Climate Change and Variability in Lebanon: Impact on Land Use and Sustainable Agriculture Development

Fadi Karam

Head, Department of Irrigation and Agro-Meteorology, Lebanese Agricultural Research Institute, Tal Amara, P.O. Box 287 – Zahlé- Phone: 00 961 8 90 00 37; Fax: 00 961 8 90 00 77; E-mail: fkaram@larileb.com

1) Introduction

Twentieth century climate was dominated by near universal warming. Almost all parts of the globe had temperatures at the end of the 20th century, that were significantly higher than when it began. In addition, increased levels of greenhouse gases appear to explain the unusual warming in the 20th century.

As remarked in the Agenda 21 of the UN Conference on Environment and Development of Rio de Janeiro (1992) and in the UN Convention to Combat Desertification of Paris (1994), the insufficient knowledge of the desertification processes and the lack of relevant information stimulate a series of priority actions. One of them mentions the necessity of the strengthening of the basic knowledge and the development of information and monitoring systems for the regions prone to desertification, including climatic, hydrological, land use and human aspects.

Establishing permanent systems for monitoring the degree of desertification and land degradation, with the main aim of improving the living conditions of the local populations, are nowadays being a priority.

In Lebanon, varying conditions of water shortage as regarding the availability of the hydraulic resources have been experienced in the last decade. This is aggravated by a rapid population growth, urbanization, industry and irrigation developments. At he dawn of the 21st century, it is estimated that the water availability per capita will in Lebanon below the scarcity level of 1000 m^3/capita/year indicated by the Food and Agriculture Organization of the United Nations.

People have observed detrimental changes in hydrology over recent decades. Ground water levels have fallen, springs and wetland areas have dried up, and rivers, mainly Litany, no longer flow in the dry season. The main causes are thought to be land degradation, changes in rainfall and interactions between these two factors. Furthermore, reduced vegetation cover, due to deforestation, overgrazing and low rainfall, and poor surface management of cultivated lands, have led to reduced infiltration rate, increased runoff and soil erosion, and a decline in groundwater recharge. The extent to which the deterioration in hydrology is reversible with improved land management and rainfall conditions is nowadays being a critical issue. Add to this agricultural activities, which are extremely sensitive to the large year-to-year climate fluctuations that are observed.

This paper deals with:

1. The status and potential future of climate change in Lebanon, including climate monitoring and information systems;
2. The current and expected future value of the above climate information in contributing to the effectiveness of agricultural management and water resources endowment in the country, with emphasis to land use associated with climate variability;

3. The evaluation of specific methodologies of how climate monitoring may reduce the impacts of climatic risks at the national scale, in order to support and plan mitigation activities.

On the national scale, the average monthly temperatures and annual precipitation are used as indicators of historical and present changes in climate. On the global scale, the North Atlantic Oscillation (NAO) and the Sea Surface Temperature (SST), (the latter is an indicator of variations associated with El Niño), are monitored.

The Department of Irrigation and Agro-Meteorology (DIAM) of the Lebanese Agricultural Research Institute (LARI) receives, controls and archives large amounts of observed climate data. These are used for monitoring the climate and for studying the causes of climate change and climate modeling. The DIAM has been appointed as one of the National Meteorological Network, which is directed and supervised by the National Meteorological Service located at headquarters of the International Airport of Beirut. Extensive analyses of the data from the different weather stations show changes in seasonal and annual precipitation and average air temperatures, especially in areas prone to prolonged drought and desertification risks. In these areas, changes are more extreme than in other areas. The decrease in rainfall averages threaten water supplies during the long summer period, where historically zero rain is recorded. Further, the DIAM has already carried out many assessments of the impact of climate change on the agricultural sector and water resources.

2) Natural climatic factors

The climate of Lebanon is typically Mediterranean, humid to sub-humid in the wet season to sub-tropical in the dry season. The wet season coincides with winter period that lasts from November till April. In winter, the atmospheric pressure perturbations originating from South Europe cause abundant rainfall at the coast and on the mountains parallel to it. A maximum transect of 50 km crosses the country in width, from a subtropical coastal climate, to semi-arid continental in the Bekaa Valley, through middle mountains, typical of the Mediterranean climate (Figure 1).

The dry season coincides with summer period, which starts in June till the end of September. During this period, no rain is recorded and a state of high pressure dominates the whole country, with a general tendency toward Northeast. In summer period, the occidental winds coming from Greece humidify the air on the coast and in the mountains and lower slightly the temperatures. The presence of natural districts at the levels of Marjaoun in the South and Dahr el Baidar in the central Mount-Lebanon permit to the occidental winds to reach partly the southern and central parts of the Bekaa valley. Whereas, in the northern Bekaa Valley, the dry and hot winds originating from the Arab Peninsula contribute to an increase of the day/night temperatures and a decrease of the relative humidity of the air, that increases by consequence the vapor pressure deficit of the air.

While the coastal and mountainous areas are characterized by abundant rainfall distributed over winter season, the Bekaa Valley has a semi-arid to continental climate with unpredictable rainfall and recurrent drought. In the central part the climate is semi-arid, whereas in the northern part it is almost arid to continental, since it is separated from the sea effect by the presence of a high and ridge mountain chain, which height near 3000 m a.s.l. In the southern Bekaa Valley, a sub-humid Mediterranean climate is dominant, with more reliable rainfall.

