DROUGHTS AND AGRICULTURE IN LEBANON

CAUSES, CONSEQUENCES, AND RISK MANAGEMENT

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WORLD BANK GROUP

ABBREVIATIONS

Exchange Rate

1 US Dollar = 1511 Lebanese Pounds (Lira)

AEZ	Agro-Ecological Zones
AHZ	Agriculture Homogeneous Zoning
ALADIN	Aire Limitée Adaptation dynamique Développement InterNational
AR5	Fifth Assessment Report
AWS	Automated Weather Station
AWSN	Automated Weather Station Network
C	Celsius
CCLM	Climate Community Limited-area Modelling
CDAS	Climate Data Assimilation System
CERFACS	European Centre for Research and Advanced Training in Scientific Computation
CHIRPS	Climate Hazard Group InfraRed Precipitation
cm	centimeters
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 5
CNRM	National Centre for Meteorological Research
CORDEX-Europe	European Coordinated Regional Climate Downscaling Experiment
CRU	Climate Research Unit
DJF	December, January, February
DRM	Disaster Risk Management
dS/m	deciSiemens per meter
E-OBS	the E-OBS gridded dataset
EC-EARTH	European Centre Earth Modelling System
ENSO	El Niño Southern Oscillation
EU	European Union
EWS	Early Warning System
FAO	Food and Agriculture Organization of the United Nations

GDP	Gross Domestic Product
GEF	Global Environment Facility
GNI	Gross National Income
GPRS	General Packet Radio Service
GPS	Global Positioning System
GWP	Global Water Partnership
ha	hectare
HadGEM	Met Office Hadley Centre Earth System Model
has	hectares
HIRHAM	High-Resolution Limited Area Model
HMNDP	High-Level Meeting on National Drought Policy
ICARDA	International Center for Agricultural Research in the Dry Areas
ICBA	International Center for Biosaline Agriculture
ICHEC	Irish Centre for High-End Computing
IDMP	Integrated Drought Management Program
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
IPSL	Institut Pierre Simon Laplace
IWRM	Integrated Water Resource Management
JJA	June, July, August
km	kilometer
KNMI	*Koninklijk Nederlands Meteorologisch Instituut*
LARI	Lebanese Agricultural Research Institute
LARI-LEB	LARI's Early Warning System smart phone application
m	meter
MAM	March, April, May
MENA	Middle East and North Africa
mm	millimeter
MO	Mediterranean Oscillation
MOA	Ministry of Agriculture
MOE	Ministry of Environment
MOHC	Met Office Hadley Centre
MOI	Mediterranean Oscillation Index
MPI-M	Max Planck Institute for Meteorology
MT	Metric Ton
NAO	North Atlantic Oscillation
NAOI	North Atlantic Oscillation Index
NAP	National Action Plan
NDMC	National Drought Mitigation Center
NDP	National Drought Policy
NFT	Nutrient Film Technique
ONI	Oceanic Niño Index
RACMO	Danish Regional atmospheric climate model

RCP	Representative Concentration Pathways
RDMS	Regional Drought Monitoring System
REMO	REgional MOdel
RMSE	Root Mean Square Errors
RPCA	Rotated Principal Component Analysis
SMS	Short Message Service
SON	September, October, November
SPI	Standard Precipitation Index
TRMM	Tropical Rainfall Measuring Mission
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	Unites States Agency for International Development
USDA	United States Department of Agriculture
W/m^2	Watt per square meter
WeMO	Western Mediterranean Oscillation
WMO	World Meteorological Office
WRF	Weather Research and Forecasting Model

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- "Climate and climate change in Lebanon—an update," Jens Hesselbjerg Christensen, Niels Bohr Institute, University of Copenhagen.
- "Drought, atmospheric systems, impacts and management in Lebanon," Dr. Rachael McDonnell, International Center for Biosaline Agriculture (ICBA).
- "Drought policy and management for the agricultural sector: international experience and in the Middle East and North Africa region," Dr. John Redwood III, Independent.
- "Early Warning System in Lebanon: climate change and the El Niño effect," Ihab Jomaa, Department of Irrigation and Agrometeorology, LARI.
- "Hydroponic system for food production: climate change and the El Niño effect," Ihab Jomaa and Randa Massad, Department of Irrigation and Agrometeorology.
- "Crops and Plants Adapted to El Niño and Climate Change," Ali Chehade and Ahmad Bitar, Department of Plant Biotechnology, LARI.

Cover photograph by Dorte Verner.

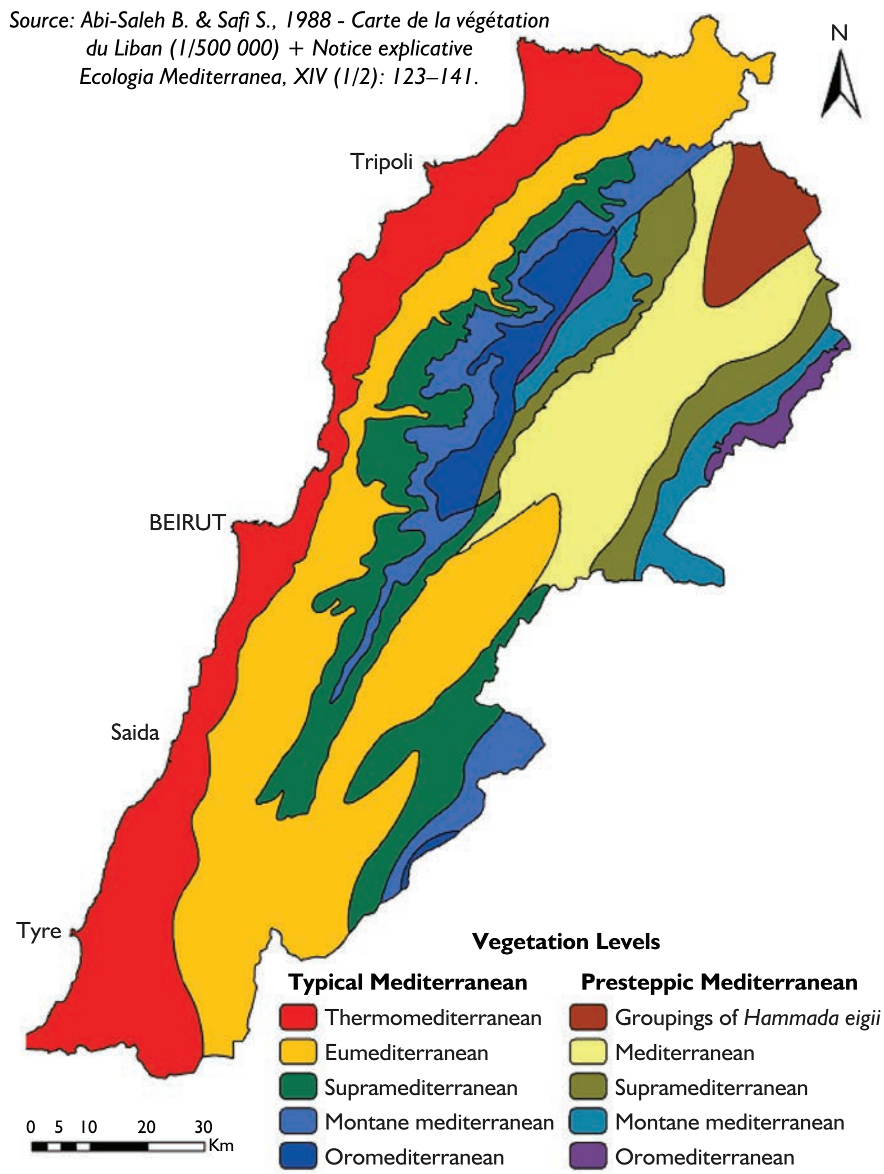
OVERVIEW

This volume examines the causes and consequences of drought on Lebanon's agriculture. Lebanon is getting hotter and dryer. Projections show droughts will likely become more frequent and severe. Climate change, El Niño Southern Oscillation (ENSO), and the North Atlantic Oscillation (NAO) impact the occurrence of drought to varying degrees, with NAO being the biggest short-term driver and climate change being the biggest long-term driver. The drier conditions will have important ramifications on Lebanon's agricultural economy and the wellbeing of citizens working in agriculture. Ramifications include production declines and the loss of livelihoods, among others. Drought was not considered an important issue in the country until recently. But, that view is slowly changing as a series of droughts and other extreme weather events over the past decade demanded the nation's attention. With greater awareness of drought, public institutions slowly begin to change, moving from reactionary responses to taking the first steps towards strategic planning. Still, much more can be done. These actions include: developing a national drought action plan, establishing drought monitoring systems, improving ministerial coordination, utilizing new technologies like Hydroponics and Early Warning Systems, improving the quantity and quality of climatic data, and other actions.

The individual chapters of this volume were compiled using information from five commissioned background papers. These background papers relied on mostly secondary data sources. But, some primary data was collected as well. Through key informant interviews and focus group discussions, thirty stakeholders were consulted. They represent various research institutes, the private sector, government agencies, and civil society organizations. The purpose of this volume is to build off the 2013 book, *Increasing Resilience to Climate Change in the Agricultural Sector of the Middle East: The Cases of Jordan and Lebanon* (Verner et al. 2013). That book prioritized agricultural needs in Jordan and Lebanon, including knowledge generation and technological advancement. This volume adds to both topics.

Agriculture and agroindustry are important economic and livelihood sectors in Lebanon, especially in rural areas. Climate change's adverse impacts on agriculture increasingly translate into a contingent liability for the Lebanese economy. This includes impacts on GDP, the balance of payments, and the trade balance as agricultural and agro-industrial outputs and exports fall but food imports rise to meet domestic demand. Moreover, rainfed crops, which are the most affected by climate variability, are produced in rural areas. These crops are critical for rural livelihoods and livestock and food security needs.

FIGURE 0.1 Lebanon's Bioclimatic Zones



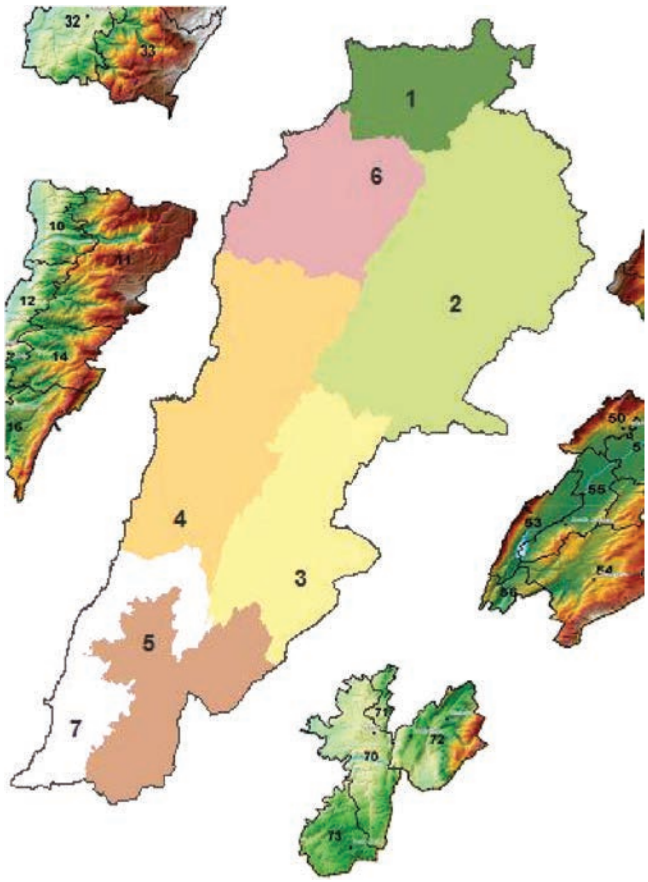
Source: Abi-Saleh and Safi 1988.

Lebanon is a small country, but because of its topographic diversity, has many bioclimatic zones (Figure 0.1). The various bioclimates mean there are also various agroclimatic zones and spatial form synergy. The many different microclimates make standardized definitions of climate zones challenging. Lebanon delineates agricultural zones according to the Agriculture Homogeneous Zoning (AHZ) method. This is less accurate than delineating zones by bioclimates, but also has some benefits. Homogenous zones follow permanent and easily-marked borders that do not change like agroclimatic zones. Figure 0.1 shows the myriad of changing bioclimatic zones compared to the organized simplified AHZs in Figure 0.2. AHZs are convenient for administrative purposes.

Lebanon hosts a diverse set of natural and agricultural plant life. The country has among the highest densities of floral diversity in the Mediterranean basin and is one of the most biologically-diverse regions in the world. It is home to 1.11 percent of the world's plant species, a relatively high proportion given the country's small land mass (Tohme and Tohme 2007). There are also 360,000 hectares of arable agricultural lands in Lebanon. This comprises 35 percent of the country's surface area (MOA 2010). The greatest concentration of agricultural lands is in the Bekaa Valley (42 percent of the total cultivated area), followed by northern Lebanon (26 percent), Southern Lebanon (22 percent), and Mount Lebanon (9 percent).

These lands grow a wide variety of crops. Thirty-one percent of total agricultural production are fruit trees, 23 percent are olives, twenty percent are cereals, 17 percent are vegetables, and the remaining nine percent are industrial crops, like tobacco, grape vineyards, and others (MOA 2010). The most important fruit species grown in Lebanon are citrus, apricots, peaches, plums, cherries, grapes, almonds, apples, and pears, in that order.

FIGURE 0.2 Agro-homogeneous Zones of Lebanon



Source: FAO 2006.

Each of these crops is vulnerable to varying degrees to drought and higher temperatures. For example, olive trees are generally resistant to rapid climate swings, but are still vulnerable to longer-term climate change. Cereal yields are vulnerable to decreased rainfall. The most vulnerable areas for cereal crops are in the Bekaa Valley where reduced precipitation is common during the growing season. Higher temperatures are also a factor for cereal production. Just a one-degree Celsius rise in temperature leads to a 13 percent loss in yields (Tsutsaka and Otsuka 2013). Food legumes, a major component of the Lebanese culinary tradition, are detrimentally impacted by heat and drought. Some crops are more suitable than others to drier and hotter conditions. For example, potatoes, the most cultivated vegetable crop in Lebanon, is a highly efficient water user.

Besides the major crops, there are also several underused crops being promoted in Lebanon. Blackberries have recently been promoted as a potential market crop. They can tolerate some drought and grow in areas of extreme aridity (Weber 1995). This makes it an important option in a hotter and drier climate. Quinoa has also been promoted. Originally from the Andes in South America, it is a highly nutritious food adaptable to different agro-environmental conditions. It can grow during droughts and high temperatures. A FAO project, "Technical assistance for the introduction of Quinoa," is being locally implemented in Lebanon. In an example of an overused crop, illicit cannabis production has risen dramatically in Lebanon since the outbreak of war in Syria.

