A 32-year aridity analysis: a tool for better understanding on water resources management in Lebanon

Amin Shaban[1] · Mohamad Awad[1] · Ali J. Ghandour[1] · Luciano Telesca[2]

Abstract

Water scarcity has been well pronounced in the Middle East Region; however, Lebanon is still characterized by wet climate and sufficient water resources. It is a paradox that Lebanon is now under water stress, and many contradictory studies on the climate of Lebanon attributed water stress to the changing climate. Most of these studies were applied with incomplete climatic data records. Therefore, all management approaches were implemented after considering climate as a major influencer on water resources. In this study, the Emberger Aridity Index (E_{Ai}) was employed to investigate the climate regime of Lebanon over more than 30 years focusing on ten representative meteorological stations where comprehensive climatic records were analysed and supported by remotely sensed data. The E_{Ai} indicates that Lebanon is still characterized by humid climate, which conflicts with the concept of drought existence. Thus, 47% of the Lebanese territory is characterized by humid to sub-humid climate and 29% by semi-arid climate according to Emberger classification. This obviously shows that even the climate impact has a role on water scarcity, but it is not the principal influencer. The results of this study help applying new approaches for water management where the negative human interference should be accounted. It guides stakeholder and decision-maker to follow appropriate water and agricultural policies and strategies for better sustainable development.

Introduction

Lebanon with its small geographic area (10,452 km^2) encompasses remarkable geomorphology where rugged mountainous topography is dominant and discriminates Lebanon from the surrounding Middle East Regions. This particular geomorphology makes the climate of Lebanon as normally wet, in which it is reflected on sufficient water resources.

In fact, the two parallel mountain ridges of Lebanon facing the Mediterranean Sea create a meteorological barrier that captures the cold air masses derived from the Mediterranean and condensates them as rain and snow. Therefore, the entire Lebanon is characterized by the Mediterranean climate with four distinguished seasons which are in general,

moderately cold and rainy in winter, hot and humid in summer and mild in spring and autumn.

In Lebanon, there are several studies done on climate and the related topics on water, agriculture and energy (Arkadan 2008; Shaban 2009; Halawani 2009; Portoghese et al. 2013; Telesca et al. 2018). The general climatic figure in Lebanon reveals that the annual rainfall rate ranges between 650 mm on the coast and 1500 mm on the mountain crests, and it averages about 910 mm (Shaban and Houhou 2015). Furthermore, snow covers annually more than 25% of the Lebanese territory and remains for a couple of months on the top mountains. Moreover, the average temperature in Lebanon changes between 21 and 23 °C.

Since the last three decades, Lebanon is witnessing serious water problem and many surface and sub-surface water resources are now under stress. Thus, water availability has been decreased from 1350 to 980 m^3/capita/year. Also, the discharge in rivers has been decreased by about 60% over the last four decades (Shaban 2011). This is also the case for springs where most of them have been dried. In addition, groundwater is also subjected to abrupt decrease in the

✉ Amin Shaban
  geoamin@gmail.com

1 National Council for Scientific Research, Beirut, Lebanon

2 Istituto di Metodologie per l'Analisi Ambientale, CNR, C.da S.Loja, 85050 Tito, PZ, Italy

pumping rate, while the water table of the major aquifers has been lowered to more than 25–30 m.

Although there is discrepancy about the major reasons behind this unfavourable situation on water resources in Lebanon, many studies attributed it to the climate change, such as Bou Zeid and El-Fadel (2002), Hreiche et al. (2009), GIZ (2013) and Haddad et al. (2014), UNDP and MoE (2018). Likewise in many regions worldwide, climate change has lately occupied a wide spectrum of discussion in Lebanon. According to the Ministry of Environment in Lebanon (MoE 2011), climate predictions showed that by 2040, temperature rate will increase from around 1 °C on the coast to 2 °C in the mainland. Besides, rainfall projections indicated a decrease between 10 and 20% by 2040. In addition, the drought periods, over the entire country, will become 9 days longer by 2040. In this respect, UNDP and MoE (2018) stated that climate change will induce a reduction between 40 and 70% of the snow cover with an increased temperature between of 2 and 4 °C. This in turn will reduce the amount of water that feeds rivers, springs and groundwater.

Nevertheless, discrepancy often exists while investigating climatic parameters due to different method applied as well as when time series data are incomplete. This is the case in Lebanon where diverse descriptions for climate exist and Lebanon is often described as semi-arid region in the dry season and humid to sub-humid in the wet season (NC 2011), while Shaban and Houhou (2015) described the Lebanon's climate as humid to sub-humid.

Recent data analysis showed that there are obvious oscillations in the climatic conditions in different regions in Lebanon (Shaban and Hamze 2017), and the estimated rainfall rate was found to be abruptly fluctuating even between neighbouring regions and within a range of ± 200 mm over the last four decades, but no remarkable change has been reported in the total volume of rainfall (CNRS-L 2015). In addition, torrential rain becomes a common precipitation pattern, and there is a remarkable shifting in the existing seasons.

There are many methods applied to identify the climate behaviour and trends in Lebanon. Nevertheless, most of these methods were applied with incomplete data records, and some of them were applied to small-scale areas. Most of these methods aimed at analysing drought and aridity or to determine the impact of climate change on water resources and the agricultural sector. However, the results were contradictory and came up with different findings.

Generally, drought is described as a long-term moisture deficiency with rainfall below the average. Some studies declared that drought can be annual, seasonal and even monthly event (Gabriels 2007). Besides, aridity is defined according to Smiley and Zumberge (1971), as a physical phenomenon that linked with dryness, desertification and paucity of fertile vegetation cover. Moreover, aridity often occurs with strong insolation, increased temperature, low air humidity and high evapotranspiration.

Lebanon is still in urgent need to enhance the status of its water sector and to follow successful approaches for water management in order to meet the agenda of the Sustainable Development Goals (SDGs) 2030. This needs a comprehensive understanding and knowledge of the major deriving forces, including mainly the climatic regime of the country.