While at the coast the rain is caused by the accumulation of heavy saturated clouds, or "cumulonimbus", the rain received by the mountains is mainly due to the difference in land topography and to the fast variation of climatic and environmental conditions between the sea and the mountains. This is very typical of the northern and central coastal areas, where the high chain of surrounding mountains constitutes a natural barrier to the clouds in the way before reaching the inland. As a result, there is a season of stable rainfall between November and April with average amounts of 800 mm at the coast, 1000 mm in the mountains and 400 mm in the Bekaa Valley. The annual average temperatures vary from 15°C at the coast to 8°C in the mountains and 6°C in the Bekaa Valley.

Figure 1. Map of Lebanon

Average annual precipitation on the coastal strip ranges between 700 and 1000 mm, with an increase tendency northward. The northern and mid parts of Mount-Lebanon chain form a natural barrier to the transversal movement of the clouds and result in heavy rains, which sometimes exceed 1500 mm, most of them fall as snow. While the western foothills of Mount-Lebanon are climatically Mediterranean, the eastern foothills are less humid, with a sub-Mediterranean climatic conditions, in which rain average 600 mm. The maximum amounts of rainfall is observed in January, which rang from 50 mm in at El Qaâ in the Northern Bekaa Valley, to 150 mm at Ksara in the Central Bekaa Valley. On the mountains, average rain recorded in January varies between 350 mm at Laqlouq in the Northern mountains, to 300 mm at Jezzine in the Central mountains. At the coast it is around 200 mm (Figure 2).

Mean annual temperature varies on the coast between 19.5 °C and 21.5 °C. It decreases approximately 3°C for each 500 m elevation. At 1000 m a.s.l., mean annual temperature is around 15 °C and becomes 9°C at 2000 m a.s.l. The lowest temperatures recorded in January vary from 7°C at the coast to –4°C on the mountains. On the contrary, the highest temperatures are obtained in July, where maximum daily temperatures exceed 35°C in the Bekaa Valley. Similar temperature values can also obtained at the coast, with less adverse effects due to the relatively high relative humidity. Figure 3 summarizes average annual maximum and minimum temperatures in climatically different locations.

Data reported by Abou Khaled and Sarraf (1970) showed high potential evapotranspiration for summer period, where maximum values were observed in July. (Figure 4). This figure shows also for Tal Amara in the Bekaa Valley and for Abdé and Tyr (Sour) on the coast the rain-potential evapotranspiration plotting curve, which indicates the width of the wet area. When potential evapotranspiration exceeds the rain, the dry period gets started with an amplitude depending on the site. Generally, less adverse effects are observed on the coast than in the Bekaa Valley, where advection effect due to wind drift and high vapor pressure deficit in the air are dominant.

