level
	Water quality	Saltwater intrusion
Soil moisture	Water content	Decrease of water content below normal level

role in water regime. Accordingly, particular indices of hydrologic drought exist in specific regions. In other words, not all indices exist in the same region. For example, snow cover can be considered as a drought index in some regions like Lebanon, but it would not be so where it does not exist like Egypt.

The analysis of drought indices follows many approaches, but some of them depend on mathematical equations to attain numerical values, thus induce the existence of drought and its magnitude of impact. The major known measures of these indices are:

– Percent of Normal: and it is computed by dividing the actual precipitation by the normal precipitation, which is typically considered to be a mean of 30-year (Monacelli 2005). It is expressed by the following equation:

$$\mathrm{I}=\frac{\langle P\rangle}{\langle P\rangle_{30}}\times 100$$

Where value of the index less than 100 means drought conditions exist
– Deciles: in which the distribution of the time series of the calculated precipitation for a given period is divided into interval each corresponding to 10% of the total distribution (*decile*). In this respect, Gibbs and Maher (1967) proposed to group the deciles into classes of events.
– Palmer Hydrological Drought Index (PHDI): which integrates water supply (precipitation) with water loss (evapotranspiration as computed from temperature) in a soil moisture model (Palmer 1965),
– Standardized Precipitation Index (*SPI*):
– Surface Water Supply Index (SWSI): is developed by Shafer and Dezman (1982) to complement Palmer index for moisture conditions, which is applied mainly to homogenous region and does not apply to snow. SWSI is designed for surface water as mountains-water dependant, in which snow pack is a major component.

The optimum period to be used in assessing hydrologic drought must represent long term interval (e.g. several decades). Whilst, analyzing drought only through a couple of months as applied in some studies (Sibai and Jinad 2005) does not reveal a comprehensive and perfect figure, especially drought is a creeping natural hazard. Moreover, all available indices must be integrated while assessing drought condition.

2 Tools and Data

Normally, in studying the hydrologic drought data availability is of great important to attain a perfect figure on climatic and hydrological regimes. The most common and typical tools are:

1. Rainfall gauges in several representative sites with a uniform geographic distribution to measure precipitation rate,
2. Hydrographs and flow-meters on rivers and springs watercourses to record water discharges measures,
3. Scale-levels to measure water level in lakes and ponds,
4. Using remote sensing data (Radarsat, NOAA, MODIS, etc) to monitor snow coverage. This can be also applied to monitor changes in the areal extent of lakes and wetlands,

5. Manometers to measure groundwater level in aquiferous rock formations, and water table measures in drilled wells,
6. Available equipments and laboratory testing to measure soil moisture.

Accordingly, error may exist while recording hydrologic data. This error is due to the human interference. For example, measuring stream flow at the outlet (stream mouth) may be influenced by direct water pumping upstream This may conflict assessing the exact decrease in stream flow, which in this case, attributed mainly to human exploitation and not to climate change.

In Lebanon, there is intermittency in some measures for drought indices. Thus, lack for sequential records and limitations of dates often exist (Table 2). While, some data are not completely available, like that for soil moisture except for limited sites and specific times.

3 Method of Analysis

The assessment of hydrologic indices in this study was achieved mainly by expressing the numerical values, from available records, into graphical relations and on time series. This enables to attain a comprehensive figure of trends for different hydrological indices. The approaches/and tools of data collection are different from one index to another (Table 2). It is obvious that the role of remotely sensed data was essential to fill the gaps in the available records, as well as this data capable to make measures', which is not easy to be done by conventional tools. Thus, the applied approaches combine between conventional methods.

Table 2 Tools and available data for hydrologic droughts indices in Lebanon

Index	Elements	Tool	Available output	Date
Precipitation	Volume	Gauge stations	Records and graphs	1967–2006
	Intensity	Gauge stations and TRMM	Records and maps	1998-to date
Rivers	Discharge	Flow-meters	Records and graphs	1965–2006
Spring	Number of springs	Topographic maps	Desk study	1963–2005
	Discharge	Flow-meters	Records and graphs	1965–1999
Lake and reservoirs	Number of lakes	Topographic maps and aerial photos	Desk study	1963–2005
	Areal extent	Satellite images	Non-continues measures	1973–2005
Snow cover	Areal coverage	Satellite images	Maps and images	1973–2007
Groundwater	Pumping	Well testing and measure records	Discharge, depth and steady state flow	No regular and continues measures
	Water table			
	Water quality			
	Submarine springs	Airborne survey	Radiometric images	1973 and 1997