In this study, the Emberger Aridity Index has been employed to characterize the climatic setting of Lebanon. Hence, it was selected here for investigation, because it is calculated from the two influencing parameters (i.e. rainfall and temperature) measures which are almost available. Therefore, the aim of this study is to: (1) characterize the climate of Lebanon according to the calculated aridity index values, and determine the changing patterns of aridity in different Lebanese regions and (2) figure out the efficiency of the implementation taken by the water sector under the concept of drought (as it is believed to be the major influencer on water resources in Lebanon, and this conflicts with the results of the current study).

Emberger Aridity Index

There are many hydro-climatic indices used to identify the climatic behaviour and its interrelation with water availability. Thus, a large number of these indices are refereed to drought and aridity as well as to the related components (e.g. vegetation, soil wetness, etc.). However, the application of drought and aridity indices should match defined geographic locations (e.g. dry zones, deserts, etc.); in addition, data availability is also significant while selecting the convenient index to be analysed. For example, the Penman equation (Penman 1948) does not fit in regions where there are no measures on daily temperature, wind speed, air pressure and solar radiation, like the case in Lebanon.

There is a miscellany of drought indices, like, for example, SPI (Standard Precipitation Index), LSTI (Land Surface Temperature Index), SWI (Simulated Water Index), CGI (Crop Growth Index), etc., which are calculated from ground measures (i.e. hydrological and meteorological) and form remotely sensed products (example: Thiruvengadachari and Gopalkrishna 1993). However, indices used ground measures are still more accurate than those elaborated from remote sensing products.

Also, there are various formula used to calculate the aridity index, such as: Koeppen, Transeau, De Martonne and Thornthwaite. Emberger (1932) formulated the so-called Emberger Aridity Index (E_{Ai}) by using two climatic variables, the rainfall (R) and temperature (T). The use

of the hottest and coolest temperature in calculating E_{Ai} makes it more reliable index since it analysed the temperature variability.

The Emberger Aridity Index (E_{Ai}) is calculated by using the mean annual rainfall and the mean temperature of both the coldest and hottest months. In this manner, an important role is played by the abrupt changing (monthly) temperature that is significant in characterizing the climate of Lebanon, which is also affected by the diverse topography. Thus, Emberger Aridity Index (E_{Ai}) is expressed as:

$$E_{Ai} = \left[(T - t) \times \frac{\frac{1000 \times R}{(t+T)}}{2} \right]$$

Even though Emberger used R as the annual rainfall, we modify it to more precise measure and applied it to average monthly rainfall in millimetre (mm). This would be more consistent with the temperature measures which are on monthly basis. Therefore, T is the average temperature of the hottest month and t is the average temperature of the coolest month, and both in degree Celsius (°C).

Emberger (1932) classified his index as follows: < 10 = per-arid, $10–45$ = arid, $45–70$ = semi-arid, $70–110$ = sub-humid, $110–150$ = humid, > 150 = hyper-humid.

Method of data analysis

Data sources and pre-processing

In this study, climatic data from all accessible and reliable sources were collected and organized, and then database was built for the period between 1985 and 2016 by integrating/overlapping different data sets. The sources were:

- NOAA climatic data system—National Oceanographic Data Center (NOAA 2013)—Remotely sensed products.
- Direction Générale de l'Aviation Civile, Lebanon (DGAC 1999)—ground measures.
- Department of Irrigation and Agro-meteorology, Lebanese Agriculture Research Institute, Lebanon (LARI 2017)—ground measures.
- Tropical Rainfall Mapping Mission (TRMM 2014)—remotely sensed products,
- Climate hazards group infrared precipitation with stations (CHIRPS 2015)—remotely sensed products.

In this study, ten meteorological stations were used for calculating E_{Ai} (Fig. 1). These stations were selected because they are characterized by most available data with long time series. Thus, we calculated the monthly means rainfall and temperature for each of the selected stations which represent different topographic regions of Lebanon, including the coastal zone, mountains and in inner plain (Fig. 1).

Some gaps in data were found in the available records (for precipitation and temperature). In order to fill the gaps,

Fig. 1 Location map of the investigated meteorological stations in Lebanon
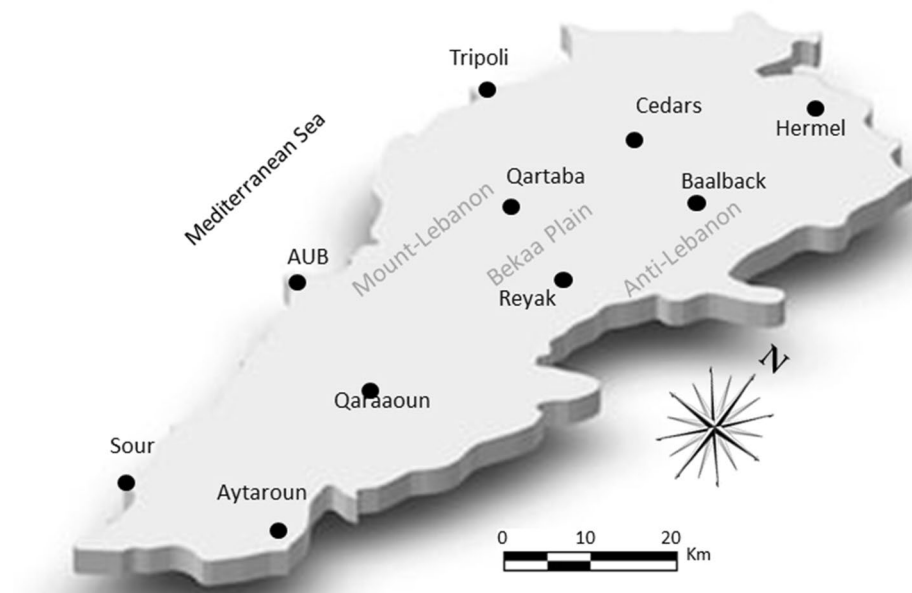
we applied the time series forecasting method (Shaban and Houhou 2015). In this method, the centred moving average (M_a) was calculated for a cycle of 12 months. To reduce the bias, the central moving average (M_{ca}) was calculated for each time.

$$M_{ca} = \sum_{i=t}^{t+5} \frac{M_a}{6}$$

Therefore, the seasonal coefficient C_t was calculated being the ratio of the available readings Y_t to M_{ca}, since $M_{ca} \approx (a + bt)$. This ratio was calculated for each month by the following formula:

$$Y_t \approx (a + bt)C_t$$

$$C_t = Avg_t \times \left(\frac{T}{\sum_{i=1}^{T-1} Avg_i} \right)$$

where T is the cycle.