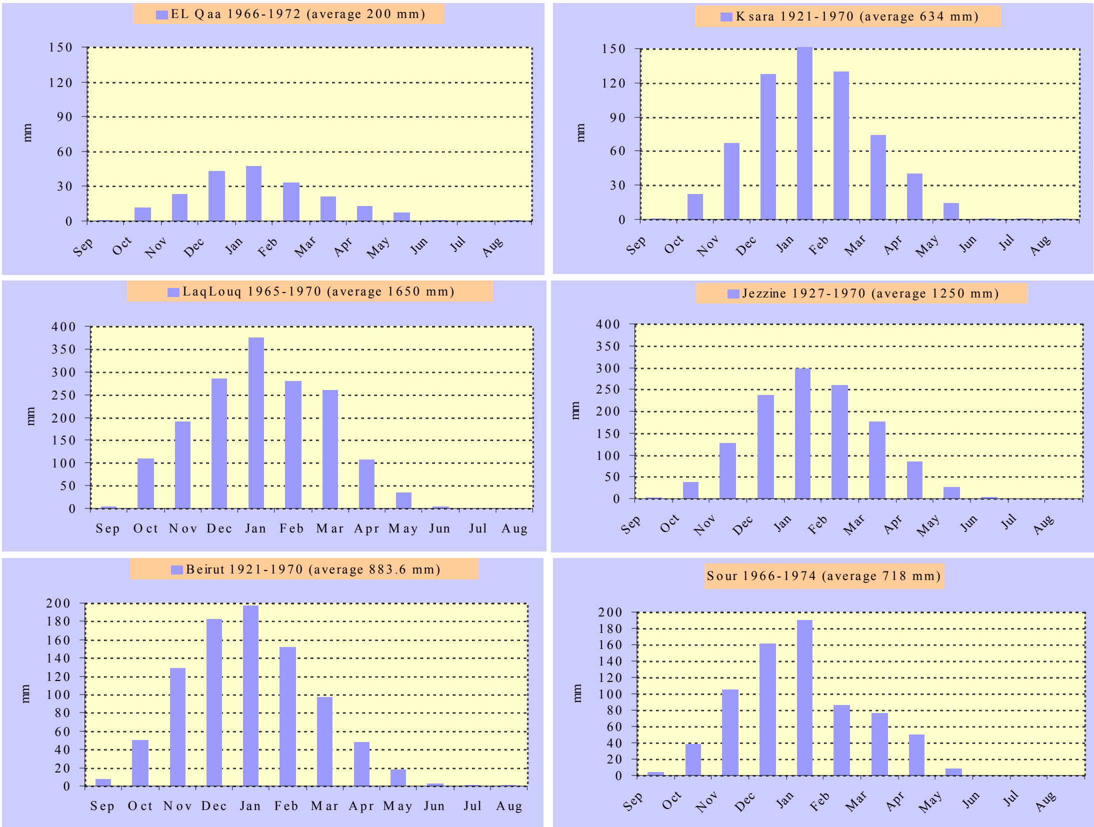

Figure 2. Monthly rain distribution at different Lebanese locations

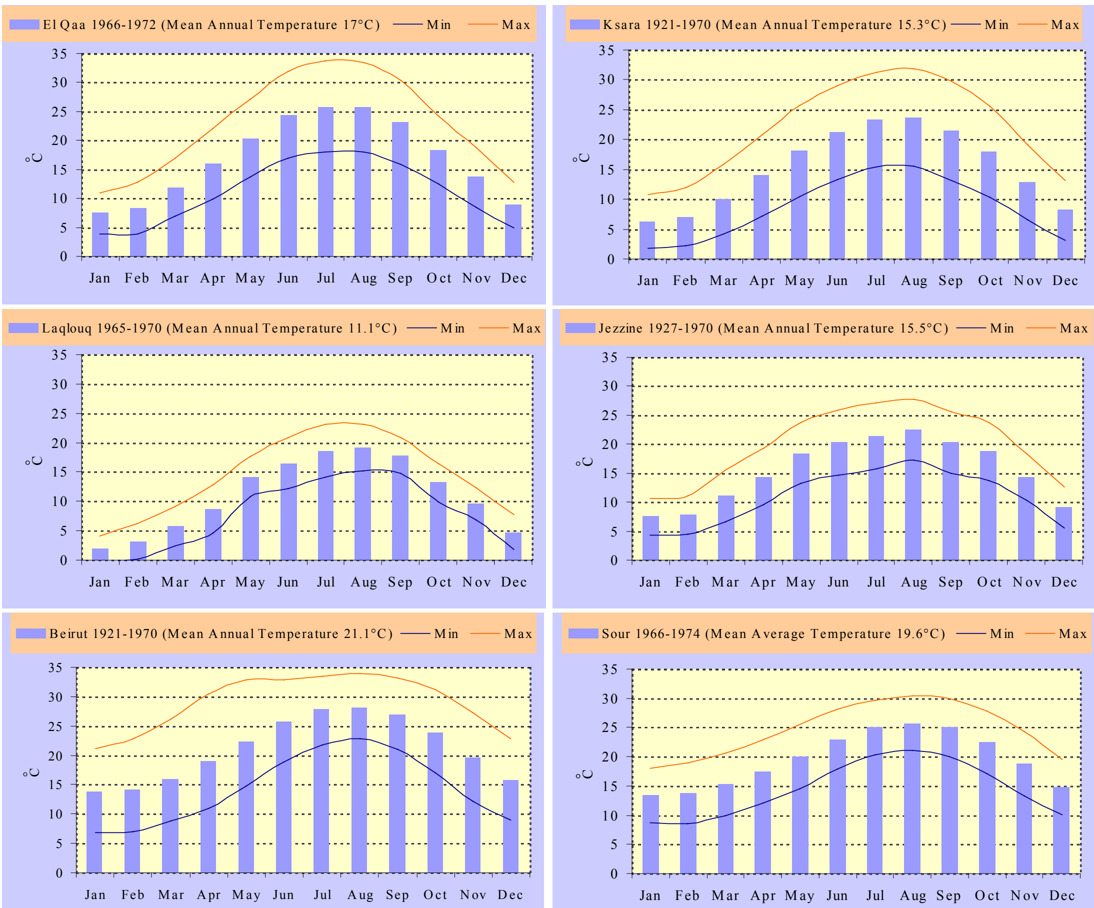

Figure 3. Monthly averages of air temperatures at different Lebanese locations

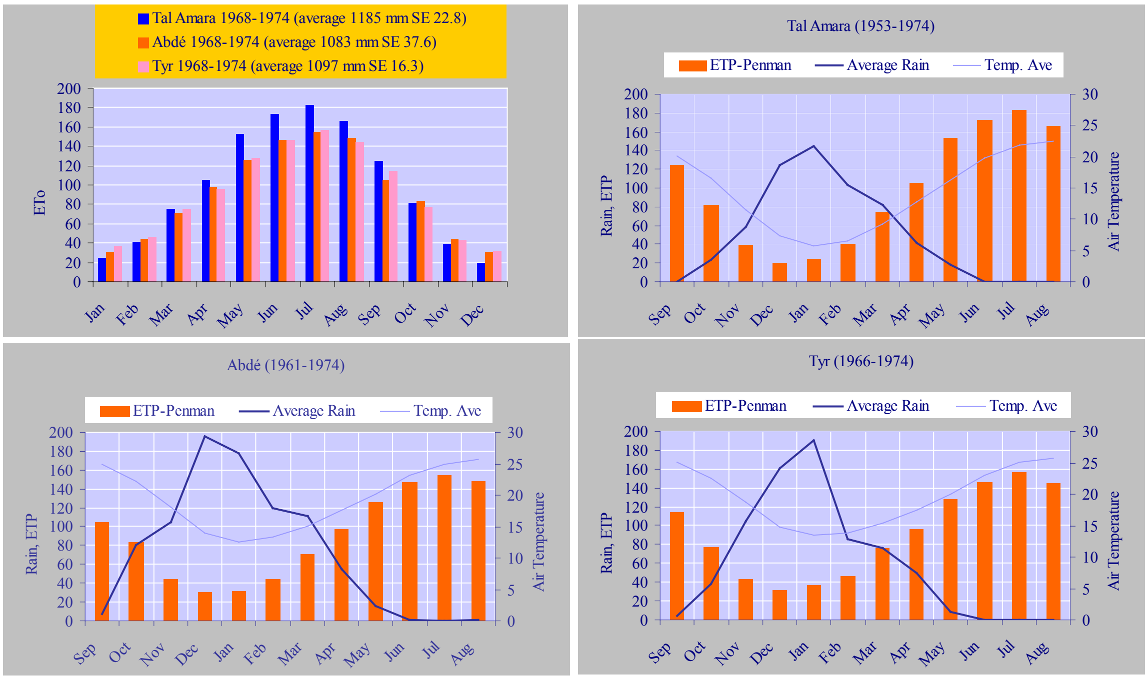

Figure 4. Average monthly potential evapotranspiration and rain-air temperature plotting curve

3) Climate change

3.1) Basic concepts

Weather and climate have a profound influence on life on Earth. The weather is the fluctuating state of the atmosphere around us. The climate is the "average weather" (more rigorously, it is a statistical description of weather, including variability and extremes as well as averages); climate involves the other components of the climate system in addition to the atmosphere (Figure 5; Met Office, Hadley Centre for Climate and Research, 2002).

The atmosphere: its circulation, the heat (terrestrial radiation) and light (solar radiation) which pass through it, and the processes which go on in it, such as the formation of clouds and the atmospheric chemical reactions that determine the concentrations of some of its important constituents, such as methane and ozone.

The ocean: There is a constant exchange of heat, momentum and water between ocean and the atmosphere. The ocean acts as a heat sink to delay climate change. In addition, ocean currents transport large amounts of heat and water around the world.

The land surface, including its vegetation and seasonal snow cover, has an important influence on the flow of air over it, the absorption of solar energy, and the water cycle.

The cryosphere: those parts of the world whose surface is affected by ice, principally sea-ice in the Arctic and Southern Oceans and the land-based ice-sheets of Greenland and Antarctica.

The biosphere: Life on land (the terrestrial biosphere) and in the ocean (the marine biosphere) play a major role in the carbon cycle and hence in determining the atmospheric concentration of carbon dioxide.