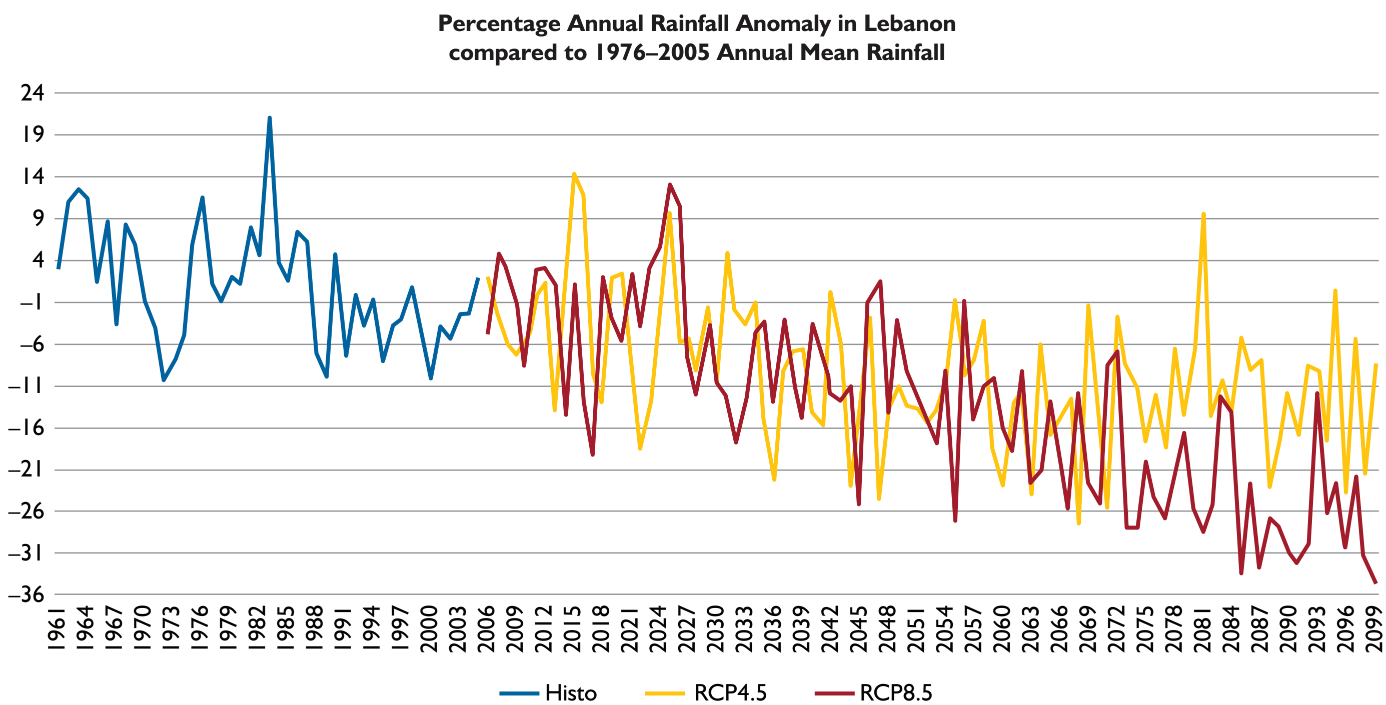
There are also efforts to protect Lebanon's many aromatic, medicinal, and wild edible plants. Aromatic plants include species of the Lamiaceae family, such as mint. These are used for mainly flavoring. Medicinal plants include species belonging predominately to the grass and legume families. These are obviously used for medicinal purposes. The primary group of wild edibles comprise of chicory, eryngo, gundelia, and black salsify. These are used in salads and for cooking. Because these plants lack clear profitability, they are often neglected and even threatened. For this reason, the domestication of several species has begun. For example, capers and Lebanese oregano are native aromatic plants that have been threatened but are now being protected and domesticated.

To sustain its agricultural sector, Lebanon largely relies on imported seeds. It is estimated that local seed production does not exceed three percent of the country's seed market. Legumes, cereals, and tomatoes comprise the limited local seed production. But, private international seed producers import most forage and vegetables seeds. To overcome this reliance on foreign seed sources, the Ministry of Agriculture is implementing a seed multiplication program. Its goal is to procure certified seeds of improved varieties for farmers at subsidized prices.

Lebanon's climate is changing. Lebanon is characterized by hot, dry summers and cool, moist winters. But, the country has experienced an annual mean temperature increase of ~0.3°C per decade since about 1970. According to the IPCC, this long-term warming trend is unequivocal, but short-term warming is more variable. These long-term trends and short-term variations are easily discerned in Figure 0.3 and Figure 0.4. Precipitation changes are often a complex consequence of large-scale drivers, like radiative forcing from enhanced greenhouse effects, and local and regional feedbacks that may work in opposing directions.

Like the rest of the region and much of the world, Lebanon faces increased drought risk. Various sources affirm this. The Lebanese Agricultural Research Institute (LARI) reported a forty to fifty percent decrease in rainfall last year compared to an average year. Moreover, 2013–14 was the driest winter on record. Lebanon's meteorological service reported there were just 431 millimeters of rainfall that winter. This was less than half the previous winter's total of 905 millimeters and well below the yearly

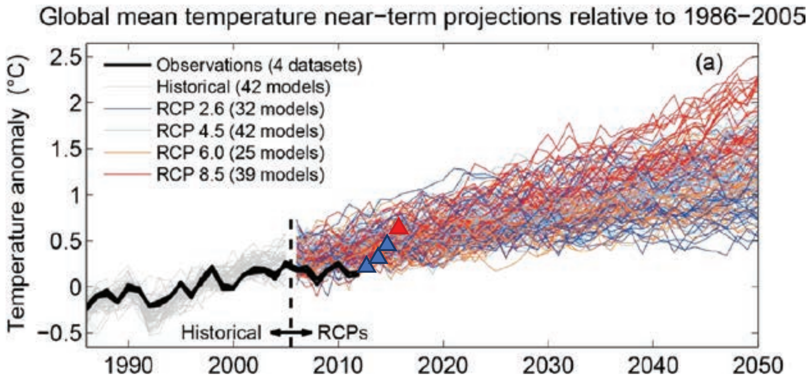
FIGURE 0.3 Annual Rainfall Anomaly in Lebanon Compared to the Mean Annual Total Rainfall for the Period 1976–2005



Source: ICBA (2017) "Drought, atmospheric systems, impacts and management in Lebanon,", International Center for Biosaline Agriculture.

Note: The blue line is the model's average for the oldest period, the yellow line is the model's average for the less-severe RCP4.5 scenario, and the red line is the model's average for the more-severe RCP8.5 scenario.

FIGURE 0.4 Projections of Mean Global Surface Air Temperatures from 1986–2050 (relative to 1986–2005) under All RCP Scenarios



Source: CMIP5 Models.
Note: The black line is observed temperature increases, the grey and colored lines are projected trends. RCPs = representative concentration pathways.

average of 812 millimeters. Figure 0.3 shows projected rainfall declines under different climate scenarios. Figure 0.4 is projected temperature increases. It shows that actual temperature increases are less than the most serious projections but still well with the projected range of change. These changes are driven by anthropogenic climate change and teleconnections.

El Niño Southern Oscillation (ENSO), which includes El Niño and La Niña, is the most well-known teleconnection. In simple terms, teleconnections are atmospheric interactions between widely separated regions of Earth (Glantz 1994). ENSO causes global climate variability on seasonal to inter-annual time scales (Wolter and Timlin 2011). ENSO clearly influences areas in Asia, Africa, and North and South America, but its influence in Europe, North Africa, and the Middle East is less clear. There is an obvious correlation between strong ENSO years and irregular precipitation in Lebanon, but a causal relationship has not been established

The North Atlantic Oscillation (NAO), by contrast, is the most prominent teleconnection in the MENA region (Barnston and Livezey 1987). The NAO consists of a north-south dipole of air pressure anomalies, with higher pressure across the high latitudes of the North Atlantic and lower pressure over Western Europe, the eastern United States, and the central North Atlantic. Long-term observations suggest NAO is a dominant influence on weather in the Middle East. Most notably, it impacts river flows, surface temperatures, and winter precipitation. NAO also drives western and southern Mediterranean precipitation. For example, winter rainfall in Lebanon has declined since the 1970s largely because of a positively phased NAO. Other important teleconnections include the Mediterranean Oscillation (MO) and the Western Mediterranean Oscillation (WeMO).

Lebanon's 2014 drought led to more people realizing drought is a danger. In preceding decades, war and political conflict dominated Lebanese people's conscience. As a result, droughts seemed relatively inconsequential. The 2014 drought raised awareness on its various threats to agriculture and the economy. The most important agricultural threat is to crop production, but drought also has many social and environmental consequences.

Drought's impacts on groundwater usage are considerable. Most crops in Lebanon require supplemental irrigation, and droughts increase irrigation demand, which is met almost entirely by groundwater abstraction. Also, utilities and organizations that provide water for refugee settlements face water shortages that are met through groundwater utilization. Increased groundwater pumping, the need to deepen or drill new wells, and water purchases for refugee relief are major cost burdens for all stakeholders. Moreover, blackouts are frequent in Lebanon, meaning pumps can fail for hours at a time.

Droughts disproportionately impact the poorest communities in Lebanon. When taking account of the entire agricultural value chain, agriculture is an important livelihood. This is especially true in the poorest governorates of Akkar and Baalbek-Hermel, where agriculture is one of the primary sources of income and employment. These communities also have limited capacity to manage drought risk.

Drought can lead to conflict or illegal behavior. Large agricultural areas in Lebanon depend on spring systems. The discharge of these springs fluctuates in response to changing snow cover and precipitation. According to stakeholder consultations, spring failures lead to conflicts within and between villages as reduced water supply must meet competing demands. Likewise, in densely populated areas with more piped water and wastewater infrastructure, farmers frequently tap these water lines illegally. This leads to leakages, water pressure drops, and, in the case of tapped sewage lines, major health risks.

Traditionally, Lebanon has relied on short-term emergency relief measures to manage droughts. Long-term drought risk management can be difficult to advance when current droughts heighten the focus on immediate crisis response. These *ad hoc* responses are a result of drought not historically being viewed by policymakers and the wider public as a major threat to Lebanon. But, *ad hoc* emergency assistance measures are "seriously flawed from the perspective of vulnerability reduction since the recipients of assistance are not expected to change behaviors or resource management practices as a condition of the assistance" (Jabar 2014). However, it is often a severe drought crisis that provides the best opportunity and impetus to implement longer-term drought risk management measures.

Lebanon has not been successful in drought risk management for several reasons. In Lebanon, drought management is not centralized. Drought is managed by individual institutions through their own frameworks. There is not a guiding national strategy for drought management and efforts are not coordinated. Government stakeholders said institutional roles in drought management are not clear. At a broader level, government dysfunction was another challenge, according to stakeholders. One source said, "corruption, bureaucracy, and the country's perennial political paralysis make the prospects for (drought management) changes uncertain" (Middle East Eye 2014). A decade passed without an elected government or an approved budget, causing instability. While institutions continue to function according to their historical roles, progress is stalled because of a lack of a cohesion, clear mandates, coordination, and a strong central authority. Connected to this, local leaders commonly have major influence over local development strategies and legal and regulatory regimes. Compounding these problems, security concerns limit government agencies' access to some areas of the country.

Lebanon's drought management lacks a concerted effort. In stakeholder consultations, only one nationally-coordinated drought relief effort was mentioned. This effort, called the Higher Relief Fund, was ill-fated. The purpose was to make payments to mitigate drought risk, but, funds did not arrive for two years, much too late to alleviate negative impacts. Also, while Lebanon possesses a National Water Sector Strategy (NWSS), it does not specifically address drought management.

One of the limits to the current drought management system is there is no drought monitoring mechanism. Monitoring systems act as information sources to trigger action. Lebanon's relatively advanced meteorological network was severely disrupted and degraded during the civil war. Only recently has this network begun to be rebuilt, so there is limited data available. This dearth of climatological data and the non-centralized nature of water resource data management are major stumbling blocks for monitoring drought. Efforts by the Ministry of Energy and Water to establish a Water Information Center to collect data and make it available have not yet materialized.

Weak subnational land and water rights are major issues during droughts. Progress has been made in Lebanon to codify, unify, and rationalize land and water regimes over the past decade, but there is still lots to do. Many laws date back to the Ottoman era and simply evolved into current laws. Government and civil society stakeholders described this as a barrier to developing coordinated management plans. There are also legal difficulties to creating local water user associations, which are typically a part of effective water management. Most agree that providing some degree of local user management over water resources would be effective, especially during droughts. In cases where local municipalities control water resources for irrigation, there have been notable successes in drought management. In an important step forward, a Water Law, drafted in 2005, was ratified by the Lebanese Parliament in October 2017.

Weak extension services were another subnational problem for drought management. Governmental extension services are under-staffed with personnel responsible for a range of duties under the regional departments of agriculture, not just extension service duties. In the areas without public-sector extension services, agricultural input suppliers become the primary "extension" agents in Lebanon. But, stakeholders said suppliers frequently promote products regardless of their effectiveness. It is not clear if suppliers have vested interests or simply provide poor advice.

Successful drought risk management requires both short-term emergency assistance and longer-term policy, structural, and institutional interventions. Drought risk management requires longer-term interventions because the complex nature of droughts and their social vulnerabilities change. These longer-term projects often focus on water resource management, agricultural technology improvements, and water-related infrastructure developments.

To help build long-term drought risk management, two immediate steps could be taken. First, scale-up a national drought monitoring system. This would improve drought monitoring capacity and the timely communication of monitoring data, both of which are important steps in initiating any drought response. Second, develop a drought management plan that focuses on risk reduction. This could include organizational frameworks and operational arrangements.

Besides these immediate steps, other longer-term steps could be initiated. The first of which is acknowledging that drought is a challenge in Lebanon. Despite the 2014 drought and the level of awareness this raised on drought risk, most Lebanese still do not view drought as a major national challenge. During stakeholder consultations, participants urged a shift in discourse on drought and water management. They said drought and water scarcity had hardly entered the public lexicon, despite Lebanon reaching extreme water scarcity in some areas.

To codify this shift in thinking, drought risk management could be embedded within Lebanon's National Adaptation Plan (NAP) and National Determined Contributions (NDC) to the UNFCCC. NAPs are national strategies by countries to adapt to climate change that are submitted periodically to the United Nations Framework Convention on Climate Change (UNFCCC).

In Lebanon's most recent NAP (UNFCCC 2015), drought was not acknowledged as an important challenge. Rather, the focus was to improve water availability and decrease water usage. By only focusing on water use and availability, Lebanon is not taking steps to identify and classify drought, and as a result, will not be prepared for it. Also, climate change adaptation and drought risk management require many of the same actions, so plans should be fully consistent and integrated (Engle 2013). Updating Lebanon's NDC with drought-related challenges and responses would further integrate the country's climate change adaptation and drought risk management.

The local level also requires embedding drought. This would come in the form of vulnerability assessments. The diverse bioclimatic and agrometeorological zones in Lebanon require local assessments of drought risk. This would help national and international efforts to properly target interventions and give communities the support they require. Assessments can lead to more efficient ways of approaching cropping, food storage systems, water resource management, and infrastructure development. Understanding local vulnerabilities can help build systems that directly respond to conditions, not impacts, so decisions can be made before impacts occur.

Lebanon could continue to engage with international organizations for technical cooperation. In other drought-prone countries, continuous engagement with international experiences has been beneficial both for the development of more dynamic risk management approaches and the infusion of updated knowledge and research findings into these approaches (Redwood 2017).