After they have been estimated, however, the seasonal coefficients were extracted from the available readings in order to get deseasonalized observations. Then, each observation, which represents a season, was divided by the corresponding seasonal coefficient. Finally, a linear regression model was introduced in order to compute the trend, where the least square method is used to estimate the parameters a and b, and hence, a new deseasonalized forecast ($T_t = a + bt$) can be determined, and consequently, the seasonal coefficient F_t was calculated as follows:

$F_t = T_t \times C_t$

When all data required became ready for the ten stations, the resulting values were represented on maps to show the spatial distribution of E_{Ai}. This can be achieved by using the geographic information system (GIS) method through the following steps:

- The location of the ten climatic stations were geo-referenced, and the geographic coordinates of each location was assigned by E_{Ai} value.
- The E_{Ai} data were divided into group of 5-year intervals, and the average of aridity index was computed for each group.
- The calculated E_{Ai} data with stations' locations were integrated into the GIS system, and managed by ESRI's ArcMap software.
- Shape-files (i.e. GIS maps products) were produced; each shape-file represents a layer of point features that were created in ArcMap linking the E_{Ai} data to each layer.
- Interpolation was applied to predict the trends of E_{Ai} values, and then to create the aridity maps. For the interpolation, spline functions were used; they are fitting

polynomials that are often applied to perform smooth multivariate interpolation of data irregularly distributed (Liu et al. 2008). Thus, the resulted interpolation has less error and more confidence for the E_{Ai} values since the spline functions were applied.

Results

The maximum calculated E_{Ai} value is 177, while the minimum is 1. Besides, the mean value of E_{Ai} is 84, indicating a sub-humid climate in general according to Emberger Aridity Index. Also, the calculated standard deviation is 117, and coefficient of variation (CV) is 139%, which evidences high variation in the climatic conditions between different stations. These simplified measures (i.e. preliminary statistical calculations) reveal that the climate of Lebanon can be broadly characterized by wetness.

Based on GIS data manipulation and following the previous systematic methodology mentioned, the aridity map for the entire Lebanon was produced (Fig. 2).

The map represents the computed geographic distribution of aridity between 1985 and 2016. It clearly shows that high humidity rates occur on the mountainous regions (i.e. elevated areas) and more specifically on the northern part of Lebanon where altitudes almost exceed 2000 m. Besides, the coastal plain is often characterized by semi-arid to sub-humid climate, while the arid climate is noticed in the north-eastern part of Lebanon (Fig. 2).

For the produced aridity map (Fig. 2), the area of each E_{Ai} aridity class was calculated (Table 1). Therefore, it is obvious that the majority of climate in Lebanon for the investigated time period ranges between semi-arid to humid where sub-humid occupied 26% of the Lebanese territory. Meanwhile, the arid and hyper-humid climate also exists and their geographic distribution encompasses 12% and 11.5% of the Lebanese territory, respectively.

There is clear relationship between the aridity values and the altitude of the investigated stations, especially on the mountain ridges of Mount Lebanon. This reveals the altitude-controlled parameter in creating wet weather. However, this is not exactly the case for the inner region where the Bekaa Plain is located, and the Anti-Lebanon regions (i.e. eastern mountain chains). This can be attributed to the fact that wind is rapidly rising up in Mount Lebanon and gently blown down in the Bekaa Plain and Anti-Lebanon regions (Shaban and Houhou 2015).

It is also noticed that there are almost definite geographic patterns of aridity over the Lebanese territory, which are represented by elongated patches extending parallel to the Mediterranean Sea and shaping the mountain ridges. Moreover, the high aridity often occurs in the middle part of Lebanon, and more certainly in the northern

Fig. 2 Complied geographic
distribution of Emberger Aridity
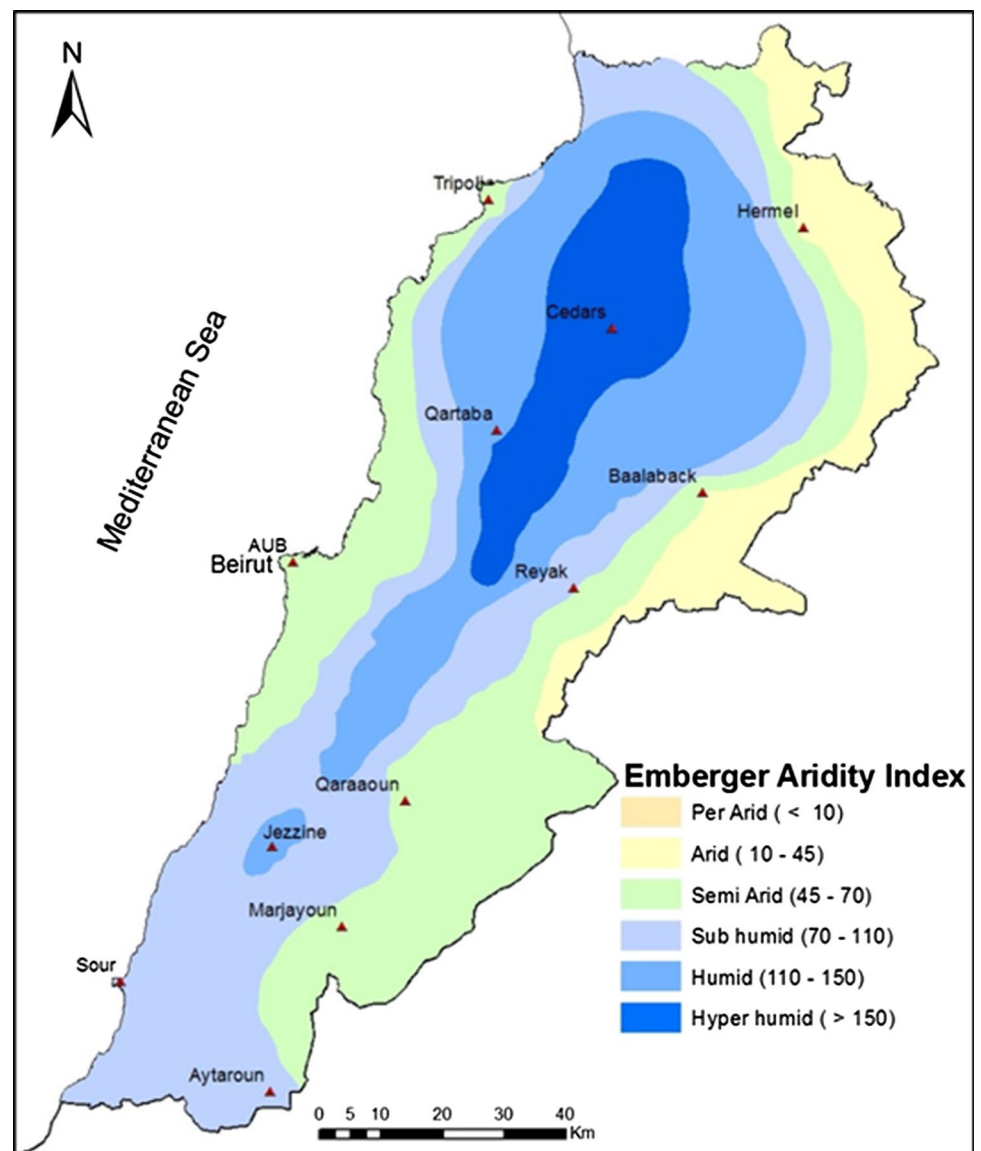Index in Lebanon for the period
between 1985 and 2016