Each land point has a value of the soil moisture content in four layers of different thickness which is altered according to how much evaporation is occurring and the amount of precipitation at that point. The vegetation plays an active role in the hydrology at the surface. When precipitation falls some is intercepted by and held in the canopy of the vegetation. The remainder is known as canopy through fall and falls to the soil's surface. This water is absorbed by the soil unless the intensity is too great or the soil is already saturated in which case surface runoff, into rivers and lakes, occurs. Soil water is primarily lost though evaporation through plants, in which case the term transpiration should be used. The amount of transpiration that can occur is limited by the soil moisture, as the soil dries it becomes progressively more difficult for plants to extract water.

Over the sea the roughness length, a representation of surface drag, is increased with increasing wind speed to represent the interaction with waves.

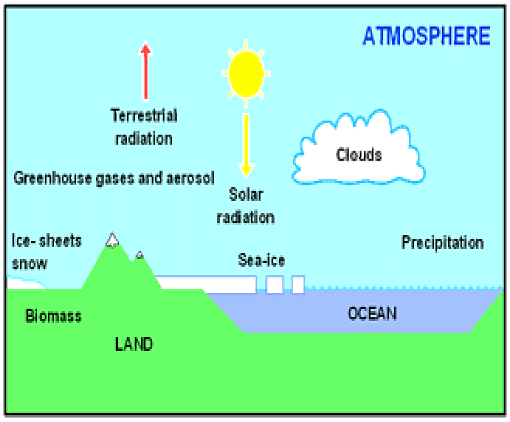

Figure 5. Components of the climate system (Met Office, Hadley Centre for Climate and Research, UK, 2002)

Each land point is assigned characteristics according to the soil type and the vegetation type. These are important in the calculation of the heat, moisture and momentum fluxes at each grid point. If land is covered by snow then the properties, such as albedo, will be drastically altered (Figure 6).

The soil temperature is calculated in four separate levels. The temperature of the soil will change according to the radiation balance at the soil surface. Snow cover will act as an insulator to the soil.

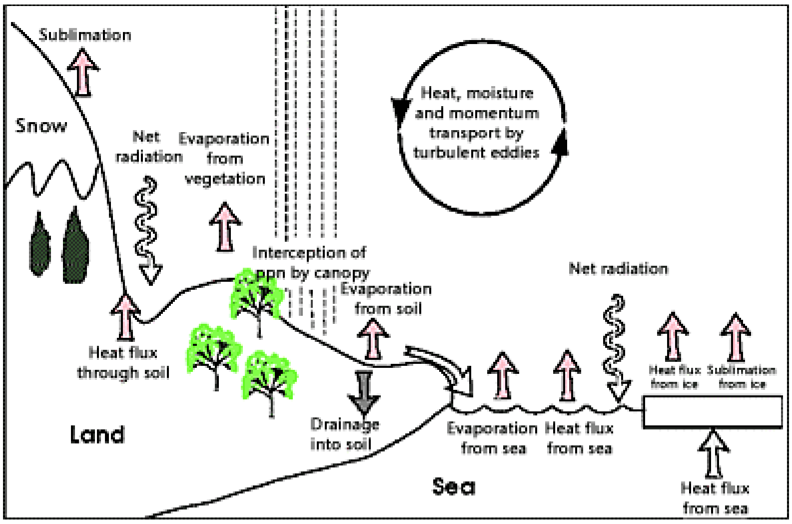

Figure 6. Surface and sub-surface processes (Met Office, Hadley Centre for Climate and Research, UK, 2002)

In order to make predictions of climate change, we have to calculate the effects of all the key processes operating in the climate system. A mathematical formulation that can be implemented in a computer program is referred as a climate model. An example for rain analysis at one-year basis for Beirut and Ksara in the Bekaa Valley is presented in figure 7.