In Lebanon, there is a strong need for an integrated, cross-ministerial, multi-stakeholder approach to drought management that reflects the new realities of politics and government. Generally, this will require establishing an empowered central authority on drought risk management and institutional coordination. This coordination must first take place within the government, but also eventually with the private sector and civil society. Combining this improved communication and collaboration among governmental agencies and non-governmental organizations with active participatory decision-making is effective in reducing drought risk (Redwood 2017). Greater coordination can also lead to a more open exchange of knowledge and information. Currently, there is a Disaster Risk Management Unit within the Prime Minister's Office, under an ongoing UNDP-funded project, but drought management is not a specified sub-unit.

Another important tool for managing drought risk, is establishing innovative financial mechanisms. Financial incentives and mechanisms like crop insurance and national drought contingency funds—or natural disaster funds more generally—may be considered. Effective drought management requires both supply side—like expanding water availability—and demand side measures—like price controls or water use restrictions. These measures conserve and allocate water during periods of water shortages according to pre-defined priorities. These mechanisms are being applied in places as different as Australia, California, and Morocco (Redwood 2017). Incentives for farmers to participate in these financial mechanisms would avoid moral risks and added fiscal costs.

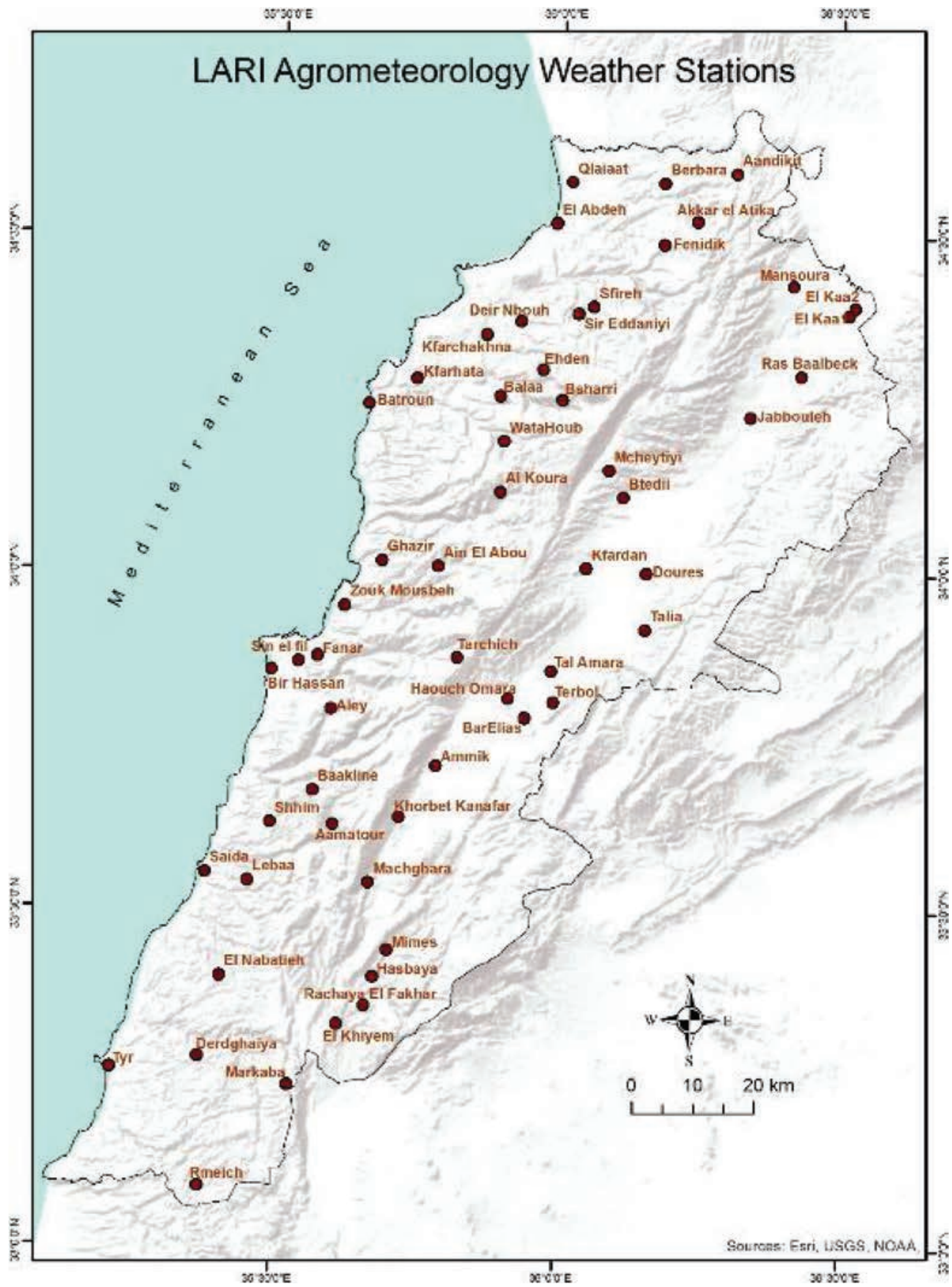
Finally, there are opportunities to improve and expand new technologies like hydroponics and a drought Early Warning System. Lebanon is ideally suited for an expansion of hydroponics. Lebanon has increasing water pressures, large urban populations, small land holdings, and large refugee communities. All challenges that hydroponics can help mitigate. But, it also has logistical conditions that are helpful. Lebanon has been engaged in protected cultivation for decades, like greenhouse agriculture. This started along the coast in the 1970s, and has lately become popular inland as well. Protected crops are gateways for growers to enter hydroponic schemes. After all, hydroponics is simply an advanced, more productive form of protected cultivation, so a transition is not such a giant leap. This is not to say a transition is simple. It will still require investment, albeit less than if starting from scratch, and still requires high technical capacity. Even small-scale hydroponics require piloting, awareness raising, technical training, and field investigations.

Currently, hydroponic cultivation in Lebanon is limited. Recently, 400 square meters of land was set aside in northern Lebanon for hydroponics crop farming (The Daily Star 2017). This was commissioned by the Hyundai Startup Company in 2015. Still, there are only four larger-sized hydroponic producers in the country. Two of these are located on the southern coast, and two along the northern coast. Previously there was one in the Bekaa Valley, but it was forced to shut down after a fungal outbreak, brought on by unseasonably warm temperatures, destroyed the crop. Also, since hydroponics require freshwater to maintain nutrient solutions, saltwater infiltration on the coast makes many of those areas unsuitable. Generally, hydroponics require relatively large capital investments and technical know-how, which has tempered its expansion in Lebanon.

LARI, the Lebanese Agriculture Research Institute, has created weather forecasting facilities and developed a nationwide drought Early Warning System (EWS) for Lebanese growers. These services necessitate daily monitoring, recording and forecasting. LARI's experts analyze the gathered weather data and develop information services before disseminating to farmers and the public. But, implementing a functional EWS in Lebanon has proven difficult. First, Lebanon's rugged topography and multiple agro-climatic zones makes it difficult to target farmers. Second, Lebanon's homogenous agricultural zoning does not properly delineate different agricultural areas. So, EWS information in certain zones may not be relevant for many farmers. And third, to achieve required accuracy levels, Lebanon needs many more long-term weather stations. Until recently, there were five meteorological stations in Lebanon, only three of which have sufficiently long recording histories to properly identify weather anomalies. These stations include Beirut (1888–2003), Ksara Obsy (1921–90), and Tripoli (1931–2003). But, this information is less helpful for the rest of the country and building and maintaining new weather stations is expensive.

Recognizing these challenges, LARI created an Automated Weather Station Network (AWSN). The AWSN generates climate data on most of the country's agro-climates for agro-meteorological services. The AWSN serves agricultural industries, researchers, and other public and private organizations. The AWS network covers much of Lebanon, and expands greatly on the five existing stations. Moreover, data is available for free to anyone. The AWSN started in 2009 with 25 stations and gradually expanded to sixty stations by 2016 (Figure 0.5). Observational climate data is transferred through GPRS technology to centrally-located computer servers. The AWSN is inspected monthly and repaired when needed. Climate sensors are replaced as specified by manufacturer recommendations. The AWSN is not ideal for monitoring climate changes because, as we discussed, a longer historical record would be needed. But, over-time these stations will be essential. Alternatively, Lebanon could consider investing in historical data collection to make better use of the AWSN, but an analysis of the costs and benefits of such research should be carried out first.

FIGURE 0.5 LARI's Automated Weather Station Network Locations



Source: LARI 2016.

CHAPTER
ONE

INTRODUCTION

This report examines the causes and consequences of drought on Lebanon's agriculture. It finds that Lebanon is getting hotter and dryer, while droughts will likely become more frequent and more severe. We see that climate change, El Niño Southern Oscillation (ENSO), and the North Atlantic Oscillation (NAO) may impact the occurrence of drought to varying degrees, with NAO being the largest short-term driver and climate change being the largest long-term driver. The drier conditions will have important ramifications on Lebanon's agricultural economy and the well-being of citizens working in agriculture. Impacts from drier conditions include production declines, loss of livelihoods, and many others. Until recently, drought was not considered an important issue in the country, but that view is slowly changing because of a series of droughts and other extreme weather events that occurred over the past decade. With greater awareness of drought, public institutions have also slowly begun to change, moving from reactionary responses to taking the first steps towards strategic planning. Still, much more can be done. These actions include: developing a national drought action plan, establishing drought monitoring systems, improving ministerial coordination, utilizing new technologies like hydroponics and Early Warning Systems, and improving the quantity and quality of climatic data, among others.

METHODOLOGY

The individual chapters of this volume were compiled using information from five unpublished background papers. These background papers relied on mostly secondary sources of information. But, thirty stakeholders in Lebanon's agricultural sector were also consulted.[1] These consultations were carried out through structured interviews and focus group discussions. They included stakeholders from research institutes, the private sector, government agencies, and civil society organizations.

This report builds off the 2013 book *Increasing Resilience to Climate Change in the Agricultural Sector of the Middle East: The Cases of Jordan and Lebanon* (Verner et al 2013). This book helped

[1] The International Center for Biosaline Agriculture (ICBA) and the University of Nebraska National Drought Mitigation Center carried out these consultations as part of a USAID funded project (MENA-RDMS) in Lebanon from June to August 2016.

Jordan and Lebanon's understanding of the specific challenges and opportunities posed by climate change in the agricultural sector. It presented local-level priorities, informed by stakeholder inputs, to build agricultural resilience in both countries. The book had three objectives. These include: (1) better understanding of climate change projections and impacts on rural communities, specifically the Jordan River Valley and Lebanon's Bekaa Valley; (2) engaging locals in a participatory fashion to craft agricultural adaptation options; and (3) developing local and regional climate change action plans.

Stakeholders in Lebanon prioritized the following actions:

- Adopt new irrigation technologies;
- Launch projects to construct water harvesting reservoirs;
- Manage climate change-related pests, diseases, and plant disorders;
- Produce and distribute plant materials adapted to climate change;
- Increase capacity for climate change adaptation; and
- Evaluate and maintain local plant varieties adapted to climatic change.

Several of these priorities are discussed in the present volume. Moreover, the authors of the 2013 book made a couple recommendations that are being expanded upon in this report. First, they recommend utilizing new technologies in the agricultural sector, with mechanisms in place for continuous revision. Chapter 8 looks at some of these new technologies. Second, they recommend Lebanon improves climate projection information and its accessibility. Chapter 4 presents the most up-to-date climate projections.

ROAD MAP

This volume continues by describing Lebanon's agroclimatic zones and agricultural sector in Chapter 2. Chapter 3 takes an in-depth look at Lebanon's agricultural sector, describing the main crops and their climate requirements. Chapter 4 describes Lebanon's climate, especially as it relates to agriculture. Chapter 5 looks at drought and its impacts in Lebanon. Chapter 6 looks at the atmospheric dynamics and teleconnections that contribute to drought. Chapter 7 projects future climate scenarios in Lebanon, with a focus on drought and the conditions that contribute to it. Chapter 8 examines how Lebanon's public and civil society sectors have responded to drought, including fledgling technological advancements like hydroponics technologies and a mobile-based Early Warning System. Chapter 9 proposes ways to improve Lebanon's drought risk management.

CHAPTER
TWO

LEBANON'S AGROCLIMATIC ZONES AND AGRICULTURAL SECTOR

Lebanon is a small, geographically diverse country with countless microclimates. This diversity makes defining agroclimatic zones difficult. Because of this challenge and a general lack of climate data, the country relies on using Agricultural Homogenous Zones to define its major agriculture producing regions. This Chapter looks closer at these diverse zones.

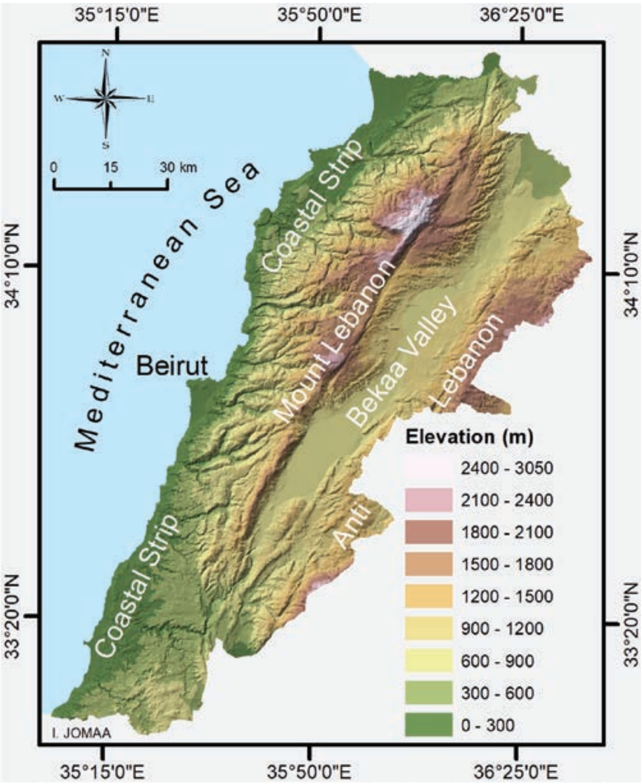
AGROCLIMATIC ZONES

Lebanon is a small country on the eastern shore of the Mediterranean Sea. Its average north-south and west-east distances are about 200 kilometers × 50 kilometers (Figure 2.1). Because of its size and placement, Lebanon is affected by both maritime and continental winds. Mount-Lebanon and Anti-Lebanon are two parallel mountain ranges that run southwest to northeast, and are separated by the Bekaa Valley. This rugged, mountainous topography generates many microclimates. More than have ever been formally defined. The general climatological setting of the region is characterized by a steep climatological gradient between the Mediterranean and the interior of the sub-continent; from a "warm Mediterranean climate" to a "warm desert climate." Explained slightly differently, the coast has a typically Mediterranean climate, while inland is characterized by a pre-steppe-Mediterranean climate (Table 2.1). Lebanon, together with its extension into Mesopotamia, forms a climate conducive with agriculture. This area, known as "the fertile crescent," was the first agricultural region in the world.