Table 1 Calculated Emberger Aridity Index over Lebanon (1985–2016) and their dimensional and physical characteristics

E_{Ai}	Emberger Aridity Index class	Area (km²)	Percentage of Lebanon's area (%)	Dominant physical setting of the region
< 10	Per-arid	53	0.5	Very limited areal extent at the NE side of Lebanon
10–45	Arid	939	12	This is almost a continuation of the above area where it is dominant near Hermel region and over parts of Anti-Lebanon
45–70	Semi-arid	2731	29	It is well pronounced along the coastal plains and in some localities of Anti-Lebanon mountain ranges
70–110	Sub-humid	3331	26	This occupies a geographic area that joins all elevated regions of Lebanon, notably those between 2000 and 2500 m.
110–150	Humid	2405	21	In the northern part of Lebanon between 2500 and 2800 m
> 150	Hyper-humid	993	11.5	It often occurs on altitude above 2800 m near Cedars region

side of Mount Lebanon (Fig. 3) where the most elevated region in Lebanon (> 2800 m) is located.

In order to figure out the E_{Ai} behaviour with limited time intervals, a 5-year period was elaborated. These time intervals (i.e. six time periods) are characterized by remarkable oscillations. These oscillations are attributed to the changing climatic behaviour between different years. This evidences the existence of abrupt dynamic changes in the climatic regime of Lebanon. Therefore, the period between 2000 and 2005 was mostly humid to sub-humid, while the period 2005–2010 was found mainly as semi-arid to arid. In addition, diversity can be even within the same period itself (Fig. 3). For example, period of

1995–2000 reveals considerable geographic extent for the semi-arid and humid climate as well.

The systematic integration of the 5-year period measures in the GIS system could determine the overall areal extent of each E_{Ai} categories. Therefore, the resulting values show that the dominant climate of Lebanon is characterized by humidity since the sub-humid and humid categories occupy 47% of the total Lebanese areas, and then it follows by 29% for the semi-arid climate (Fig. 4).

In order to identify the overall trend of the E_{Ai} for the total studied period, a simplified illustration was also established for E_{Ai} (Fig. 5). Therefore, the general curve of aridity does not show any remarkable trending, which means that the humid climate of Lebanon still exists.
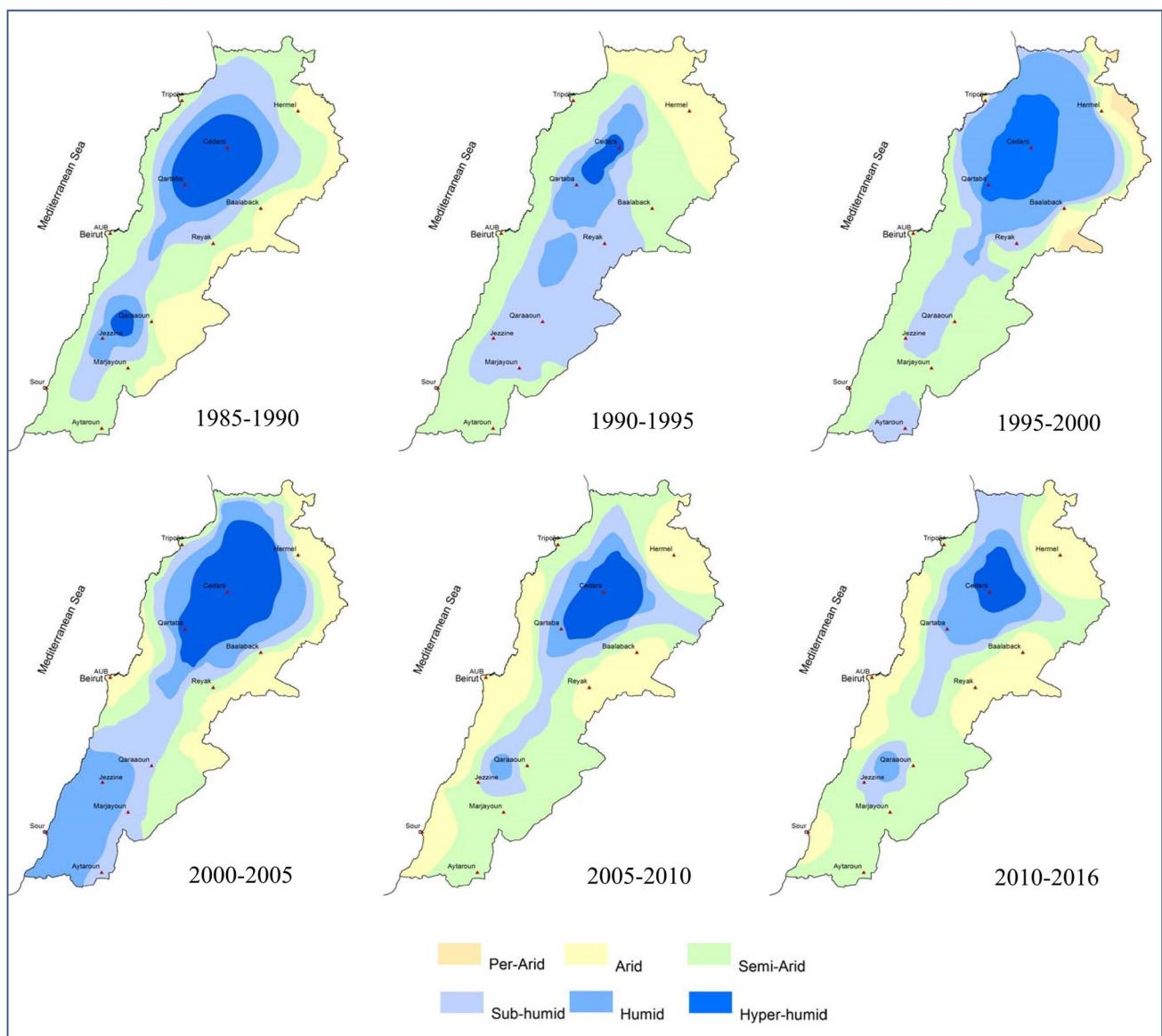