The importance of rainfall analysis for the precision of climate changes in a Mediterranean-type climate could be pointed out through the followings:

- Number of days in which the rain exceeds the threshold rainfall of the area, on a weekly, 10-day, or monthly basis;
- Probability and recurrence at 10-year basis for the mean monthly rainfall;
- Probability and recurrence at 10-year basis for the minimum and maximum monthly rainfall;
- Frequency distribution of rainy days.

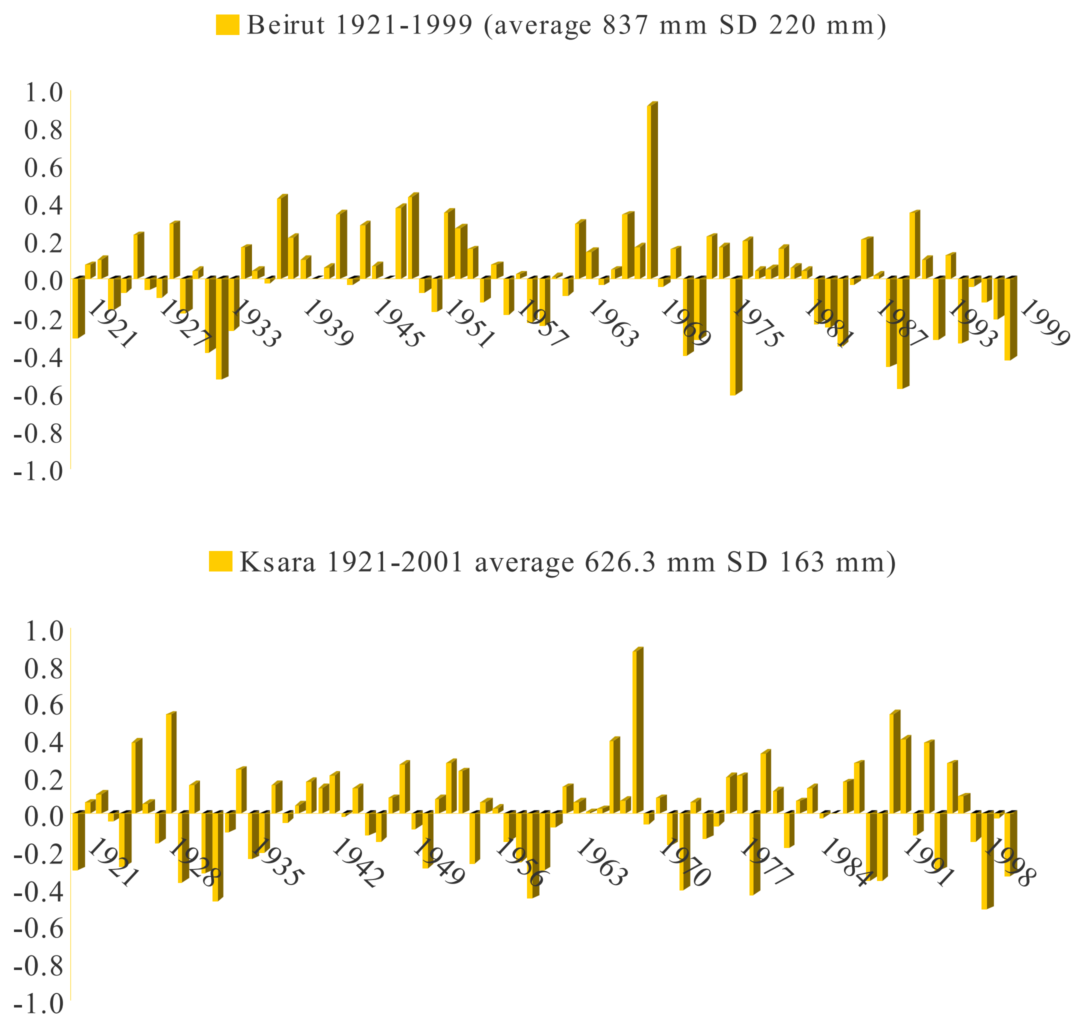

Figure 7.Long-run rainfall analyses for Beirut, and Ksara in the Bekaa Valley

New scenarios of how climate may change in Lebanon over the course of the century have been studied at the Department of Irrigation and Agro-Meteorology. The scenarios are based on past and present rain and temperature patterns, which were undertaken by the Department of Natural Resources of the Mediterranean Agronomic Institute of Chania (Greece). The images produced by METEOSAT showed changes in much more detail than has been available previously. New climate maps for rain and temperature were produced with a resolution of 50 km (Figures 8 and 9).