Before describing Lebanon's agroclimatic zones, we should define some terms.

- Agroclimatic zones refer to areas that share similar soil types, temperatures, rainfall patterns, and water availability that influence vegetation types.
- Bioclimatic zones are vegetation zones that correspond to mean annual temperatures at different latitudes and altitudes.
- Agro-ecological zones (AEZs) are geographical areas exhibiting similar climatic conditions that determine their ability to support rained agriculture. At a regional scale, AEZs are influenced by

FIGURE 2.1 Lebanon's Geography



latitude, elevation, temperature, and seasonality, and rainfall amounts and distribution during the growing season.

- Hardiness zones are geographically-defined areas where certain plants are capable of growing because of temperature hardiness or the ability to withstand minimum temperatures. The United States established USDA hardiness zones to delimit various crop types suitable for those areas. The American Horticulture Society has developed the Plant Heat Zone, which is an expansion on traditional hardiness zones to include the number of days per year when temperatures exceed 30°C.
- Agroecology is the study of ecological processes applied to agricultural production systems. The prefix agro- refers to agriculture. Bringing ecological principles to bear on agroecosystems can suggest novel management approaches that would not otherwise be considered.
- An agroecosystem is the basic unit of study in agroecology. It is somewhat arbitrarily defined as a spatially and functionally coherent unit of agricultural activity. It includes the living and nonliving components of that unit and their interactions.

TABLE 2.1 Vegetation and Bioclimatic Zones of Lebanon and Forest Types

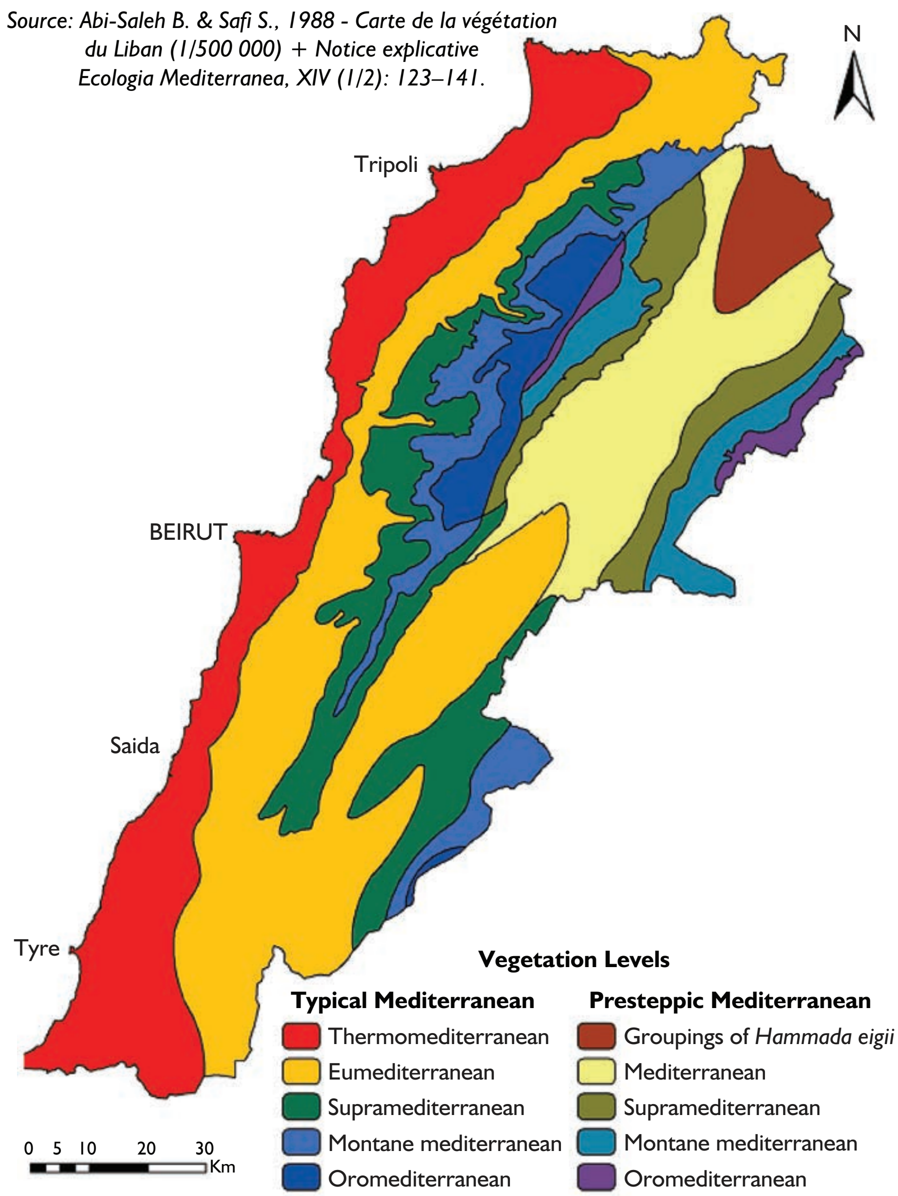
Floristic Ensemble	Forest Types	Q Calliprinos*	Ceratonia Siliqua	Pinus Pinea	Pinus Brutia	Cedrus Libani	Juniperus Excelsa	Abies Cilicica	Cupressus Sempervirens
Mediterranean	Thermo (0–500 m a.s.l)								
	Eu (500–1,000 m)								
	Supra (1,000–1,500 m)								
	Mountainous (1500–2000 m)								
	Oro (>2,000 m)								
Mediterranean presteppe	Medit. presteppe (1,000–1,500 m)								
	Supra (1,500–2,000 m)								
	Mountainous (2,000–2,500 m)								
	Oro (>2,500 m)								

**Quercus infectoria* could be found more dominant in oak forests at Supra and mountainous at both floristic ensembles.
Sources: Modified from Abi Saleh 1978, and Abi Saleh et al. 1996.

- ✦ Agriculture homogeneous zones are areas that share socioeconomic conditions conducive with producing similar crop systems behavior. Lebanon uses this to define its agroclimatic zones.

Lebanon includes several bioclimatic zones (Figure 2.2). First, is the thermo-Mediterranean zone that starts at the shoreline and climbs to an elevation of 500 meters. Mainly, sub-tropical Mediterranean trees inhabit this zone. Second, is the EuMediterranean zone that lies between 500 and 1,000 meters above sea level. Here are oaks and other hardwoods. Third, is the Supra-Mediterranean bioclimatic zone between 1,000 and 1,500 meters in altitude. This is where pines and Cyprus trees (*Pinus brutia* and *Cupressus sempervirens*) grow. As the land climbs into the mountains these species start to disappear,

FIGURE 2.2 Lebanon's Bioclimatic Zones



Source: Abi-Saleh and Safi 1988.

giving way to Cedars and Junipers (*Cedrus libani* and *Juniperus excelsa)*. Fourth, is the Oro-Mediterranean and pre-steppe zones above 2,000 meters. These zones are dominated by juniper forests (Table 2.1).

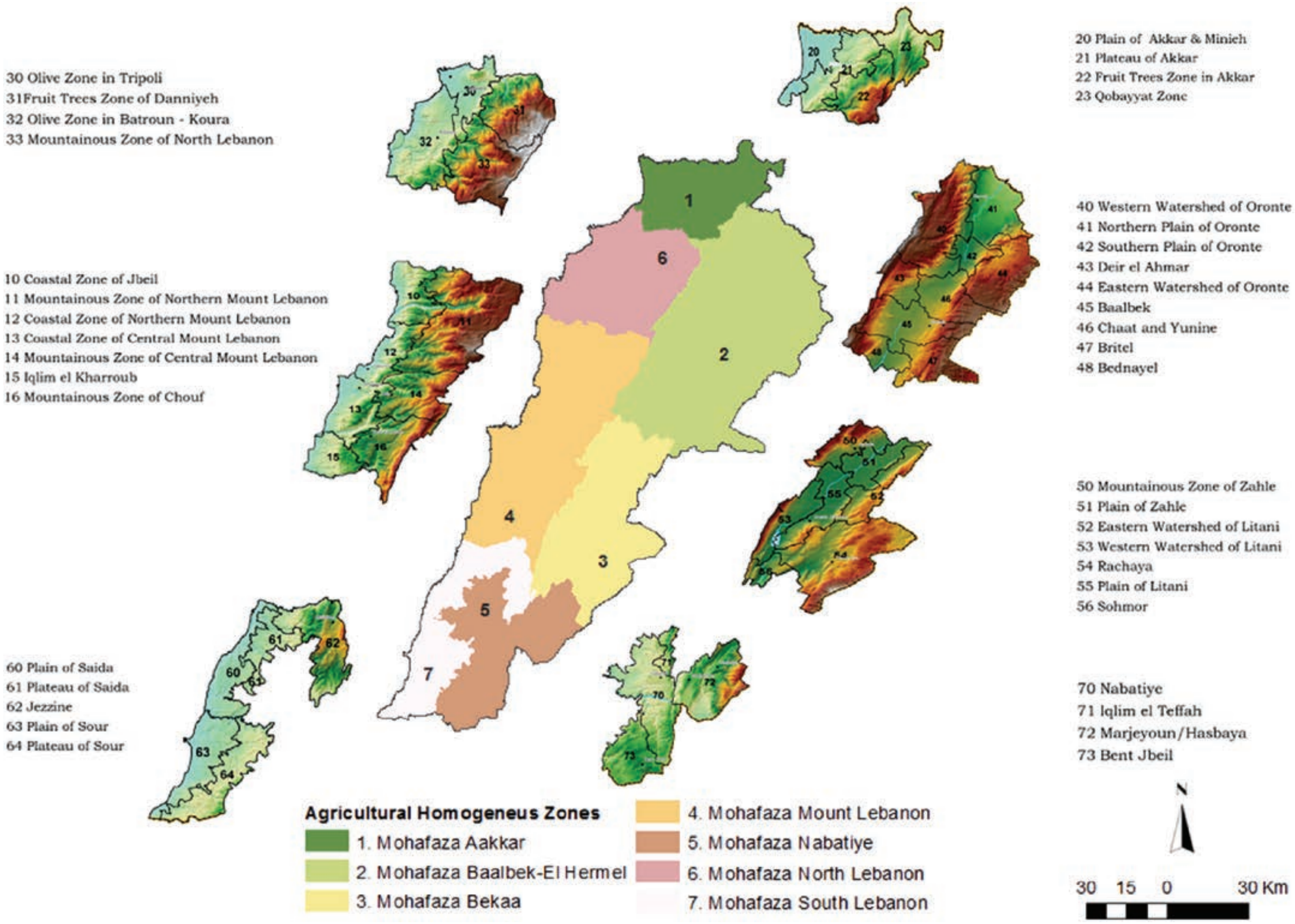
Lebanon's vegetative distribution is highly varied. The many different microclimates have made standardized definitions challenging. Many ecologists have tried to understand the geographic distribution of the natural vegetation and the country's climatic, ecological, and geographical subdivisions (Abi Saleh 1982; Abi-Saleh and Safi 1988; Beals 1965; Chouchani, Khouzami, and Quezal 1974; Mouterde 1966; Pabot 1959; Zohary 1973). They did this first by dividing and delimitating the country into zones based on climatological characteristics (Figure 2.2). But later, natural vegetation was found to be influenced more by soil types and rock substrata than climate (Abi Saleh 1978).

The various bioclimatic zones of Lebanon mean there are also various agroclimatic zones. While these two zone types are not the same, they often overlap. Agroclimatic zones are determined by rainfall, soil type, and temperature characteristics, but it is also these characteristics that usually determine the vegetation of bioclimatic zones. Whatever the case, there is a high level of spatial form synergy. But, from year-to-year the detailed outline of these zones shift because of climate variability.

Climate and soil characteristics are used to define agriculture zoning (Padbury et al. 2002). Agriculture zoning—the process of formally defining the different agricultural regions within a country—is meant to manage yields, recommend crops, and study climate change impacts on agriculture (Fakhry 2004; Fischer et al. 2005; Williams et al. 2008). Generally, agriculture zoning is created for strategic management at local, national, and international levels. There are different costs and benefits associated with using different zoning methods.

Lebanon delineates agricultural zones according to the Agriculture Homogeneous Zoning (AHZ) method (Figure 2.3). This has some benefits over using the agroclimatic zoning method. The biggest disadvantage of agroclimatic zoning is it depends on climatic data averages. This means that zone boundaries will shift depending on a year's climate variability (Parry, Carter, and Konijn 1988). The AHZ method, by contrast, changes less frequently, which becomes a convenience for administrative purposes. Therefore, the AHZ method, also used in the United States, was selected by the Ministry of Agriculture for rural land use planning. In 2000, the UN's Food and Agriculture Organization (FAO) and the International Institute for Applied Systems Analysis (IIASA) developed global Agro-Ecological Zones (AEZ). This method is standardized and highly accurate because it considers cropping systems, administrative boundaries, and the area's historical classification. These AEZs are updated every few years but requires more resources and more comprehensive databases than what Lebanon has at its disposal.

FIGURE 2.3 Agro-homogeneous Zones of Lebanon



Source: FAO 2006.

CHAPTER THREE

LEBANON'S AGRICULTURAL SECTOR

This chapter provides background to Lebanon's agricultural sector. It then looks at Lebanon's key crops and the climate requirements of each. It also describes the country's seed production system. We find that agriculture is a significant sector in Lebanon that possesses many fruits, legumes, cereals, and vegetables. Each of these is vulnerable to drought and climate change, though some more than others. Several new crops could be promoted to better adapt to the changing climate.

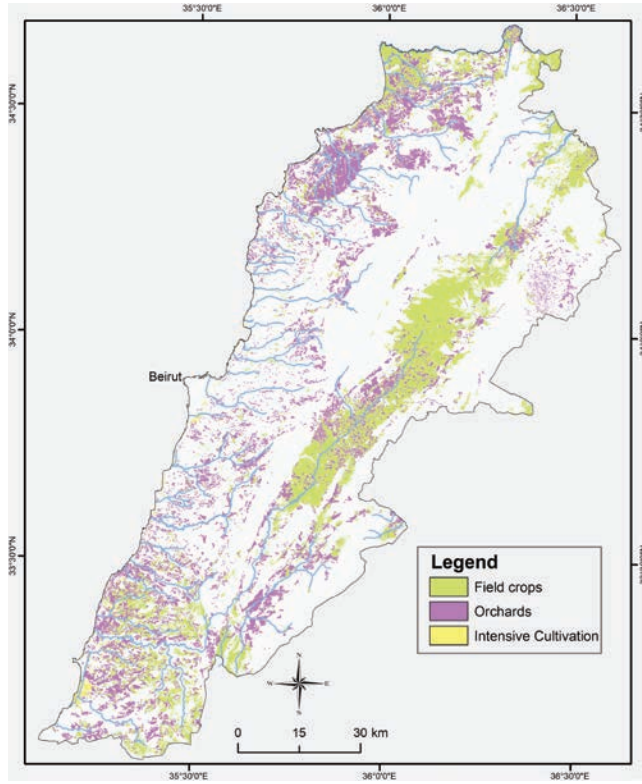
AGRICULTURAL CONTEXT

Agriculture is a significant sector in Lebanon. In 2011, agriculture accounted for 4 percent of Lebanon's Gross Domestic Product (GDP) and employed 6 percent of the labor force (FAO 2009) with wide regional variations (up to 25 percent). In 2012, agriculture accounted for 15 percent of total national exports and imports. In areas where most crops are produced, agriculture contributes up to eighty percent of local GDP. There are an estimated 360,000 hectares of agricultural arable lands in Lebanon. This comprises 35 percent of the country's surface area. Currently, Lebanon has 232,200 hectares of cropland, including 102,471 hectares of temporary crops, 125,928 hectares of permanent crops, and 3,801 hectares of greenhouses (MOA, 2010). The greatest concentration of agricultural lands is in the Bekaa Valley (43 percent of the total cultivated area), followed by northern Lebanon (26 percent), Southern Lebanon including Nabatiye (22 percent), and Mount Lebanon (9 percent) (Figure 3.1). The Bekaa Valley has mainly shallow soils that are cultivated with rainfed crops and, where water is available, with irrigated fruits and field crops. The entire valley is suitable for mechanization. The northern and southern Lebanon coastal plains are characterized by shallow or deep soils. About 90 percent of the region's cultivated land is irrigated. The Mount Lebanon Range has diverse soils—both deep and shallow—and lands—both wide and narrow valleys. The area is cultivated with rainfed and irrigated wheat, fruit trees, tobacco, and vegetables. According to the last census in 2010, there were 169,512 farm holdings in Lebanon (MOA and FAO 2010) (Table 3.1). On average, each holding was only 1.4 hectares of land.