Fig. 3 Geographic distribution (5-year period) of Emberger Aridity Index for Lebanon
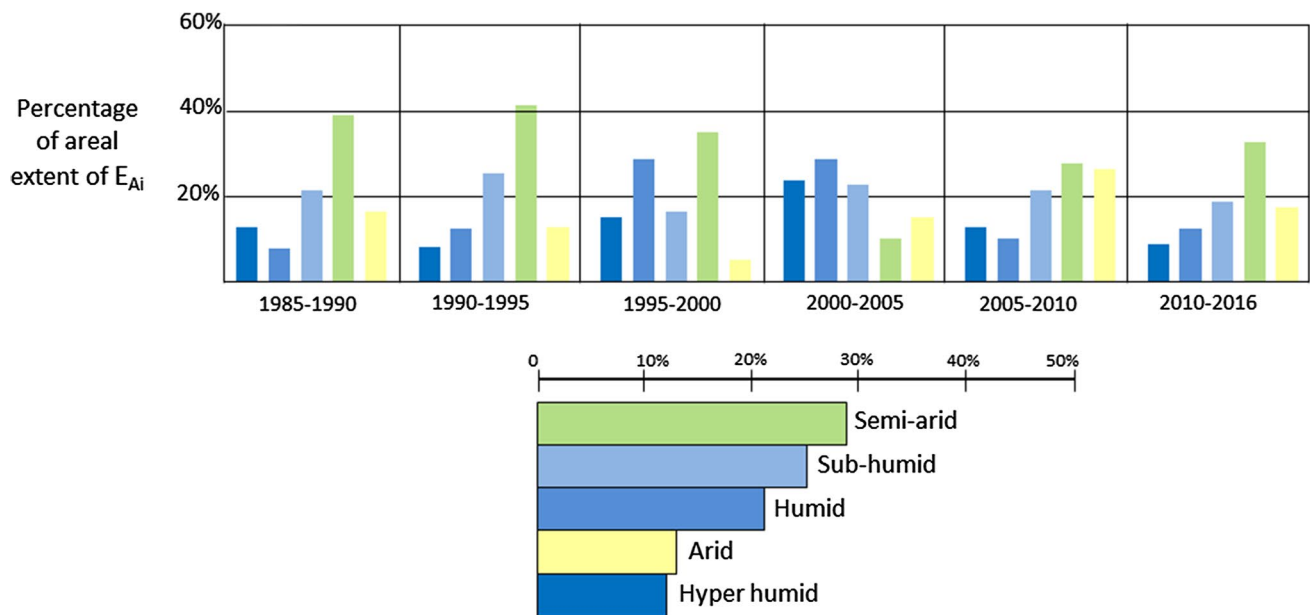
Fig. 4 Percentage of area; extent of Emberger Aridity Index in Lebanon
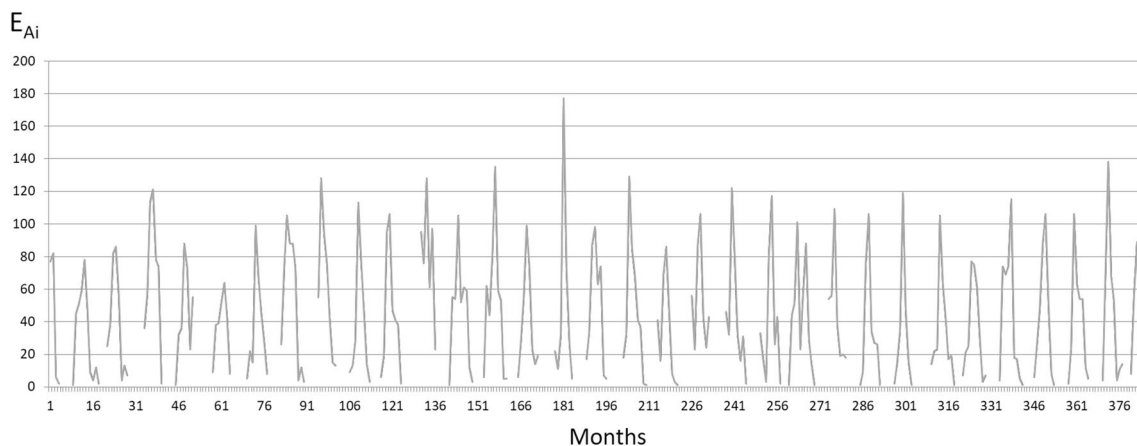

Fig. 5 General trend calculation of E_{Ai} in Lebanon between 1985 and 2016

Also, for each investigated meteorological station, the overall aridity trend was elaborated for the entire 32 investigated years between 1985 and 2016. The illustrated trends show different behaviours between all stations which almost show steady state (i.e. no trends were identified), but positive and negative trends are also found. Hence, four stations revealed remarkable changes in the E_{Ai} trends. These are: Tripoli, AUB, Cedars and Hermel (Fig. 6). The first two stations, which are located along the coastal zone, show relatively low change in aridity behaviour over the 32 investigated years. This is well observed by gentle-sloping trends +0.15 and -0.80 for Tripoli and AUB, respectively, (Fig. 6).