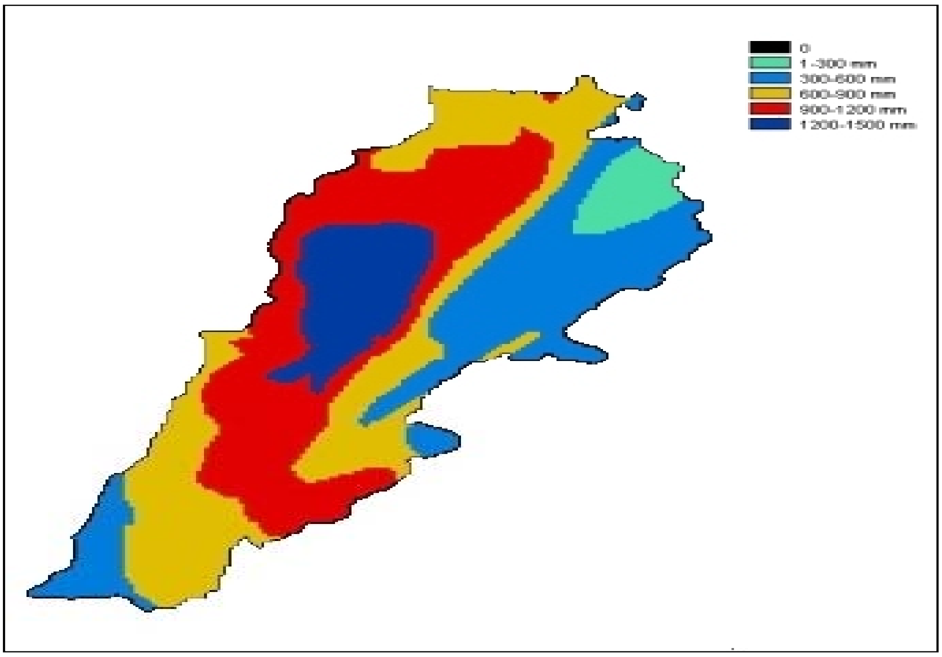

Figure 8. Climatic map of precipitation ranges (*source:* Careaux-Garson, 2001)

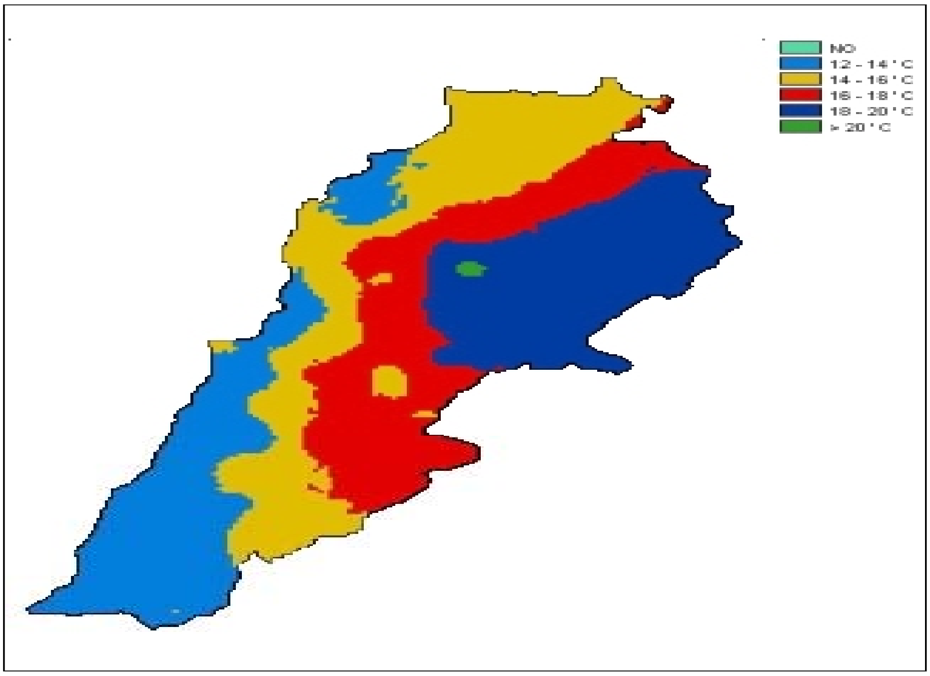

Figure 9. Climatic map of temperature classes (*source:* Careaux-Garson, 2001)

4) Climate change and sustainable Agriculture development

The limitations of visible surface water supplies placed an immediate restraint on economic growth of agricultural sector. Technological improvements in groundwater pumping opened up a vast invisible stock of water which, in turn, is considered the most developed in the country. The search for an increased supply of water was accelerated and giving urgency during the 1980s by the striking expansion in the urban-industrial activities.

Water use was estimated in 1994 at 1293 million m^3, of which 68% for agricultural purposes, 28.4% for domestic use and 4% for industry (Figure 10). The assessment of agricultural water use is based on a water use of 11200 m^3/ha per year from surface water and 8575 m^3/ha per year from groundwater. Because of the absence of collective irrigation networks in most of the agricultural areas, the use of groundwater by farmers throughout deep wells has increased in the last decade, increasing thus the supply of groundwater (Figure 11).