Lebanon hosts a rich variety of plants and wildlife. The country has among the highest densities of floral diversity in the Mediterranean basin and is one of the most biologically-diverse regions in the world. It is home to 1.11 percent of the world's plant species, a relatively high proportion given the country's small land mass (Tohme and Tohme 2007). Lebanese flora counts 2,600 species of vascular plants, 8.5 percent of which are endemic to Lebanon, Syria, and Palestine. Another 3.5 percent, or 92 species, are strictly endemic to Lebanon (MOA,UNEP, and GEF 1996).

The agricultural sector produces many plant and animal products. Thirty-one percent of total plant production are fruit trees, 23 percent are olives, 20 percent are cereals, 17 percent are vegetables, and the remaining 9 percent are industrial crops, tobacco, grape vineyards, and others (MOA and FAO 2010). Each crop within these systems has different water and climatic requirements. These are examined in detail below. Over eighty crops are cultivated in Lebanon, which does not include forage, forest, medicinal, or ornamental plants. Moreover, many wild harvested plants are used for food. This includes leafy vegetables and aromatic plants. These plants are important for their cultural and nutritional value. Livestock—like goats, sheep, and cattle—are also raised, while poultry is the country's most productive agricultural commodity (in dollar terms) (Table 3.2). Tomatoes, potatoes, almonds, and milk are the next most productive (in order). Table 3.3 shows the top commodity exports from Lebanon by total value. The illicit production of cannabis is described in Box 3.1.

FIGURE 3.1 Lebanon's Agricultural Land Types



Source: Modified from MOA/MoE 2002. Landcover map of Lebanon for the year 1998 (MOS: Mode d'Occupation du Sol). Prepared by the Lebanese National Council for ScientificResearch (CNRS) Remote Sensing Center with the collaboration of IAURIF (Institutd'Aménagement et d'Urbanisme de la Région d'Ile de France). LEDO program,UNDP. Ministry of Agriculture and Ministry of Environment (Lebanon).

TABLE 3.1 Number of Holdings and Area of Cultivated and Irrigated Cultivated Land

Mohafazat	Number of Holdings		Cultivated Land		Irrigated Cultivated Land	
	Total	%	Area (ha)	%	Area (ha)	%
Bekaa (w/ Baalbeck-Hermel)	34,085	20	99,274	43	61,569	55
North Lebanon (w/ Akkar)	55,756	33	59,417	26	24,849	22
Mount Lebanon	31,178	18	20,588	9	9,396	8
Nabatiye	26,382	16	26,095	11	4,939	4
South Lebanon	22,111	13	25,621	11	12,203	11
Total	169,512	100	230,995	100	112,956	100

Source: MAO and FAO 2010.
Note: ha = hectares.

TABLE 3.2 Major Agricultural Production Sectors in Lebanon, 2010

Rank	Commodity	Production (US$1,000)	Production (MT)
1	Indigenous chicken meat	198,091	139,069
2	Tomatoes	102,739	278,000
3	Potatoes	92,880	574,100
4	Almonds, in shell	84,103	28,500
5	Cow milk, whole, fresh	78,171	250,500

Source: MoE 2010.
Note: MT = metric tons.

CLIMATE IMPACTS AND REQUIREMENTS OF KEY CROPS

Crops in Lebanon are diverse, each with its own unique climate requirements and potential climate impacts from El Niño Southern Oscillation (ENSO) and climate change. Details of all major production crops are described below.

Fruit Trees

Fruit trees represent the plurality of agricultural production in Lebanon. Thirty-six percent of this cultivation is concentrated in the Bekaa Valley, 25 percent in Northern Lebanon, 22 percent in Southern Lebanon, including Nabatiyeh, and 17 percent in Mount Lebanon (MOA 2010). The most important fruit species grown in Lebanon are citrus, apricots, peaches, plums, cherries, grapes, almonds, apples, and pears (Table 3.4). Each is described in turn.

Apples

Apple blossoms are sensitive to high temperatures (>40°C). Apples require from 400 to over 900 hours of chilling temperatures per season depending on cultivar (Steffens and Stutte 1989). If chilling hours are not ensured, apples' production potential is reduced (Austin and Hall 2001). High temperatures are also associated with drought and less cloud cover, both of which cause damage to apple harvests; apples require sufficient water resources and are vulnerable to sunburn (Trillot et al. 2002). But, climate

TABLE 3.3 Top Five Agricultural Commodity Exports from Lebanon, by Value, 2010

	Commodity	Quantity (tons)	Value (US$1,000)	Unit value (US$/ton)
1	Food prep, nes	16,159	30,217	1,870
2	Sugar confectionery	4,544	24,374	5,364
3	Vegetables preserved, nes	13,509	22,658	1,677
4	Beverage, non-alcoholic	27,194	22,375	823
5	Prepared nuts (excluding groundnuts)	5,657	21,677	3,832

Source: FAO,2010.
Note: nes = not elsewhere specified.

BOX 3.1 Lebanon's Cannabis Production

Cannabis production in Lebanon has risen dramatically since the outbreak of war in Syria. It is estimated that production has climbed more than thirty percent since 2012 (UNODC 2011). According to Al-Monitor (2017), General Ghassan Chamseddine, head of Lebanon's drug enforcement unit, says 3,600 hectares of Lebanon are cultivated with marijuana. These are more cultivated hectares than each of the country's major vegetable crops except tomatoes and potatoes. In fact, Lebanon is the third largest hashish producer in the world (UN 2011). The industry is valued at $4 billion (BBC 2016).

Eradication efforts faltered. Cannabis production initially boomed during Lebanon's 15-year civil war from 1975 to 1990. In the 1990s, there were some efforts to eradicate the illicit crop, and for some time, production declined. But, with the Lebanese military's efforts to control spillover from the Syrian war, efforts to control cannabis growth lost momentum. Authorities—including local governments, the federal government, and even Hezbollah—are too understaffed, underfunded, and preoccupied with Syria to confront powerful hashish producers or crackdown on cannabis farmers (Al-Monitor 2017). As a result, production again increased. Much of the marijuana growth is concentrated in the Bekaa Valley. Once it is harvested, it is taken to one of dozens of processing stations, where it is converted to hashish.

There has been some support for legalizing Cannabis production, but this includes many challenges. Economist Marwan Iskander said legalizing cannabis would contribute $400 million to the public budget and $2 billion to the national economy (Al-Monitor 2017). Walid Jumblatt, the Lebanese Druze leader, called for legalization in 2014—the first prominent national figure to do so (BBC 2016). Also, according to Time Magazine (2015), the powerful hashish producers that once fought the government's efforts to eradicate cannabis plants, are now fighting extremists trying to cross into Lebanon from Syria. This has created an uneasy alliance between drug producers and government forces.

TABLE 3.4 Fruit Tree Cultivation Areas by Governorate

Fruit Trees	Mount Lebanon (ha)	Akkar (ha)	North (ha)	Baalbeck-Hermel (ha)	Bekaa (ha)	South (ha)	Nabatiyeh (ha)	Total (ha)
Apples	3,237	1,627	2,895	2,758	1,455	177	274	12,425
Grapes	1,070	892	479	3,629	3,945	279	315	10,609
Citrus	286	1,378	1,225	12	2	6,362	728	9,994
Cherries	267	73	186	4,073	1,590	20	83	6,291
Almonds	152	1,256	331	2,708	754	68	160	5,427
Apricots	61	48	301	3,947	96	10	52	4,516
Peaches	613	146	646	938	831	78	309	3,560
Plums	413	106	752	242	294	12	102	1,921
Pears	223	157	930	111	300	20	68	1,809

Source: MOA 2010.
Note: ha = hectares

vulnerability is not the only factor. Demographic pressures in Akkar, Bekaa Valley, and other areas are reducing water supplies for irrigation. Thus, large areas of production will suffer from the lack of water, and other areas in lower altitudes will have a diminishing yield due to the decrease in chilling hours. Main apple varieties grown in Lebanon include Gala, Soukari, Red Delicious, Golden Delicious, and others with lower chilling requirements.

Grapes

Both temperature and precipitation changes affect grape production and the quality. These changes will eventually decrease yields and wine quality. The main wine varieties in Lebanon include Syrah, Cinsault, Grenache, Chardonnay, Alicante Bouchet, and Cabernet-Sauvignon. Temperature will be the major limiting factor for grapes in the Bekaa Valley and, to a limited extent, in Akkar. Higher temperatures lead to early budding. This increases the eventual risk from spring frosts (Quirk 2007). This will also expose grapes to sunburn and early ripening. Water demand will rise from excessive evapotranspiration. Growers need to implement adaptive strategies to continue the production of high-quality wines in a warmer and dryer climate. Among various options, the use of adapted plant material is one of the better tools, because it has the advantage of being cost effective and environmentally friendly.

Citrus

Increased water scarcity will have negative effects on citrus production. Citrus' water needs could also degrade local ground water quality (Jensen et al. 1990). In Lebanon's coastal areas, the over-exploitation of groundwater is causing salt water intrusion into aquifers (Bosch et al. 1992). The resulting soil salinity limits citrus production. Although data is limited on the extent of salinity damage to fruit yields, what does exist indicates oranges are among the most sensitive of all agricultural crops. Fruit yields decrease by about 13 percent for each 1.0 deciSiemens per meter (dS/m) increase in the soil's electrical conductivity. But, this problem can be minimized by using certain rootstocks (Maas 1993). Moreover, higher temperatures will accelerate fruit development, leading to earlier maturity, lower acidity levels, and less sugar content in the fruit. About 60 percent of citrus production is locally consumed. The rest is exported to other Arab countries.

Cherries

Cherries are also sensitive to higher temperatures (over 21°C). Chilling requirements are relatively high for cherries. Most local cultivars need more than 700 chilling hours, which is equivalent to about seventy days. If harvests do not reach minimum chilling hours, production declines. As such, vulnerability is impacted by higher winter temperatures that limit frost days. Winter highs also increase the risk of wood insects.

Almonds

Almond cultivation is at risk from many climatic factors, but especially spring frosts (Rodrigo 2000). Although almond is resistant to low winter temperatures, low temperatures in spring during blooming is lethal to almonds' reproductive organs. Higher temperatures, which lead to early bud bursts, increase vulnerability to spring frosts. Traditional almond varieties—like Awja—are especially vulnerable to frost since they tend to bloom early. In response, new late-blooming varieties—such as Tuono, Texas, Ferragnes, and Super Nova—have been introduced to Lebanon.

Apricots

Increased temperatures during apricot budding induce early flowering and have clear negative effects on the subsequent fruit. Warm conditions accelerate anthesis, but not pistil development, leaving flowers with reduced pistils and shorter styles (Rodrigo and Herrero 2002). Short styles and unswelled ovaries are associates with smaller fruits. These flower abnormalities can lead to female sterility, which has been reported in many varieties (Meyer 1966). Traditional varieties, such as Ajami, Biadi, Dahabi, are more tolerant to high temperatures.

Peaches

Increased temperatures during flowering reduces peach flower size and germination. It also stunts the embryo sac's development. High temperatures also significantly reduce a peach tree's fruit set (Kozai et al. 2004). Lebanon has both improved varieties and traditional varieties adapted to climate change (Chalak et al. 2006).

Plums

Heat can damage plums in different ways. The most obvious of which is discoloration caused by too much direct sunlight. Though the most severe damage is caused by as low as a 1°C rise in average air temperature between February and April. This causes the plum tree to blossom early (Chmielewski et al. 2003). This leads to a shorter lifespan and lower production (Cosmulescu et al. 2010).

Pears

Pears are sensitive to rainfall and temperature extremes. Lebanon is already a bit warmer than ideal for pear production so temperature rises are troublesome. These rises lead to drought stress, reduced chilling hours, disrupted reproductive processes, and increased incidence of sunburn (Wand, Steyn, and Theron 2008). This will impact both yields and fruit quality, including poor color development.

Figs

Fig trees can be grown in arid or semi-arid regions. They prefer abundant sunshine and moderate water supplies. At the maturity and development stages, fig trees prefer dry climates. Another advantage is these trees can survive summer temperature highs of 45°C. The fig's tolerance to drought and high temperatures, combined with growing market demand beyond just sustenance, means fig tree planting should be considered an adaptation strategy in Lebanon.

Mulberries

Mulberry trees are also well-adapted to warmer, drier climates and have an important cultural role in Lebanon. At the turn of the 20th century, Lebanon was known for its high-quality silk industry. Besides bearing delicious fruit, mulberries are also an ideal food source for silkworms. The silk tradition in Lebanon goes back 2,000 years. The Phoenicians of Tyre and Sidon produced imperial purple silk, a Mulberry silk considered among the best in the world. But after 1945, the sericulture industry declined sharply and mulberry cultivation was marginalized. Yet, Lebanon's climate is ideal for Mulberry trees. They can survive late spring frosts and withstand severe temperature swings. This, plus the trees' general tolerance to drought and high temperatures make it a useful crop as the climate continues to change.

Bananas

Banana is a tropical fruit tree that requires heat and humidity, and cannot withstand frost. Increased water scarcity from climate change, demographic pressures, sea intrusion into the water table, and increased soil salinization hinders banana growth. This is especially true on the coastal plains. As such, bananas require irrigation to ensure its water needs are met during the arid season. To meet these challenges, greenhouse banana plantations have been introduced in Lebanon. But, these are relatively expensive and require irrigation and infrastructure.