TRMM Tropical Rainfall Mapping Mission extended by NASA

Table 3 Tools and data availability for hydrologic droughts indices in Lebanon

Year	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Precipitation (mm)	967	1,120	1,023	987	1,021	1,103	1,054	1,034	956	1,093	987	1,032	1,002	895
Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Precipitation (mm)	1,065	944	1,065	955	942	953	1,021	942	910	897	933	974	876	822
Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005			
Precipitation (mm)	987	873	864	876	888	856	971	834	803	875	894			

In this study, data analysis was obtained to assess the majority of climatic and hydrologic trends. Therefore, out of the seven indices of hydrologic drought mentioned in Table 1, six ones could be analyzed as follows:

3.1 Precipitation

Available data on precipitation in Lebanon is found to be reliable to build a complete figure on rainfall trends for more than 40 years, i.e., since 1966, (Table 3 and Fig. 2). In this study, the precipitation trend was built for the whole Lebanon and not for selective sites. This data was collected primarily (i.e., 1966 to1978) from 70 gauging stations distributed over all Lebanon, where 66% of them were in the western part of the country. However, after this date (1978) the number of gauge stations was reduced to 11, until 1997, and then increased to 24 ones.

It is clear that the major trend is descending and the first decline in precipitation started in the early 1980s (Fig. 2). Before that time, the average precipitation rate was 1043 mm, thus it decreased to 917 mm (up to 2006), which is equivalent to 12%.

Rainfall intensity was also assessed through graphic illustrations of data adopted from TRMM (Tropical Rainfall Mapping Mission), which was extended by NASA from 1998 till quite recent (Fig. 3). The creditability of the TRMM data was verified

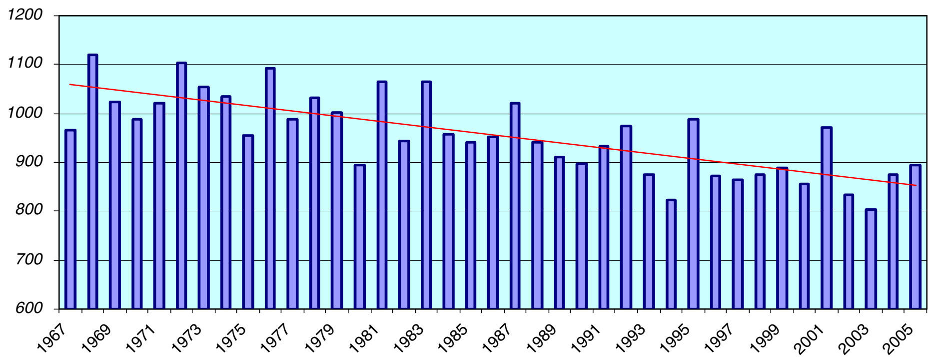

Fig. 2 The general trend of precipitation rate in Lebanon between 1967 and 2006 (CAL 1982; DGAC 2006)

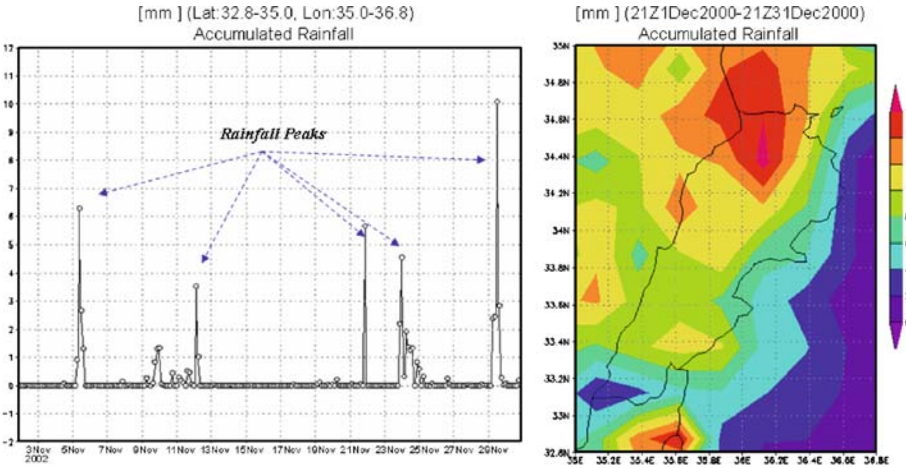

Fig. 3 TRMM data for precipitation and rainfall peaks in graphic and mappable forms