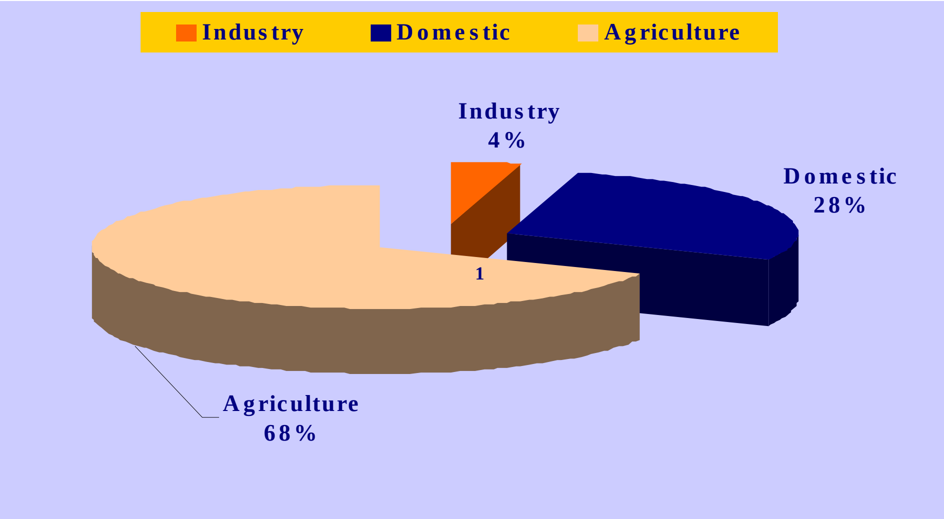

Figure 10. Water use by sector (Irrigation in the Near East Region, 1996)

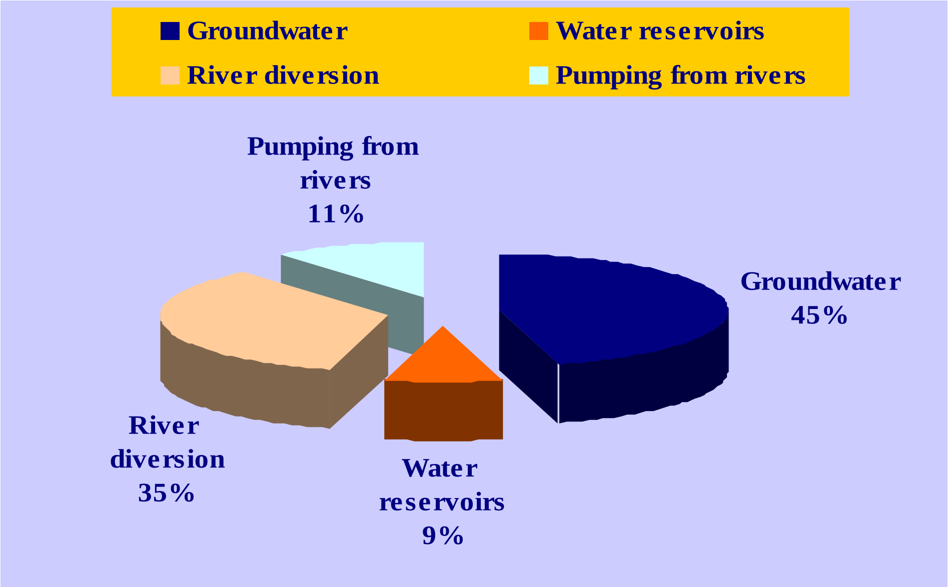

Figure 11. Water withdrawal in % (Irrigation in the Near East Region, 1996)

Government irrigation policy which has been pursued in the middle of the fifty's has contributed substantially to agricultural growth and irrigation development. It was expected that in the second half of this century, an additional agricultural area of approximately 163 000 hectares will be brought under irrigation, and represents twice more the actual irrigated land in Lebanon (Table 1).

Table 1. Perspectives of irrigation development in Lebanon (Irrigation in the Near East Region, 1996)

Irrigation scheme's size	Irrigated lands (in hectares) deriving from both surface and underground water		
	Surface water	Underground water	**Total**
Very small	-	28 000	28 000
Small	50 000	-	50 000
Medium	8 300	2 700	11 000
Large	64 800	9 200	74 000
Total	123 100	40 000	163 000

5) Land use and agricultural practices

In Lebanon, the cultivable land is estimated at 360 000 hectares, or 35% of the total area. In 1994, the total cultivated area was estimated at about 189 206 hectares, of which about 55% (104 120 hectares) consisted of annual crops and the remaining 45% (85 086 hectares) of permanent crops under irrigation conditions. Fruit trees, including olives and nuts, occupy about 54% of the agricultural area, cereals and pulses about 23%, potatoes and sugar beet about 6% and vegetables account for 17% (Lebanese Ministry of Agriculture, 1994). Table 2 gives soil occupation in Lebanon.

Data reported by the Lebanese Agricultural Research Institute in 1996 showed that 44% the Lebanese agricultural lands are located in the Bekaa valley, among them about 57% are rainfed and the remaining 43% are under irrigation. Major crops include irrigated vegetables, cucurbits, potatoes and sugar beet, over 30% of the total cultivable area, whereas rainfed wheat and pulses over 40%. Traditional fruit trees, mainly stone fruits and grapes occupy about 10% and some 20% of the agricultural lands remain in fallow distributed widely in the mild sloppy downhill.

Cropping is relatively intensive, but suffers from poor water management and poor husbandry. Most of the agricultural lands are marginally cultivated to wheat. Cropping pattern concerns not only rainfed crops but also potatoes, vegetables and tree fruits. In North Bekaa, present cropping intensity is only 75% due to limited surface water supply during summer period and high cost of groundwater extraction for irrigation use. Irrigated vegetables, cucurbits and potatoes are used over 15% of the total cultivated area. Rainfed wheat and pulses over 57% and traditional stone fruits and grapes over 5%. The remaining 23% is left in fallow and used as communal grazing land.