Olive Trees

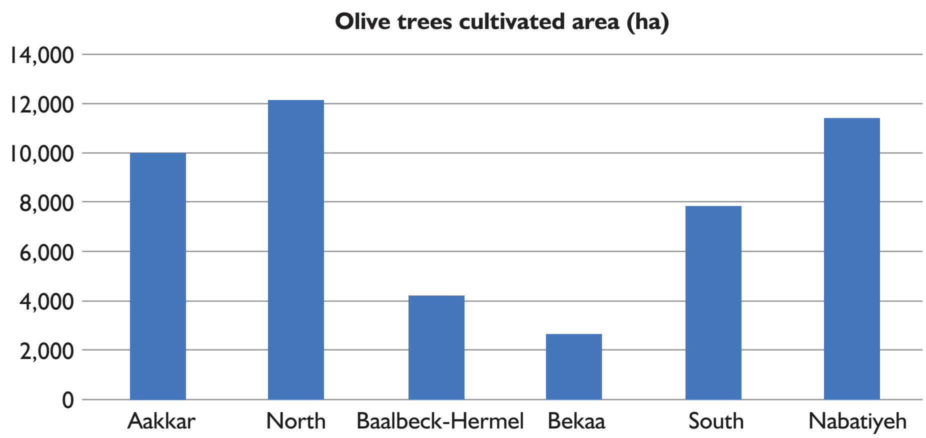
Olives hold cultural and culinary value in Lebanon. Olive trees are largely non-irrigated and represent 23 percent of total cultivated land. Production increased from 48,000 trees in 1990 to 85,200 trees in 2009 (MOA 2010). Figure 3.2 shows the number of hectares over which olives are cultivated in each governorate.

Olive trees are generally resistant to climate swings, but are still vulnerable to changes. The olive tree can withstand long droughts and high temperatures (above 40°C), but warmer or colder weather and wetter or drier conditions can have negative impacts too. Olives are sensitive to prolonged cold weather and freezing winter temperatures. Spring frosts and warm winters can jeopardize production (Loussert and Brousse 1978; MOA and LARI 2008). A study by Chehade and others (2015) reveals that temperature increases can negatively impact olive oil quality. Decreased rainfall can also lead to slight yield reductions especially when combined with reduced chilling.

Cereals

Cereals are the third most-widely grown crop type in Lebanon. They occupy nearly 45,000 hectares, almost half of which are irrigated (47 percent). The Bekaa Valley makes up 65 percent of this area, followed by 20 percent in Akkar, nine percent in Nabatiyeh, four percent in South Lebanon, and two percent in North Lebanon. Wheat and barley are the most important cereals in Lebanon (Table 3.5).

FIGURE 3.2 Cultivation of Olive Trees by Governorate



Source: MOA 2010.

TABLE 3.5 Rainfed and Irrigated Cultivation Areas of Wheat and Barley by Governorate, in Hectares

Governorates	Rainfed Wheat	Irrigated Wheat	Rainfed Barley	Irrigated Barley
Mount Lebanon	32	8	25	0
Akkar	5,359	1,117	574	78
North	428	57	136	1
Baalbeck-Hermel	2,123	2,161	5,708	2,889
Bekaa	2,603	10,645	335	414
South	1,606	36	139	4
Nabatiyeh	3,552	114	371	10
Total	15,702	14,138	7,289	3,396

Source: MOA 2010.

Wheat occupies almost 30,000 hectares of land, almost half of which is irrigated. Barley occupies just over 10,000 hectares, about a third of which is irrigated (MOA 2010).

Wheat

Wheat yields in the Mediterranean region are mostly correlated to rainfall levels, but temperature is also a factor. Spring rainfall declines are the most damaging to wheat production. The most vulnerable areas are in the Bekaa Valley where reduced spring precipitation is common. For temperature, a 1°C rise leads to a 13 percent loss in wheat yields (Tsutsaka and Otsuka 2013). Though, higher autumn temperatures also reduce frost risk.

Barley

Barley has some of the same vulnerabilities as wheat but tolerates poorer soils and lower temperatures. Barley genotypes had a higher tolerance to post-anthesis heat stress than wheat genotypes. Average grain yield reduction in barley and wheat genotypes exposed to heat stress after anthesis, was only 17 percent for barley and 24 percent for wheat (Modhej, Farhoudi, and Afrous 2015). Moreover, certain barley varieties are even tolerant to low rainfall and high temperatures.

Food Legumes

Increased heat and more frequent droughts will detrimentally impact food legumes, which are a major component of the Lebanese culinary tradition. The most important legumes are green pulses like fava beans (1,845 hectares), common beans (1,420 hectares), chickpeas (1,800 hectares), lentils (762 hectares), and dry beans (342 hectares) (MOA 2010). Predicted temperature increases over the next 60 years will expose legumes at every growth stage. Higher temperatures during the flowering and seed development stages are particularly damaging. Heat sensitive cultivars may be rendered sterile if exposed to temperatures above 35°C during flowering (Yadav et al. 2010). The combined effect of drought and heat on grain legumes causes between 18 and 28 percent yield losses. Variety breeding can increase the heat tolerance of food legumes.

Vegetables

Lebanon grows both leafy vegetables and fruit-bearing vegetables. Leafy vegetables include cauliflower (1,950 hectares), lettuce (1,413 hectares), cabbage (1,244 hectares), and artichoke (64 hectares). Fruit-bearing vegetables include tomatoes (4,060 hectares), cucumbers (3,100 hectares), watermelons (2,384 hectares), eggplants (1,700 hectares), melons (1,000 hectares), and peppers (800 hectares). All are grown in irrigated areas except for cucumber, which grows well in hot, dry climates. Lebanon also cultivates 20,100 hectares of potatoes. Potatoes and tomatoes are the most important vegetables in Lebanon in terms of cultivated area, so will be discussed in turn.

Potato

Being a tuber, potatoes are highly efficient in water use. Potato constitutes almost half of the total vegetable cultivation in Lebanon. Potatoes cultivated area doubled from 1999 to 2007. It is an essential crop for food security and trade, as Lebanon is a net exporter. All potato is irrigated in the Bekaa Valley and supplementally irrigated in Akkar (MOA and LARI 2008). Besides water needs, tubers also require mean day temperatures below 20°C, and mean night temperatures below 15°C (Stäubli et al. 2008). Production is affected when temperatures rise or fall out of the range of 10–30°C. As such, higher winter temperatures make potatoes vulnerable, with higher humidity and milder temperatures leading to a higher frequency of disease. In the spring and autumn, potatoes are mostly affected by water availability and temperature extremes. In the summer, potatoes are vulnerable to drought if there is insufficient irrigation water.

Tomato

Tomato is a warm weather crop, with extreme temperatures affecting production. It is the second most-widely grown vegetable crop, equaling 8.8 percent of total vegetable cultivation. Whereas most vegetable seeds are imported from private seed companies, tomato seeds are collected within Lebanon. Tomato is grown in both fields and greenhouses, mostly as an irrigated crop. The tomato plant cannot withstand frost or high humidity. Temperatures below 10°C and above 38°C damage the plant's tissues. Although tomatoes are not particularly water demanding, water stress and long dry periods crack fruits and reduce productivity (Pervez et al. 2009). Tomato production will be affected by predicted temperature rises by the 2050s, but yields could decrease significantly by the end of the century at current warming rates. Under this scenario, the growing period would be shorter, producing less fruit set in summer from water shortages and temperature extremes. Medium altitudes like in the Bekaa Valley and Marjayoun plains will make production vulnerable. But, coastal areas could be the most severely impacted with predicted water shortages and soil salinization.

MINOR AND UNDERUSED CROPS

In addition to the predominant crops listed above, there are several minor and underused crops in Lebanon. Minor crops are those high in value but not widely grown. Underused crops are those that have been used for centuries, but have less importance in Lebanon. Some examples of minor and underused crops are corn, sunflower, sugar beet, blackberry, and quinoa among others.

- Corn was introduced in Lebanon for human consumption and to feed livestock. Its growth is limited to the Bekaa Valley, as profitable corn production requires mechanization and robust irrigation requirements.
- Sunflower was also introduced, but those efforts failed when no sunflower oil industry developed in Lebanon.
- Sugar beet was subsidized by the Government and widely cultivated for several years. When the subsidies stopped in the late nineties, its cultivation area almost disappeared from 7,000 hectares in 1999 to 55 hectares in 2011.
- Blackberries have been promoted more recently as a potential market crop. No significant blackberry plantations exist in Lebanon except for a few individual projects in southern Lebanon and the Bekaa region. But, more projects are being planned, for example, by the Lebanese Agricultural Research Institute (LARI). Blackberries require moist soil but can tolerate some drought and areas of extreme aridity (Weber 1995). They can withstand strong winds but not maritime exposure (Bean and Clarke,1991; Huxley, Griffiths, and Levy 1992).
- Quinoa is an Andean plant which originated in Peru and Bolivia. Quinoa is a highly nutritious food that contains protein, vitamins, minerals, dietary fiber, and polyunsaturated fat. Quinoa is adaptable to different agro-environmental conditions from subtropical sea-level conditions to cold, highland conditions at 4,000 meters above sea-level. It can grow during droughts and high temperatures. Low temperatures (2°C) can delay quinoa germination without impeding it totally. An FAO project, "Technical assistance for the introduction of Quinoa and appropriation/institutionalization of its production in Algeria, Egypt, Iraq, Iran, Lebanon, Mauritania, Sudan and Yemen" is being locally implemented by LARI.
- Many other crops could be considered minor or underused. These include pine, walnut, carob, loquat, prickly pear, pistachio, and pomegranate. Other newly introduced subtropical crops, like Annona and avocado, are expected to increase in importance in the coastal plains.

Aromatic, Medicinal, and Wild Edible Plants

Lebanon possesses several aromatic, medicinal, and wild edible plants. The main group of wild edibles comprise of chicory, eryngo, gundelia, and black salsify. These are used in salads and for cooking. Aromatic plants include species of the Lamiaceae family, such as mint. These are used for mainly flavoring. Medicinal plants include species belonging mainly to the grass and legume families. These are obviously used for medicinal purposes. Because these plants lack clear profitability, they are neglected and even threatened. For this reason, the domestication of several species has begun. Two examples of this domestication are Lebanese oregano and capers.

Lebanese oregano is a native aromatic plant that has been threatened but is now being domesticated. Lebanese oregano grows well under direct sunlight and in a wide range of soils. It can endure hot, dry conditions. The leaves are used for food, flavor, and seasoning in Lebanon. The sustainability of this plant is threatened by climate change, habitat loss, and overharvesting. To protect it, harvesting methods are being controlled and domestication has begun.

Capers are also being domesticated. Capers grow all over Lebanon, even in arid and degraded soils. It is a xerophyte plant, able to survive in areas with salinity, calcareous soils, low annual precipitation, and high temperatures (Barbera 1991; Kenny 1995). They have efficient root systems that fix nitrogen and can help replenish lands. Caper pickles are used in preparing many foods and sauces in Lebanon. Caper buds and leaves are used as spices in many foods. The domestication of caper is being conducted by LARI in Kfardan, Tal Amara and Jabbouleh.

SEED SYSTEMS

Lebanon imports most of its seeds. It is estimated that local seed production does not exceed three percent of the country's seed market. Legumes, cereals, and tomatoes comprise the limited local seed production. Most seed and seedlings are provided by: a) the public sector, LARI produces legume and cereal seeds; b) the private sector, which imports most forage and vegetables seeds from agricultural companies and fruit seedlings from local nurseries; and, c) the informal sector, which includes on-farm seed production and distribution through rural farms.

In 2010, the Ministry of Agriculture adopted a seed multiplication program to procure certified seeds of improved varieties for farmers at subsidized prices. The International Center for Agricultural Research in the Dry Areas (ICARDA) provides technical support for this program by certifying seed health. Still, there is no national seed law in Lebanon. As such, there is no registration of varieties nor controlled distribution system. Recently, however, the MOA, with support from FAO, drafted a seed law which has not yet been considered by lawmakers. Box 3.2 describes Lebanon's "doomsday" seed bank.

BOX 3.2 Lebanon's Doomsday Seed Bank

Lebanon is participating in a global effort to store and develop seeds that can withstand natural or human disasters. This includes war, pests, widespread drought, and climate change tipping points, among others. As part of this effort, Lebanon's International Center for Agricultural Research in the Dry Areas (ICARDA) created a "doomsday seed vault," in the Bekaa Valley. They received seed samples from the Millennium Seed Bank at Kew, Sussex, the largest wild plant seed bank in the world, and the Svalbard Global Seed Vault, which is located on Norway's Svalbard Island, near the North Pole and currently houses nearly a million doomsday seed varieties. ICARDA has contributed a number of domestic varieties to this international seed vault (Clark 2017).

Lebanon's doomsday seedbank has grown in response to Syria's civil war. Syria's own doomsday vault is unreachable, behind battle lines in Allepo, as such the Millenium Seed Bank has donated an additional 70,000 resistant seed varieties to Lebanon's vault. ICARDA hopes to store thousands of disaster resistant varieties of wheat, barley, fava, and lentils. In fact, the new delivery includes wild wheat, grass pea, fava bean, and wild lentil. ICARDA is also carrying out research on these seed varieties in an effort to develop new doomsday-resistant seed varieties (Pettit 2017).