Stations of Cedars and Hermel show more acute sloping trends; however, Cedars has positive trend (+3.04) and Hermel

shows a negative trend (− 1.50). The positive trending existing in Cedars can be attributed to the fact that torrential rain has been recently developed and the amount of rainfall and snow reveals higher rates (Shaban 2011; Shaban et al. 2013). Besides, the localities in the northeastern side of Lebanon, notably Hermel region and it surrounding, has been witnessing obvious drought as it was evidenced by several studies (Bou Zeid and El-Fadel 2002; Karam 2009; Ramadan et al. 2013; CNRS-L 2015).
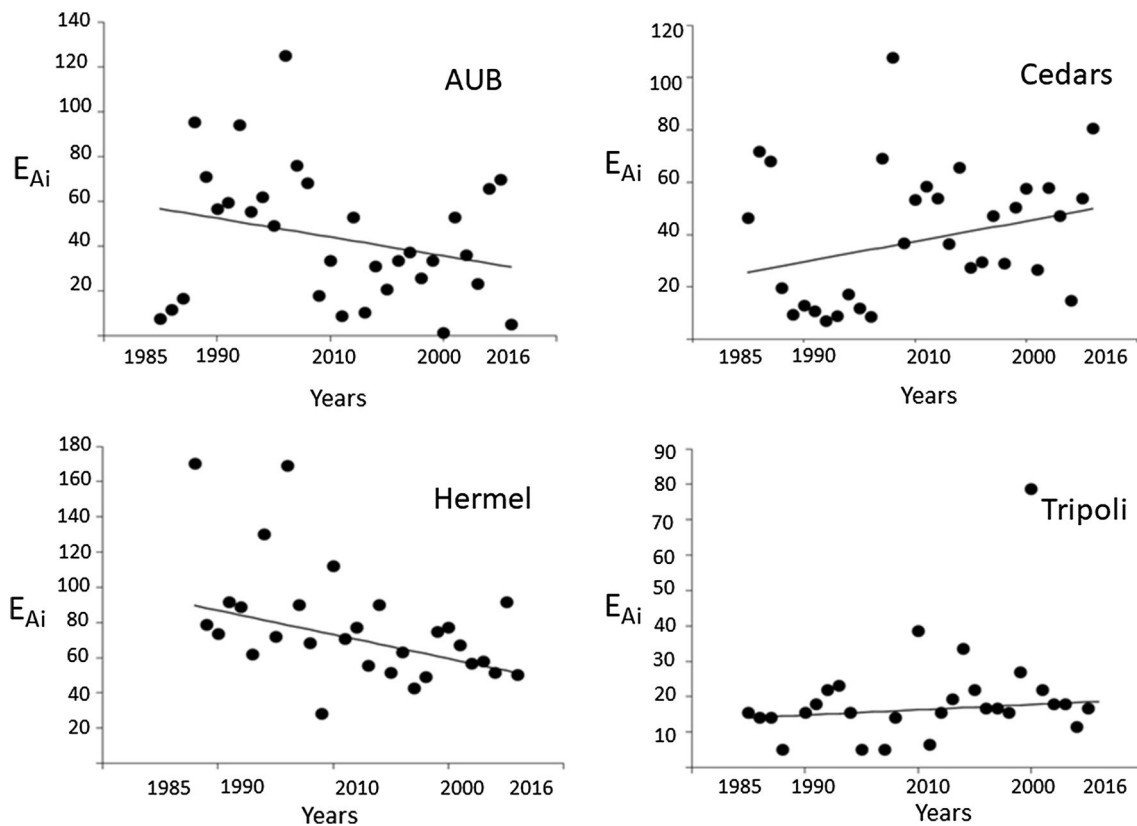
Fig. 6 Trends of the calculated E_{Ai} in four stations in Lebanon

Conclusion and discussion

The climate of Lebanon is always an issue of debate, notably that the climatic regime is not well defined yet. Thus, many studies were done and they were based on different methods of analysis. Some of these studies established projections and scenarios (Bernier et al. 2003; Khawlie and Shaban 2005; Makké 2010; Katurji et al. 2013); however, contradictory results often exist. Meanwhile, the climate of Lebanon has been lately oscillating as a global meteorological phenomenon.

The undefined climatic regime of Lebanon makes it difficult to establish appropriate water management approaches and investment policies notably that demand for water which became a striking challenge that influences the socioeconomic sector.

One of the major problems in identifying the climatic behaviour of Lebanon is the absence of comprehensive climatic data. These data are usually incomplete, and if it exist, it is owned by different sources and then tedious to collect. Another problem is the lack of sufficient knowledge for data analysis and therefore, most studies are obtained by investigators who are not skilled with hydrology and climatic processes, and this has been well pronounced lately in Lebanon.

The current research was established after obtaining a detailed inventory for the largest time series of available climatic data, where several data sources were used. Therefore, remotely sensed products play a major role in providing measures on rainfall and temperature for the ten investigated stations, notably that remotely sensed products can cover large areal extent and it helped in gaps filling.

The Emberger Aridity Index was selected in this research, because it mainly treats the major two climatic parameters (rainfall and temperature). Also, it focuses on the discrimination of mean temperature for both the coldest and hottest months which is a significant catalyst for selecting the Emberger Aridity Index. This is because the temperature is the most meteorological deriver in Lebanon's climate where it has been increased by about 1.6 °C, and thus it sharply affects water resources and agriculture (Shaban and Hamze 2017).

In addition to the used statistics in this research, the GIS analysis played a major role in plotting the aridity values in geo-spatial figures and therefore, the dynamic changes were identified for each 5-year period between 1982 and 2016. It is therefore obvious that Lebanon is passing cyclonic meteorological events including different aridity classes (according to Emberger Aridity Index). Hence, the elaborated aridity maps in Fig. 3 show that the climate of Lebanon is

oscillating between semi-arid–sub-humid and humid classes. Nevertheless, the sub-humid class can be considered as the most dominant one to characterize the entire climate of Lebanon. This was also evidenced in the previous study where De Martonne Aridity Index was used for the coastal zone of Lebanon (Shaban and Houhou 2015).