by a comparison between graphical illustrations for ground data from gauging stations in Lebanon and those extracted from TRMM data. A clear coincidence in timing of events between ground stations data and those obtained from TRMM, in spite of some variance in the amount of recorded precipitation. In this concern, several studies proved the reliability of TRMM data. Such as those studies obtained by Ohsaki et al. (2000), Chiu et al. (2002) and Scott et al. (2007).

In assessing hydrologic drought, the rate of rainfall and the number of rainfall peaks are of utmost concern. They have direct and indirect influence on water resources. The decrease in rainfall rate is directly affecting the volume of surface waters and groundwater. Whilst, the high rainfall peaks cause flooding, which are indirectly influences water volume through the losses of water to the sea. This, in turn, helps establishing inflow scenarios (Rao et al. 2001).

There is an obvious increase in the number rainfall peaks was reported and as well as in the level rate of peaks themselves, notably in the period after 1980s. Therefore, the average number of rainfall peaks was <15 peak/year and 24 peaks/year for the periods before and after the1980s; respectively. Moreover, the average rate of torrential water from these peaks was between 15 and 20 mm/day before the 1980s and 18–22 mm/day after it.

3.2 Rivers

There are 12 permanent watercourses (rivers) in Lebanon. Additionally, there are about 60 major temporary streams (Wadis) that capture rain water for limited time interval (few months). These watercourses (both permanent and temporary) have witnessed obvious decrease in water level, and some have lost about 50% of their normal level.

Graphic plotting was applied to assess rivers discharge in this study. Hence, the available data on rivers flow was presented for the period between 1965 and 2006 (Fig. 4). However, some measures were lacking due to the damage in some hydrographs, which have not re-activated until the beginning of the 1990s.

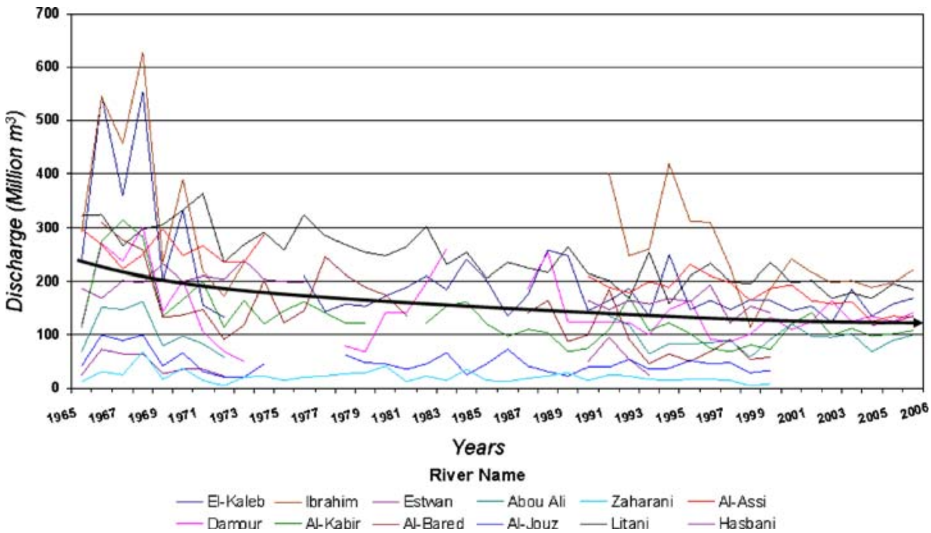

Fig. 4 Discharge from Lebanese rivers between 1965 and 2006 (LRA 2006)

The fixed hydrographs along the primary courses of the Lebanese rivers are cited at different confluences and diversions. In addition, many hydrographs were fixed on river mouths (outlets). In this study, the analysis of rivers discharge were obtained only for hydrographs along the river mouths to avoid any error along the river course that may exist due to the direct exploitation by human upstream.