CHAPTER
FOUR

LEBANON'S CLIMATE

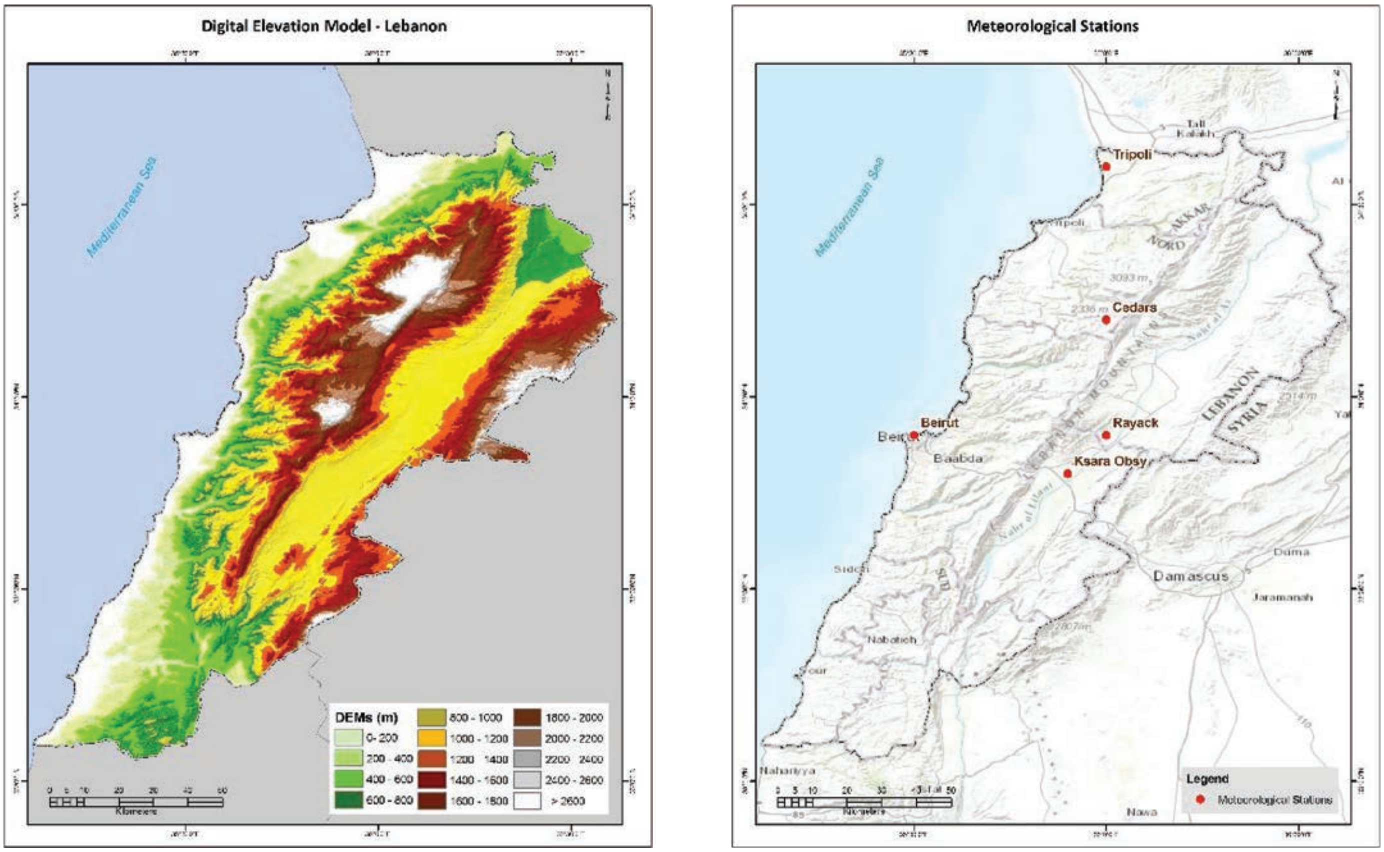
Lebanon's climate is changing. The country has experienced an annual mean temperature increase of ~0.3°C per decade since about 1970. This increase is well above the global mean trend of ~0.15°C over the same period. Recent years have been especially warm and several temperature highs have been broken. There have also been several very dry seasons. These low precipitation levels have led to droughts and severe water scarcity. Though drought has been especially damaging to agriculture in Lebanon, there have been other extreme weather events that impacted the sector. These include frosts, wild fires, and flash floods. The temperature extremes, increased water scarcity, and extreme weather events have damaged crops, lands, and agricultural infrastructure. This chapter describes the specifics of Lebanon's climate.

CONTEXT

Lebanon is characterized by hot, dry summers and cool, moist winters. Humidity can reach 90 percent and temperatures are commonly over 30°C in July and August, sometimes 40°C. Most rainfall, which comes in dramatic bursts, occurs from October to May. Precipitation is irregular and varies considerably from the narrow (only 6.5 kilometers at its widest point) and relatively moist coastal plain to the almost desert-like conditions in the Anti-Lebanon mountain chain. Rainfall patterns result from extratropical weather systems from Europe and the Atlantic Ocean that bring clouds and cold air. The typical rainfall distribution from these systems results in a south-to-north gradient. This leads to the northern, mountainous parts of the country receiving the most precipitation (see Figure 4.4). Throughout the year, some convective clouds develop occasionally, even during the dry season, when subtropical maritime air masses converge in the region. In rare cases, these develop into heavy thunderstorms.

There are two main difficulties when trying to assess Lebanon's climate. First, there is a need for high-resolution data since the country has a complex topography and various microclimates. Second, there is a lack of, or disruption to, meteorological records, because of the 1975–1990 civil war and other political strains. Therefore, to conduct climatological studies in Lebanon, it is necessary to use various external data sources. This is because local data over an extended timeframe is not readily available. The main data sources are from the Climate Explorer stations, which are hosted by the Royal

FIGURE 4.1 (a) Digital Elevation Model of Lebanon (left), (b) Meteorological Stations with Available Data (right)



Source: ICBA (2017). "Drought, atmospheric systems, impacts and management in Lebanon," International Center for Biosaline Agriculture.

Dutch Meteorological Institute, or KNMI (*Koninklijk Nederlands Meteorologisch Instituut*). Five stations have significant data for Lebanon: Beirut (1888–2003), the Cedars (1961–80), Ksara Obsy (1921–90), Rayack (1951–86) and Tripoli (1931–2003) (Figure 4.1b). As we will see in Chapter 8, the Lebanese Agriculture Research Institute (LARI) has built many more, but they lack the long-term data needed to spot anomalies.

The World Bank Group maintains two databases related to Lebanon's climate. First is the Climate Change Knowledge Portal.[2] The Portal provides data on climate change, impacts from these changes on water and agriculture, and specific country-level climate change vulnerabilities. Second, is The Global Forecasting Drought Tool.[3] This tool measures both drought risk and drought severity, but it lacks sufficient data to provide these measurements at the local level. A number of other independent tools could also be exploited, such as Zhao and others (2017) satellite observations of regional drought severity.

[2] The World Bank Group's Climate Change Knowledge Portal for Lebanon: http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_future_climate&ThisRegion=Asia&ThisCcode=LBN.

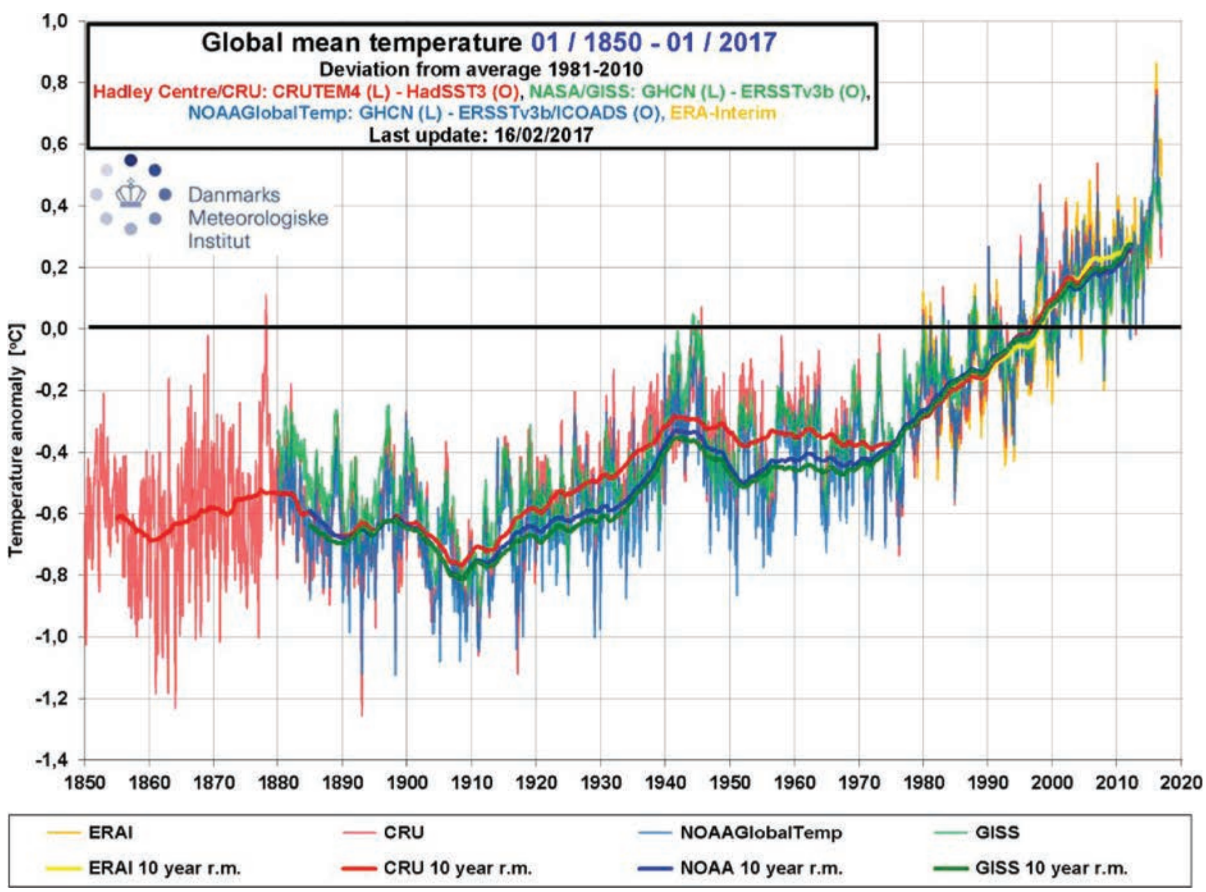
[3] The World Bank Group's Global Forecasting Drought Tool: http://iridl.ldeo.columbia.edu/maproom/Global/World_Bank/Drought_Monitor/index3.html?gmap=%5B5%2C10%2C2%5D.

TEMPERATURES

Temperatures are rising. The Intergovernmental Panel on Climate Change (IPCC's) Fifth Assessment Report (AR5) established that average global surface air temperature increased by approximately 0.85°C from 1880 to 2012. Figure 12 shows that this long-term warming trend is unequivocal. But, over the shorter-term, the warming is much more variable. For example, from 1998 to 2012, there was no perceived warming, but from 2012 to 2016 the warming picked up again. 2016 was the hottest year on record. Even so, a decade is a short period when it comes to climate. The important thing to remember is that the magnitude of global warming varies from year to year, but is unambiguous over time.

Different climate centers report different air temperatures from year to year, but again the warming trend remains constant over the long-term. Air temperature data are maintained by several research groups, or climate centers, and based on peer-reviewed scientific methods. These centers use slightly different datasets and apply different averaging methods. As a result, they calculate different annual temperatures. Figure 4.2 shows the averages from the different climate centers. Since 1979, the European Centre for Medium Range Forecasts (ECMWF) also started to track surface temperatures.

FIGURE 4.2 Mean Average Global Monthly Temperature Anomalies (thin lines) and the 10-Year Running Mean (heavy lines) Since 1850



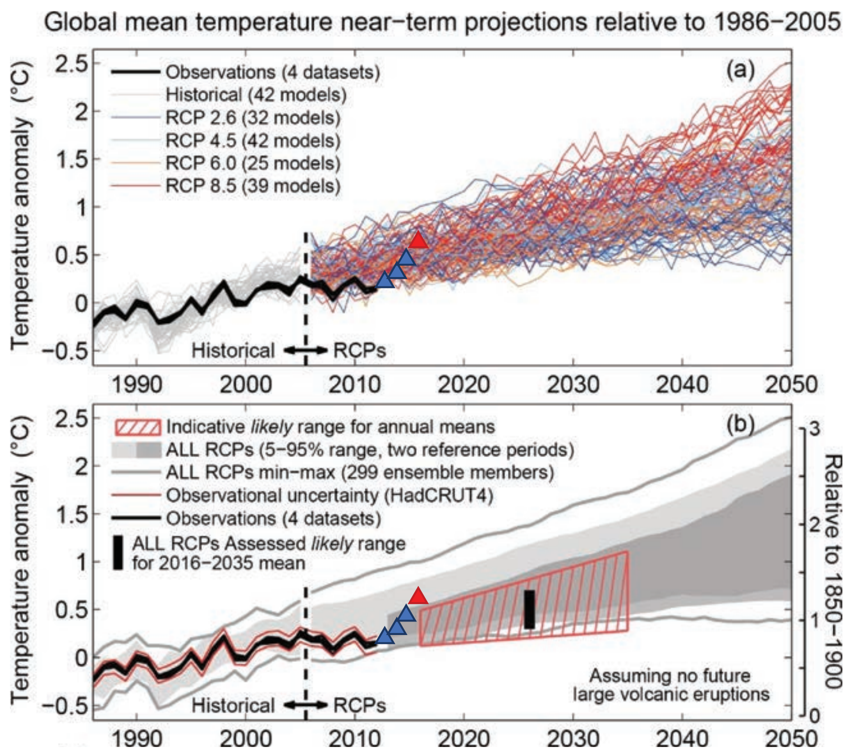
Source: DMI (2017). Global Mean Temperature. Danish Meteorological Institute (DMI). Updated by Martin Stendel, DMI.
Note: The red lines (Hadley Center and Climatic Research Unit [CRU]) are since 1850, the green (NASA/GISS) and blue (NOAA) lines are since 1880. GISS = Goddard Institute for Space Studies; NASA = National Aeronautics and Space Administration; NOAA = National Oceanic and Atmospheric Administration.

Their data is based on an advanced data assimilation technique and only started in 1979 when satellite technology became available.

At the time when IPCC AR5 was issued, temperatures were rising but not as quickly as most models predicted. In IPCC AR5, projections of 21st century temperature changes were based on simulations from 42 global climate models (Flato et al. 2013), using the 20-year mean temperature for 1986–2005 as a baseline. Figure 4.3 shows that from 2006 to 2012, the observed global mean temperature rise was lower than the models' average simulated projection. But, the observed change was still well within the model results' variation. Since 2013—the first post-AR5 year—global mean temperatures have been surging (depicted by the blue and red triangles shown in Figure 4.3b).

Of course, the global mean temperature is not expected to rise steadily from one year to the next because of natural climate variability. Part of this natural variability is caused by solar variations

FIGURE 4.3 Mean Global Surface Air Temperatures by Climate Models



Source: IPCC, AR5 with updates.

Note: (a) Projections of mean global surface air temperatures from 1986–2050 (relative to 1986–2005) under all RCPs from CMIP5 models (grey and colored lines), with four observational estimates: HadCRUT4, ECMWF ERA-Interim, GISTEMP, and NOAA for the period 1986–2012 (black lines). (b) Showing the 5 to 95% range of annual mean CMIP5 projections for all RCPs using a reference period of 1986–2005 (light grey shade) and all RCPs using a reference period of 2006–12, together with the observed anomaly for (2006–12) minus (1986–2005) of 0.16°C (dark grey shade). Grey lines show the maximum and minimum values from CMIP5 using all ensemble members and the 1986–2005 reference period. Black lines show annual mean observational estimates. The red-shaded region shows the likely range for mean global surface air temperatures during 2016–35. On the right-hand side, the temperature scale relative to 1850–1900 assumes mean global surface air temperatures will warm prior to 1986–2005 by the 0.61°C estimated by HadCRUT4. The blue and red triangles show the observed mean annual temperatures from 2013 to 2016 based on the same data providers. The size of the symbols represents a measure of uncertainty in estimating the mean annual temperature. CMIP5 = Coupled Model Intercomparison Project Phase 5; ECMWF = European Centre for Medium-Range Weather Forecasts; ERA-Interim = interim re-analysis of global atmosphere and surface conditions; GISTEMP = Goddard Institute for Space Studies Surface Temperature Analysis; HadCRUT4 = Hadley Centre/Climatic Research Unit gridded surface temperature data set 4; NOAA = National Oceanic and Atmospheric Administration; RCP = representative concentration pathway.

and volcanic eruptions. For example, cooling in 1991 was attributed to low solar activity and the eruption of Mt. Pinatubo in the Philippines (Lockwood 2010). Significant natural variability is also generated by internal fluctuations within the climate system, particularly the oceans. 1998 had exceptionally strong El Niño warming in the tropical Pacific and, as a result, had the highest global mean temperature increases, whereas the relative coolness of 2008 coincided with a La Niña—the opposite of an El Niño.