In fact, the characterization of Lebanon's climate as sub-humid is most creditable finding because Lebanon is situated parallel to the Mediterranean Sea and the existing mountains build a meteorological barrier to obstacle the cold air mass. In particular, Lebanon would not be remarkably affected by the drought which is the common phenomenon for the entire Middle East Region, as it was described in many studies (for example: Lelieveld et al. 2012). Therefore, the geography of Lebanon, with the two mountain chains, acts in capturing the cold air masses and makes it a wet region. It is also erroneous to include Lebanon while obtaining regional models and projections without discriminating its remarkable climate, such as models obtained by Zhang et al. (2005) and Alexander et al. (2006).

Meanwhile, oscillations in climatic conditions are well noticed, and it can be considered as normal meteorological cyclone. Therefore, the general trend of aridity was found with steady state or with negligible changes over the investigated time period.

Recently, deterioration has been occurred in many climate-related sectors in Lebanon and mainly in the water sector. Therefore, many stakeholders pointed out to climate change as the reason behind this unfavourable situation in the water sector of Lebanon, and they emphasize the concept of drought occurrence as a newly climatic condition. This concept was believed from the decrease in the precipitation rate plus increased temperature. Nevertheless, the results of this research, which were based on the analysis of long time series data supported by data from remotely sensing products, conflict with the concept that Lebanon is under drought and thus, they confirm that Lebanon is still characterized by acceptable humidity, and no remarkable changes have been reported in the precipitation rate besides a reported increase in temperature ($\sim 1.6\ °C$) over the last five decades (Shaban 2011).

Built on the concept that Lebanon is changed towards drought climate; however, there are several implementations taken (and some others are under study) by the formal water and water-related sectors (e.g. ministries, water authorities, etc.) to face this physical phenomenon.

Even though some of these implements should be considered, different ones must be also taken into account due to the fact that Lebanon is still characterized by wet climate. This will help properly to improve the water sector in Lebanon and reduce water shortage.

Table 2 shows the majority of implementations taken by the formal water sector in Lebanon, as it was based on drought existence. In addition, Table 2 also shows the new implementations which should be taken as they were built on the results of this study which characterizes Lebanon as a sub-humid region.

It is obvious that most of the implementations taken to improve the status of water resources in Lebanon are still unsatisfied and sometimes they have uncertain functions, except the treatment of polluted water and some water harvesting works which still need to be managed by mitigating pollution from its source, and the harvesting must follow advanced applications (Table 2).

There are only the implementations to manage water demand done by the individuals (consumers). These implementations proved to be more reliable, even though consumers are still in need for awareness and incentivize from the formal water sector (Table 2).

Finally, there must be much concern to identify the exact climatic setting of Lebanon and then diagnose the related hydrologic regime. Hence, the misunderstanding on Lebanon's climate reduces the effectiveness of the applied approaches for the enhancement of water sector and even for the adaptation measures taken to cope with the climatic oscillations plus the increased population. In contrast, water in Lebanon still occurs in considerable amounts, and the country has humid climate; therefore, new management approaches were recommended in this study (Table 2) as a first-hand information for in-depth water exploitation and conservation approaches.

Table 2 Implementations taken in the water sector in Lebanon based on the understanding of drought concept, and the proposed implementations to be taken in the view of the concept that Lebanon is characterized by sub-humid climate

Basic implement	Implementations taken*	Effectiveness of the implementations taken					Existing gaps in the implementations taken	New implementations to be taken**
		CS	S	UC	US	CUS		
Institutional implements	Establishing National Water Strategy (NWS)			X			There are still many items to be included to modify NWS	Mainstreaming climate change after considering that there is still considerable precipitation rate
								Coordination between different intuitions related to water sector
	Water supply partitioning			X			Consumers are still complaining about water supply deficit	Applying economic water policies (e.g. tariffs, water metering, etc.) to mitigate the chaotic and irresponsible water use
								Maintaining water supply pipes to reduce leakage which exceeds in some regions
	Different-scale water projects (dams, etc.)				X		These are insufficient to cope with water demand	Increasing the number of projects to conserve water
	Increasing water treatment plants		X				Pollution sources still exist and with high exacerbation	Pollution mitigation must be taken rather rapidly than treating the contaminated water
								Reserving replenishment areas for rivers, springs and groundwater
	Increasing groundwater boreholes				X		Yet, there are many uncontrolled boreholes dug chaotically	Effective controls on groundwater exploitation must be taken
								Artificial recharge in the coastal aquifers
Adaptation measures	Water harvesting (e.g. dams, lakes, etc.)		X				Water harvesting methods still need to follow scientific bases and occur only in mountainous regions	Water harvesting can be applied in the coastal zone depending on proper hydrological studies
	Using drought-tolerant crops				X		This is still very limited, and it affects the domestic crop production	Applying efficient irrigation techniques
	Water desalination					X	Poor management approach since water availability is still considerable	Use on non-conventional water sources
								Well management of shared water resources
Individuals implements	Small-scale water storage constructions (ponds, etc.)	X					–	Mainstreaming awareness for consumers
	Water commercialization	X					–	Providing incentives for consumers

CS completely satisfied, *S* satisfied, *UC* uncertain, *US* unsatisfied, *CUS* completely unsatisfied

*Implementations taken by the formal public sector, **Implementation to be taken built on the concept that Lebanon is a sub-humid region

References

Alexander L, Zhang X, Peterson T, Caeser J, Gleason B, Tank A, Haylock M, Collins D, Trewin B, Rahimzadeh F, Tagipour A, Kumar K, Rupa K, Revadekar J, Griffiths G, Vincent L, Stephenson D, Burn J, Aguilar E, Brunet M, Taylor M, New P, Zhai M, Rusticucci J, Vazquez-Aguirre L (2006) Global observed changes in daily climate extremes of temperature and precipitation. J Geophys Res. https://doi.org/10.1029/2005jd006290

Arkadan A (2008) Climate changes in Lebanon, predicting uncertain precipitation events-Do climatic cycles exist? Climate Change and Water Resources in the Middle East, Springer, p 552