Even though, there is turbulence in the discharge in many of the located rivers, yet the overall discharge is obviously in a descending trend for all issuing rivers (Fig. 4). It is found that the average discharge rate of the Lebanese rivers was 246 million m^3/year in the year 1965, thus it is reduced to about 186 million m^3/year in the year 1965, which is equal to 23% over 40 years.

3.3 Springs

A big number of springs is known in Lebanon, and most of them are attributed to the karstic, overflow and fault types. For example in western Lebanon (~5,000 km^2) there are 853 major springs, in which 60% of them are located at altitudes over 750 m (Shaban 2003). They are, on average, of the fourth class (6.31–28.3 l/s) of the known magnitude according to Meinzer classification (1923), also the third class is frequently existed and there 22 springs with second and first magnitude (0.283–$>$2.83 m^3/s) according to Meinzer classification.

In this study, analysis of springs followed two comparative methods. These are: comparison of the number of spring over the past four decades, and a comparative analysis for the discharge of the major springs, which is expressed in graphic illustrations.

Counting the number of spring (of all magnitudes) in this study followed dividing Lebanon into three parts according to its geomorphologic units. These are: Occidental, Oriental and the Bekaa plain. In each area the number of springs was counted from the topographic maps, which were produced in 1963, consequently they counted

Table 4 Comparison between the number of springs in 1963 and 2005

Geomorphologic unit /year	Number of spring[a]		
	Occidental Lebanon	Bekaa plain	Oriental Lebanon
1963	853	345	237
2005	419	196	158
Decrease (%)	52	43	33

[a]Springs of all magnitudes according to Meinzer Classification (1923)

again in 2005 from field survey data using the same topographic maps. Therefore, a 50–55% decrease in the number of springs was resulted Table 4.

Accordingly, the graphic illustrations were plotted for the discharge of the major springs in spite of the incomplete records for some springs. In this study, the eight major issuing springs in Lebanon were investigated. They are typical of the spring types in the country, since they represent the three major types of springs (karstic, overflow and fault springs).

The overall trend of discharge from these springs is shown in Fig. 5, which is clearly descending and abruptly changed since three decades. The average discharge from these springs was 104 million m^3/year, and reduced to 49 million m^3/year between 1965 and 1999. This is equivalent to 53% over 34 years.

3.4 Lakes and Reservoirs

All existing lakes and reservoirs in Lebanon are man-made ones, and were constructed according to their geomorphic setting, which is almost a depression-like area. All of the reservoirs are of small-scale type (several hundreds of meters in diameters) and can be ascribed as local reservoirs (Berrkah). The only two large-scale ones are the Qaraoun Lake (4.5 km^2), which was made in 1962 after

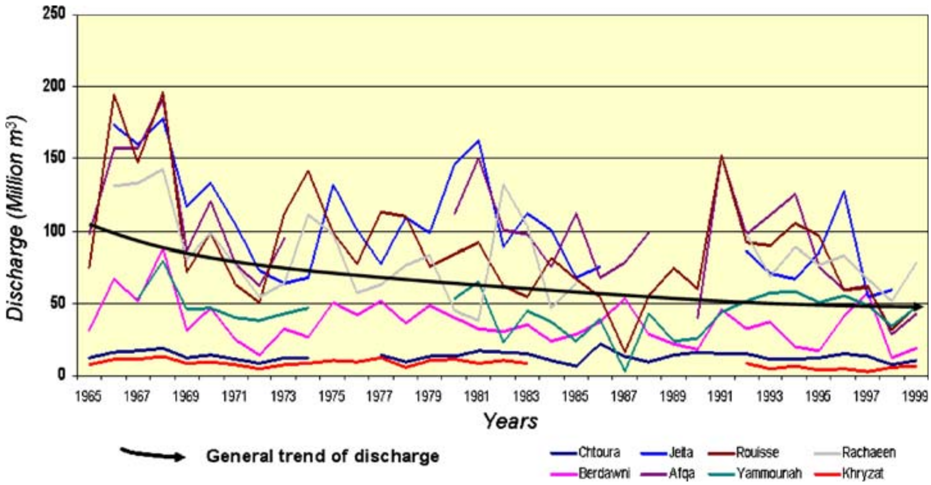

Fig. 5 Discharge from major Lebanese springs between 1965 and 1999 (LRA 2006)

constructing an earth dam (Shaban and Nassif 2007) and Shabrouh Dam (recently constructed).