Table 2. Use of the cultivable soils in Lebanon (*source: Litany River Authority, 1993*).

Soil occupation	Area (in hectares)
Irrigated area	67 500
Seasonal irrigation and gardening	22 500
Pasture	100 000
Forest and uncultivated soils	80 000
Irrigable soils	90 000
Total	360 000

A study of the ecological characterization should therefore be planned for Lebanon. The study covers climates, soils, topography and land-cover. This in practice involves compiling and adapting of public-domain spatial data sets that can be integrated and implemented through a GIS project, using adequate and accurate software. Spatial data sets include altitude, slopes, agro-climatic zones, soil type, land cover and weather information. For land cover, global or regional data sets could be in some cases insufficient. For this reason, a new methodology can be developed using the Normalized Difference Vegetation Index (NDVI). This methodology for land cover classification is built on the hypothesis that for a country like Lebanon, with many different climatic domains, it is not possible to adopt a single set of NDVI threshold for different land cover types. The current method relies on linking NDVI indicators with climate and land-use information. Through this approach, it would be possible to identify, with a high degree of accuracy, the different land cover types, and to select among them what are the most vulnerable ones to drought risks. For this reason, data sets of climatic information from the national spread weather stations can be used as a part of the National Meteorological Database. Potential evapotranspiration can also be computed using one of the methods recommended by the FAO Consultant Group. The data sets can then be converted into Excel spreadsheets, which allow the users to access easily to individual stations data, and to visualize the derived agro-climatic information, such as climate charts, heat and water balances of specific regions.

The main consideration resulting from the analysis of weather data can then be used for producing maps of eco-zones, i.e. homogenous land classes for physical-climate characteristics, and maps of desertification classes of risk based on the calculation of a Desertification Risk Index (DRI), using mean annual temperature, mean annual precipitation, mean monthly precipitation, and the Normalized Difference Vegetation Index (NDVI), the latter is defined as:

Where ρ_{NIR} is the reflectance in the near-infrared band and ρ_{RED} is the reflectance in the red band. NDVI permits to detect the changes and trends of the vegetation in last

$$NDVI = (\rho_{NIR} - \rho_{RED})/(\rho_{NIR} + \rho_{RED})$$

years by means of high-resolution spatial sensors.

DRI is then calculated as:

$$DRI = \frac{T}{PxNDVIxJ'(P)}$$

Where $T = \frac{t}{t_{\max}}$ (t = average annual temperature, t_{max}= maximum annual temperature)

$P = \frac{p}{p_{\max}}$ (p= average annual precipitation, p_{max}= maximum annual precipitation)

J’(P) =Pielou’s precipitation evenness.

6) Concluding remarks

The pressing question of desertification progress in the Mediterranean drylands, particularly in the Middle East and North Africa, is based on many correlated factors, among which the most relevant are climate change and overexploitation of natural resources. Adding the human implications of large scale regional land use changes, as a part of the global climate-land use feedback. Another factor rises from the slights in hydrological balances, producing in some regions severe drought.

To improve our understanding of the past and struggle to predict the future, the intimate knowledge of the climate is becoming increasingly obvious.

Many of the climate variations can be described as having occurred abruptly, that is within decades or less.

The historical weather records give what we call it the "climate-modulating trajectory", which can be used as warning tool to anticipate sudden changes. These include:

a) Potentially major variations in regional precipitation patterns;

b) Abrupt changes in average regional temperatures;

c) Sudden increases in the rate of gas methane and nitrous oxide to the atmosphere.

Furthermore, human societies are constantly making themselves more vulnerable to climate shifts. Given the human-induced forcing of climate, we can expect societal distress as climate changes is superimposed or increasingly vulnerable populations. Mitigative actions to limit such forcing are thus highly compelling.

For this reason, a weather monitoring system is needed with the aim to improve the knowledge of the climate change over the country, through the intervention of the technical and the institutional capacities of the meteorological service. This can be achieved by the establishment of a computerized meteorological network, the one task is to provide consistent information that can be transmitted in real or near time to national and regional databases. Such network will undoubtedly facilitates the dissemination and use of weather-related information at national and regional scales.

6.1) Recommendations

A risk assessment tool in the dry areas under climate changes is urgently needed to develop guidelines for policy making and management actions.

Research in this field is essential in order to:

- Increase our understanding on the effects of climatic stress on the function of the dry areas;
- Provide a scientific basis for political decisions and relevant management actions to protect these areas in the face of climate change;
- The results from such action strategy will play a major role in formulating policy and management options to:
- Optimize land use and landscape planning, balancing and preserving natural resources and creation of environmentally sustainable agri-tourism and other recreation activities;

- Limit the environmental impact from the industrial sector and any other form of air pollution within the context of global warming.
- Elaborate or indices for the evaluation of the state of environment and the associated risks of desertification, based on the measurement of weather parameters in specific test areas;
- Integrate these indexes with advanced methods of land analysis based on GIS techniques to assess the dynamic evolution of the measured weather parameters t regional unit scale;
- Define classes of risk of degradation associated to the environmental variables and extend the risk analysis to the non-test areas in order to detect their vulnerability to desertification;
- Propose standard methodological guidelines for land degradation assessment of the areas under desertification, and eventually indicating some guidelines to restoration.

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