Bernier M, Fortin P, Gauthier Y, Corbane C, Somma J, Dediev P (2003) Intégration de données satellitaires à la modélisation hydrologique du Mont Liban. Hydrol Sci J 48(6):999–1012

Bou Zeid E, El-Fadel M (2002) Climate change and water resources in Lebanon and the Middle East. J Water Resour Plann Manag 128(5):343–355

CHIRPS (2015) Climate hazards group infrared precipitation with station data. http://chg.geog.ucsb.edu/data/chirps/

CNRS-L (National Council for Scientific Research, Lebanon) (2015) Regional coordination on improved water resources management and capacity building. Regional Project. GEF, WB

DGAC (Direction Générale de l'Aviation Civile) (1999) Rapport annuel, Beyrouth, Liban, 32p

Emberger E (1932) Sur une formule climatique et ses applications en botanique. La Météorologie 423–432

Gabriels D (2007) Aridity and drought indices. Technical report. IAEA, UNESCO, ICTP: 1867-11, 46p

GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), German Cooperation, LAS (League of Arab States) (2013) Mainstreaming climate change adaptation in national water policies, strategies and action plans, Lebanon. Study Report for for ACCWaM 20 pp

Haddad E, Farjalla N, Camargo M, Lopes R, Vieir F (2014) Climate change in Lebanon: higher-order regional impacts from agriculture. Region, the Journal of ERSA Powered be WU 1(1):9–24

Halawani J (2009) Climate change and water resources in Lebanon, climate change: global risks, challenges and risks, IOP conference, earth and environmental science 6 (2009) 202, 911

Hreiche A, Najem W, Bocquillon (2009) Hydrological impact simulations of climate change on Lebanese coastal rivers. Hydrological Sciences Journal, Issue 6, Dry land hydrology in Mediterranean Regions, vol 52

Karam F (2009) Climate change and variability in Lebanon: impact on land use and sustainable agriculture development. Unpublished report. http://www.fao.org/sd/climagrimed/pdf/ws01_24.pdf

Katurji M, Soltanzadeh I, Kuhnlein M, Zawar-Reza P (2013) High resolution regional climate modelling for Lebanon, Eastern Mediterranean Coast. EGU General Assembly 2013, 7–12 April, Vienna, Austria, id. EGU2013-209

Khawlie M, Shaban A (2005) Applicability of climate research and information for water resources management in semi-arid and arid regions. UNESCO-WCRP, Cairo, April 18–20

LARI (Lebanese Agricultural Research Institute), Climatic Data. Monthly Bull. Department of Irrigation and Agro-meteorology (DIAM)

Lelieveld J, Hadjinicolaou P, Kostopoulou E, Chenoweth J, El Maayar M, Giannakopoulos G, Hannides C, Lange M, Tanarhte M, Tyrlis E, Xoplaki E (2012) Climate change and impacts in the Eastern Mediterranean and the Middle East. Clim Change 114(3–4):667–687

Makké TM (2010) La pluviometrie moyenne annuelle au Liban, Interpolation et cartographie automatique. Lebanese Sci J 11(2):11–25

MoE (Ministry of Enviroment) (2011) Lebanon's Second National Communication to the United Nations Framework Convention on Climate Change. Accessed online in November 2013 at: http://www.moe.gov.lb/ClimateChange/snc.htm

NC (National Communication, Second edition) (2011) Submitted to the UNFCCC. Ministry of Environment. GEF. UNDP, 191 pp

NOAA (National Oceanographic Data Center) (2013) Lebanon climatological data. Library. <http://docs.lib.noaa.gov/rescue/data_rescue_lebanon.html>

Penman H (1948) Natural evaporation from open water, bare soil and grass. Proc R Soc A193:120–146

Portoghese I, Saqallah S, Vurro M, Darwish T, Shaban A, Khadra R (2013) Modeling climate change impact on the water balance of a coastal watershed in Lebanon. In: First CIGR inter-regional conference on land and water challenges, Bari, Italy 2013 10–14 September

Ramadan H, Beghley R, Ramamurthy A (2013) Temperature and precipitation trends in Lebanon's largest river: the Litani River. J Water Resour Plann Manag 139:86–95

Shaban A (2009) Indicators and aspects of hydrological drought in Lebanon. Water Resour Manag J 23(2009):1875–1891

Shaban A (2011) Analyzing climatic and hydrologic trends in Lebanon. J Environ Sci Eng 5(3):483–492

Shaban A, Hamze M (2017) Shared water resources of Lebanon. Book published with Nova Publishing, NY, 152pp

Shaban A, Houhou R (2015) Drought or humidity oscillations? The case of coastal zone of Lebanon. J Hydrol 529(2015):1768–1775

Shaban A, Darwich T, El-Hage M (2013) Studying snowpack and the related terrain characteristics on Lebanon mountain. Int J Water Sci 2:1–10. https://doi.org/10.5772/57435

Smiley T, Zumberge H (1971) Polar deserts. Science 174(4004):79–80

Telesca L, Shaban A, Awad M (2018) Analysis of heterogeneity of aridity index periodicity over Lebanon. Acta Geophys. https://doi.org/10.1007/s11600-018-00243-5.TRMM (Tropical Rainfall Mapping Mission). 2014. Rainfall archives. NASA. <http://disc2.nascom.nasa.gov/Giovanni/tovas/TRMM_V6.3B42.2.shtml>

Thiruvengadachari S, Gopalkrishna HR (1993) An integrated PC environment for assessment of drought. Int J Remote Sens 14(17):3201–3208

UNDP, MoE (2018) Vulnerability and adaptation: climate change Lebanon. http://climatechange.moe.gov.lb/projects

Zhang X, Aguilar E, Sensoy S, Melkonyan H, Tagiyeva U, Ahmed N, Kutaladze N, Rahimzadeh F, Taghipour A, Hantosh T, Albert P, Semawi M, Ali M, Al-Shabibi M, Al-Oulan Z, Zatari T, Khelet I, Hamoud S, Sagir R, Demircan M, Eken M, Adiguzel M, Alexander L, Peterson T, Wallis T (2005) Trends in the Middle East climte extreme indices from 1950 to 2003. J Geophys Res 110:D22104. https://doi.org/10.1029/2005jd006181