At this time, most of the know local reservoirs have been neglected since they became unable to store water due to the deficit in the amount of rainfall if compared with last decades when they were in-use. In addition, the only large-scale lake of the Qaraoun has witnessed an obvious decrease in its area.

The small-scale reservoirs were counted at two different times. First was from topographic maps and aerial photos (Fig. 6), which were made in 1963, then in 2005 as obtained from high resolution satellite images and field survey.

Obtained results show that: out of 234 known local reservoirs in Lebanon during 1963, only 48 are still in use until 2005. While some other ones remain, but no water storage has been noticed among these reservoirs, except few days after each rainfall period. Besides, another type of reservoirs has recently created, but they are done on the channel courses of melting snow in the mountainous regions and ascribed as “hill lakes”.

The change in the area of the Qaraoun Lake was investigated using satellite images. It is undergoing several fluctuations in its dimensions from year to another. A general decrease in the lake size is recorded and obviously noticed by the inhabitants. The obtained comparative analysis in this study depended on the available satellite images to induce the changes in the lake volume at different periods of time.

Although, the analyzed satellite images were not in complete sequential time series, but they could form a clear figure for the size of the Qaraoun Lake. The processed images are attributed to different dates as follows: 1973, 1984, 1985, 1987, 1989, 1992 and 1997–2005. These dates were adapted from different available satellite images (i.e., Landsat MSS, TM, ETM+, SPOT and ERS) to compose the most favourable time order. They own different spatial resolution (5–120 m) and were processed using Erdas Imagine, ENVI-4.2 and PCI software. Therefore, several

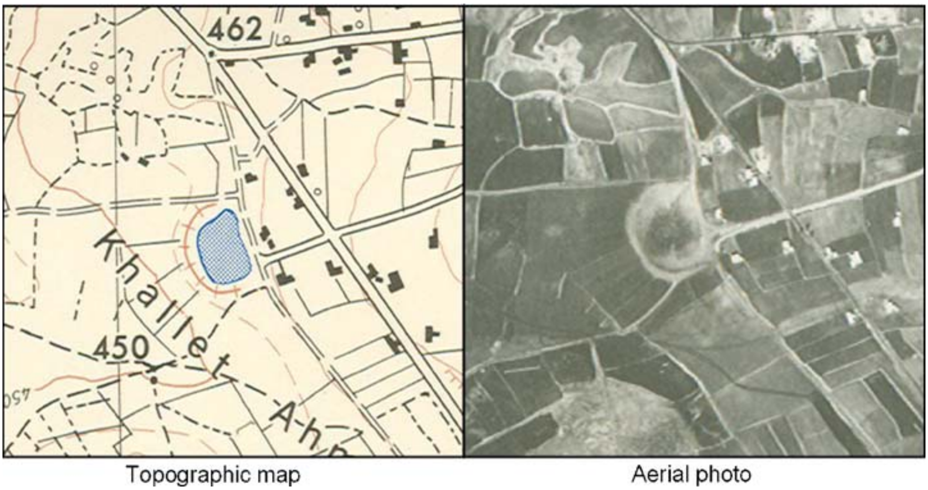

Fig. 6 Identification of local reservoirs from topographic map and aerial photo

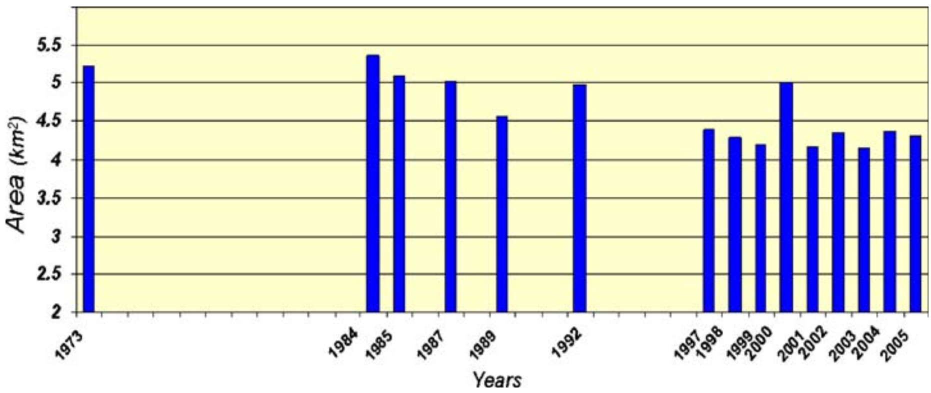

Fig. 7 Change in Qaraoun Lake area at different years, between 1973 and 2005

optical and digital advantages were applied to measure the exact area of the lake at different dates.

The selected dates of these images were often close to each other, which in winter. Then, the width and length of the lake were calculated for these years (Fig. 7).

Figure 7 shows the change in the area of the Quaroun Lake at different years between 1973 and 2005. Even though, the time series is not complete; however, the general trend exhibits reduction in the area of the lake through the investigated dates.

The average area was 5.14 km^2 in the period before 1990 and thus decreased to 4.35 km^2 after 1990 until 2005, which is equivalent to 15% of the normal area of the lake.

3.5 Snow Cover

Lebanon, the country with about 60–65% of mountainous terrain, receives a considerable amount of snow that covers about 25% of its area (Shaban et al. 2004). Normally, snow covers the regions above 1,200 m, thus shapes the mountain chains of Lebanon.

Till quite recent, no creditable in-situ measures on snow cover have been done in Lebanon; and only local measurements for snow depth were obtained for different dates and regions.

Recently, the development of remotely sensed techniques helped estimating the area of snow cover. Yet, this estimation depended on the availability of satellite images. In this study, MODIS-Terra and SPOT 4-Veg. images, which have 1 km resolution were also processed (Fig. 8). The data on the area of snow cover could be obtained at different periods since 1973 and thus from 1998 until February 2007. The depth and density of snow were not estimated as they need field verification. Nevertheless, the areal extent of snow cover is indicative to the intensity of snow, thus to the amount of water derived from snowmelt was calculated (Shaban et al. 2004). For the processed MODIS-Terra images, they were on a daily basis, thus the maximum snow cover was calculated for each year (Fig. 8). The same approaches and software, as for the Qaraoun Lake, were used also in the case of snow cover, since both deal with measuring the areal extent.

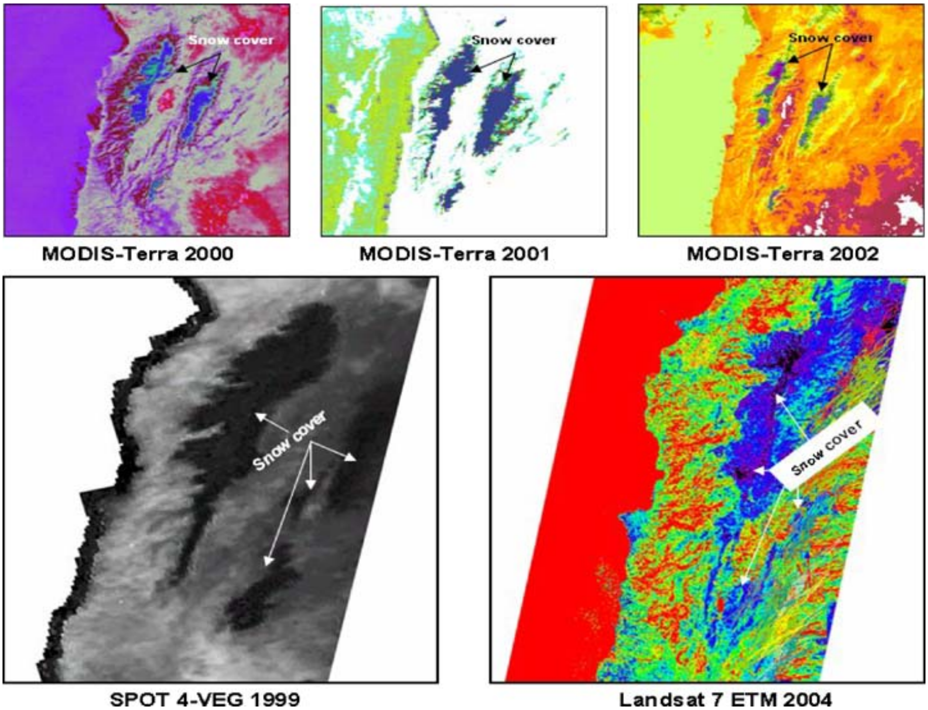

Fig. 8 Different satellite images and dates showing the change in snow cover in Lebanon

The analysis of satellite images for different dates show a noticeable decrease in the area of snow cover. This accompanied with a decrease in the residence time (i.e., time snow remains before melting) of dense snow cover as a reflection of the increase in temperature level (Fig. 9).

Even though, the number of the analyzed satellite images is not complete (in terms of time series) to figure a perfect snow cover change, yet they show a general changing trend. Thus, before 1990s, dense snow often covers more than 2,000 km^2 of

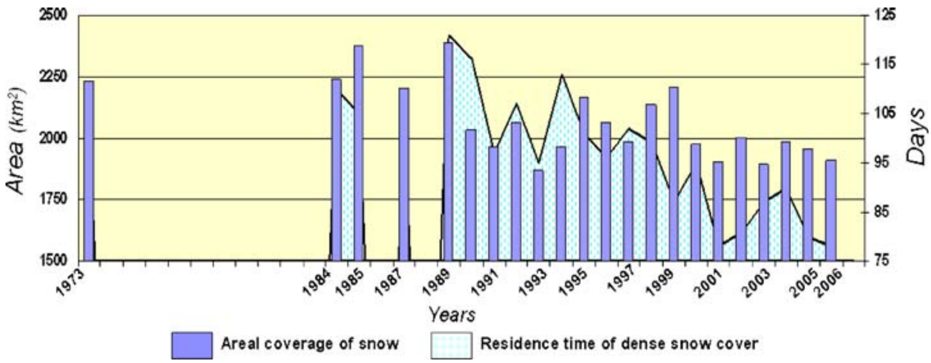

Fig. 9 Areal extents of snow cover in Lebanon and their residence time

the Lebanese mountains and averaging about 2280 km^2. Lately, it declined reduced to less than 2,000 km^2 with an average area of about 1925. In addition, the average time that dense snow remains on mountains, before melting processes have taken place, was also decreased from 110 days to less than 90 days.

3.6 Groundwater

Several aspects of groundwater regime are indicative for hydrologic drought conditions and, in many instances, they can give accurate results because they less affected by climatic conditions, notably after the time water percolates downward into aquiferous rock formations. Besides, the chaotic and immeasurable pumping from dug wells into the existing aquifer misleads the accurate estimations for the pumped water.

No reliable records for discharged water from dug wells have been made in Lebanon, but decrease in water quantity and level as well as the non-steady state in pumped water are well observed by owners. In addition, the coastal aquifers are witnessing obvious saltwater intrusions that exceeded the known limits (El Moujabber et al. 2005). All these elements (water table depletion and seawater intrusion) if combined together; however, they clearly indicate a regression in groundwater volume. In this view, human impact on groundwater regime has an essential role, notably with the excessive exploitation of groundwater that accompanied with population increase.

In this study, a comparison for water discharge at two dates (according to data availability) was applied in water wells from different regions (Fig. 10). It tackled the major water-bearing strata in Lebanon (Cenomanian Limestone aquifer and Jurassic Limestone aquifer). In the Cenomanian aquifer, 193 water wells were investigated from four different regions to induce the change in water yield between two dates (1984 and 2005). For the Jurassic aquifer, 122 wells were investigated and also in another four regions in Lebanon (Fig. 10).

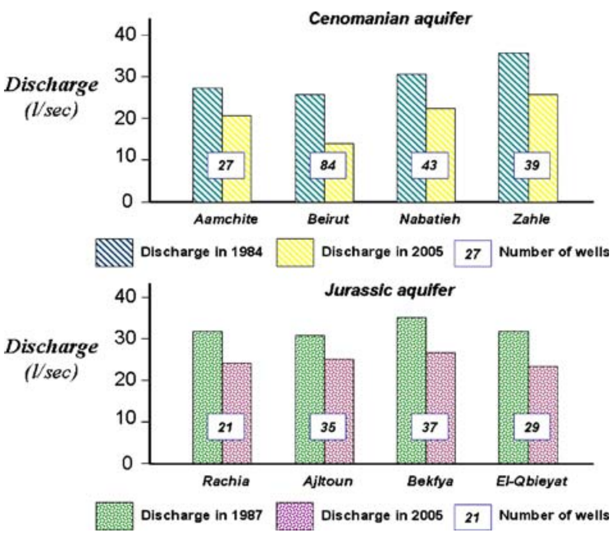

Fig. 10 Change in the discharge from wells in the major aquifers in Lebanon

For both aquifers, an obvious depletion in the pumped water was recorded, notably in the coastal regions, thus reflecting, in addition to climate influence, the human over exploitation. The average discharge from wells of the Cenomanian aquifer in 1984 in the four studied regions was 29.5 l/s. It was decreased to 20 l/s. While the in the Jurassic aquifer, the discharge was decreased from 31.75 to 23.5 l/s, for 1987 and 2005; respectively.

Accordingly, the variation in the level of water table has several values and differs from one area to another. However, the general estimates were adopted as an average from different water wells in Lebanon. For example, the average drawdown in water table was reported as 20–25 and 5–10 m in the Cenomanian and Jurassic aquifer; respectively in the area of the Litani River watershed in the last fifteen years (CNRS 2007).

Another aspect of groundwater influences, and can be considered as indicative to hydrologic drought, is the saltwater intrusion, in which the coastal area of Lebanon is witnessing. This phenomenon has been known since the last three decades, but lately it has shown a dramatic increase, notably in areas with high population, such as Jbeil, Jounieh, Beirut, Choueifat and Saida. In this concern, different studies were done for different coastal zones and all reported an increase in the salinity ratio as well as stretching in the saltwater boundaries to several kilometres on-land. Examples of these studies those obtained by Lababidi et al. (1987), Hachache (1993), Khawlie et al. (2003) and El Moujabber et al. (2005).

Another related phenomenon to groundwater regime, is the decrease in the number of the groundwater discharges (i.e. submarine springs) into the sea, which is a major index for hydrologic drought in Lebanon, and is it relates to saltwater intrusion. These springs were found to be in a descending trend since three decades. A comparative study was applied on these springs along the coastal stretch between Beirut and Anfeh (North Lebanon). It was found that in 1972 the number of the springs along this stretch was 46 and decreased to 27 in 1997. These results were obtained by FAO (1972) and NCRS (1997) through thermal infrared airborne survey.

4 Conclusion

Recently, the impact of climate change has been raised in many regions of the world, but it does not show the same level and type of effect. For example, the precipitation rate has been decreased in the Mediterranean region, while it has been increased in southwestern USA (Felzer and Heard 1999). Thus, hydrologic drought is absolutely reflected by a number of changes and influences on different physical and anthropic processes, where water resources occupy the large portion in this respect. Therefore, a clears decrease in water availability has been recognized and affected the social living.

The regression in water availability can not be attributed only to climate change, as many researchers believe, but also to the human interference. This interference is due to the increase in population and the improper use of water resources. This in turn, affects the behaviour of the hydrologic cycle and the quantity of water in many areas.

Although several studies have been recently done to assess hydrologic drought, yet detailed monitoring and comparative analysis are still needed. For optimum analysis, complete series of data are favourable in terms of time and records. Although, there is non-continuity in some records of the climatic and hydrologic data, yet this study exhibits a clear decrease in water resources. However, different approaches of analysis were applied, but all of them were reached the same conclusion though the variance in the resulting numbers in some cases.

In this study, the hydrologic drought indices were analyzed through a comparative assessment of the available data and records. Resulting trends from these indices showed a remarkable decrease in water quantity in different aspects and at different scales. However, this decease varies from one index to another, but all revealed alarming status.

Accordingly, the climatic indices exhibit their influence through the decrease in the amount of rainfall water and snow cover area. This decrease ranges between 12% and 16% in the last four decades. While, the decrease is much bigger in the case of rivers and groundwater and ranges between 23% and 29%. The larger increase ratio in the latter reflects the human interference from direct pumping from rivers an over exploitation form groundwater. Besides, the most usable and dependant conventional water resources were also affected by hydrologic droughts. That was viewed from the decrease in the number of springs and the reduction in their discharge. Additionally, the number of local reservoirs has subjected to the most excessive influence, as they were a major source of water in before 1960s. Consequently, 43% and 79% are the decrease values for springs and local reservoirs; respectively.

Though the lack of complete and sequential records in Lebanon; however, an overall estimation on hydrologic drought could be attained. In this regard, immediate implements must be taken to conserve water resource in Lebanon. This needs to apply appropriate water resources management plans.

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