PRECIPITATION

Precipitation in Lebanon varies from region-to-region. Lebanon is a relatively small country (10,452 square kilometers) that can be divided by precipitation into three contrasting regions. These include: (1) the semi-arid Bekaa Valley (200 to 450 millimeters of annual rainfall), (2) the coastal Mediterranean (900 to 1,000 millimeters); and (3) the humid coastal Mount-Lebanon (more than 1,000 millimeters) (Figure 4.4).

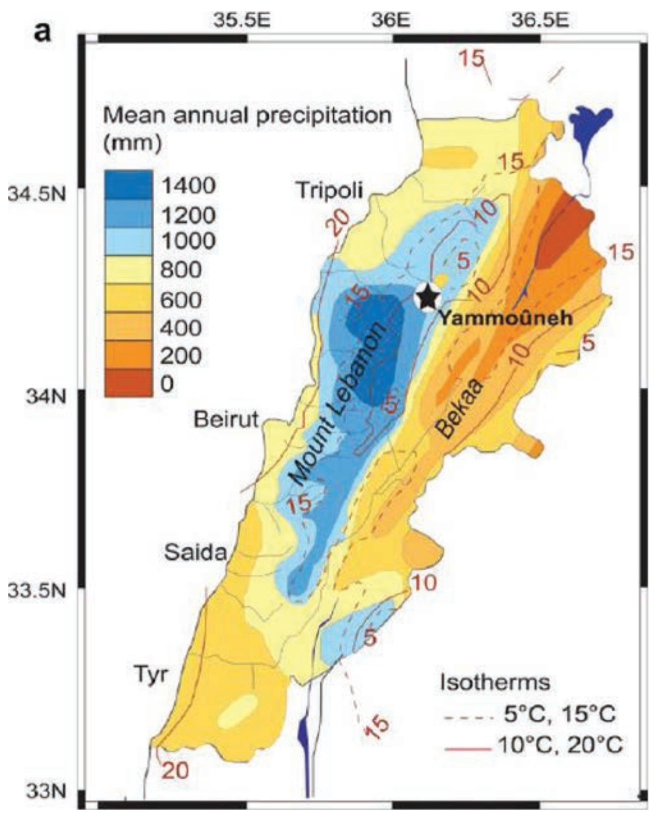
Figure 4.5 portrays Lebanon's seasonal precipitation patterns. This data comes from the only three observational stations with sufficiently long and complete data records (Tripoli, Beirut and Bsharri). The fertile areas near the Mediterranean coastline are hydrated by their proximity to the sea. Mount Lebanon forms a high barrier that virtually wrings water from the clouds as moist air rises, cools, and is released as precipitation. This rain and snow create rivers and streams that run through the mountain villages and water the valley farms.

CLIMATE CHANGE

Mediterranean climates are among the most vulnerable to climate change (Christensen et al. 2007, 2013). This is demonstrated by increasing temperatures in the region. Figure 4.6 shows annual mean temperature trends for Beirut and Tripoli. Beirut has the most complete data series, which spans nearly 150 years of data. The most recent data are from 2004, more recent data has not yet been made publically available. Lebanon has experienced ~0.3°C per decade since about 1970, which is well above the global mean of ~0.15°C per decade for the same period.

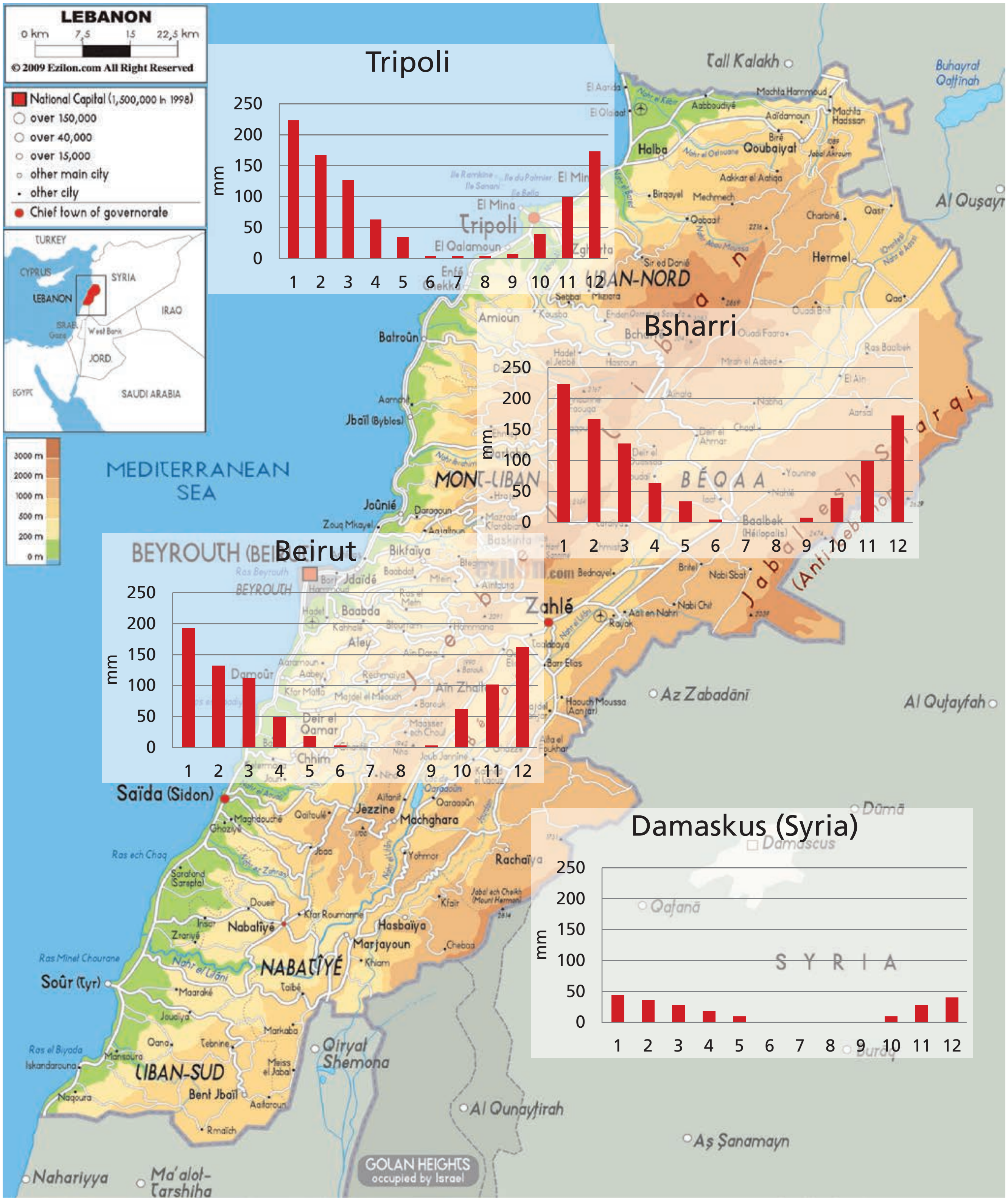
Long-term precipitation changes are much less clear. Precipitation changes are often a complex consequence of large-scale drivers, like radiative forcing from enhanced greenhouse effects, and local and regional feedbacks that may work in opposing directions. Hartman et al. (2013) reports most of the Mediterranean region experienced a drying trend between 1950 and 2010. But, station data from Beirut and Tripoli are inconclusive in confirming an overall trend (Figure 4.7). That data indicates large decadal and interannual variations that cannot be linked directly to the global or regional warming trends. Future climate change projections will be examined in Chapter 5.

FIGURE 4.4 Mean Annual Precipitation and Temperature over Lebanon



Sources: Abi-Saleh and Safi 1988; Develle et al. 2010.

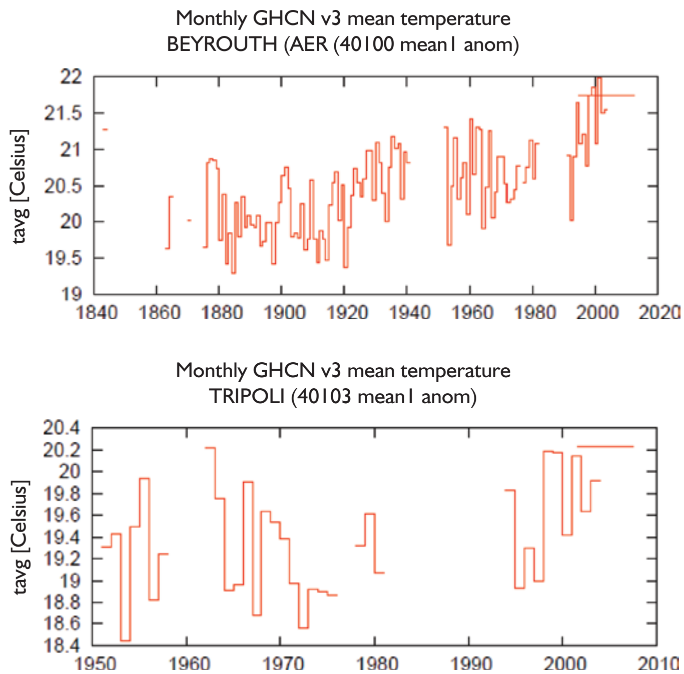
FIGURE 4.5 Mean Monthly Precipitation in Millimeters from 1961 to 1990 for Three Lebanese Climate Data Series



Source: KNMI Climate Explorer, https://climexp.knmi.nl/start.cgi.

Note: Also shown is Damascus, in Syria, depicting the strong trans-mountain east-west precipitation gradient.

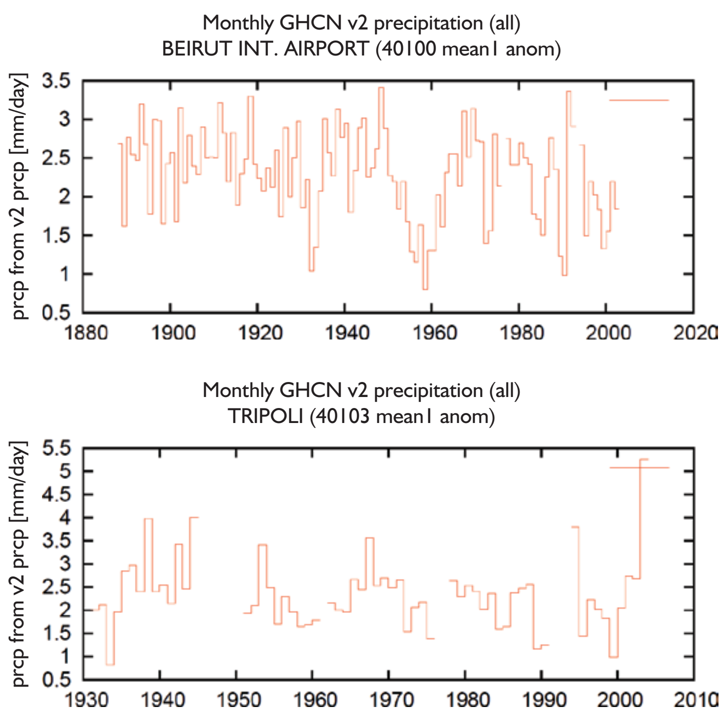
FIGURE 4.6 Annual Mean Temperature Series for Beirut and Tripoli



Source: KNMI Climate Explorer, https://climexp.knmi.nl/start.cgi.

Note: The series is incomplete and terminates in 2004.

FIGURE 4.7 Annual Mean Precipitation Series for Beirut and Tripoli



Source: KNMI Climate Explorer; https://climexp.knmi.nl/start.cgi.

Note: The series is incomplete and terminates in 2004.

CHAPTER
FIVE

DROUGHT

This Chapter examines the occurrence of drought globally, in the Middle East and North Africa (MENA) region, and in Lebanon. In all cases, droughts are becoming more frequent and more severe. But, Lebanon is not typical to the rest of MENA. It is generally smaller, less arid, and more climatically diverse, while the population is more affluent and less rural than most of the countries in the region. This presents unique challenges and opportunities. To facilitate this discussion, we begin by defining drought.

DEFINITIONS

Drought is defined as "a phenomenon related to precipitation reduction over an extended period, such as a year or season" (Dai 2011; Mishra and Singh 2010). Drylands are particularly prone to drought (Sun et al. 2006). These regions show strong spatial and temporal variability in rainfall and have fewer stored water sources to offset resource deficits. Drought is also compounded by other issues like reduced winter rainfall and increased evapotranspiration (Hoerling et al. 2012; Mathbout and Skaf 2010; Romanou et al. 2010;). A drought, which lasts months or years and has impacts that increase over time, is distinct from a heat wave, which lasts days or a week and has impacts which remain constant (Chang and Wallace 1987). Though, drought is not necessarily related to an increase in temperature. Droughts are also less predictable than other climate extremes, like floods. Several recent research papers show climate change contributes to drought frequency and intensity in the Mediterranean region.

There is no universal definition of "drought." This has led to confusion in predicting and responding to them. Mishra and Singh (2009) argue there are two main types of drought definitions:

1. Conceptual definitions are stated in relative terms, for example drought is a long dry period. But, defining "a long dry period" will differ depending on where you are.
2. Operational definitions attempt to identify the onset, ending, and severity of droughts. But, this will also take account of frequency.

For our purposes, we define drought using FAO's definition: "drought is an extended period of deficient precipitation compared to the statistical average for a particular region which results in water shortages for some activity, group, or environmental sector" (FAO and NDMC, 2008). FAO goes on to define four types of drought. These include:

- Meteorological—when precipitation departs from the long-term normal.
- Agricultural—when there is insufficient soil moisture to meet the needs of a particular crop at a particular time, which typically occurs after a meteorological drought but before a hydrological one.
- Hydrological—when deficiencies occur in surface and subsurface water supplies.
- Socio-economic—when human activities are affected by reduced precipitation and related water availability. This definition associates human activities with elements of agricultural, hydrological, and meteorological drought (FAO, n.d.).

WORLDWIDE

Over the past few decades, droughts have become more frequent and intense worldwide, affecting both developed and developing countries. Projections by the Intergovernmental Panel on Climate Change (IPCC) indicate droughts are likely to become even more frequent and intense in the future because of global climate change. The IPCC says that, "while regional droughts have occurred in the past, the widespread spatial extent of current drought is broadly consistent with the expected changes in the hydrological cycle under [global] warming." Though it is not certain if El Niño Southern Oscillation (ENSO) causes drought, droughts have been more severe in ENSO years, such as 2016. This will be discussed more in Chapter 6.

FAO has described drought as "the slow, creeping natural disaster," that has social, economic, and environmental impacts (Hanlon and Christie 2016). They affect agriculture and related sectors, such as livestock, forestry, and inland fisheries, because of these sectors' strong reliance on surface and subsurface water supplies. Direct impacts of drought include: (i) reduced crop, forest, and rangeland productivity; (ii) reduced river, lake, and reservoir water levels; (iii) increased fire hazards; (iv) damage to fish and wildlife habitat; (iv) higher livestock and wildlife mortality rates; (v) insect infestations; (vi) increased plant disease; and (vii) greater wind and soil erosion. Increased erosion often leads to increasing desertification, which is defined as "the degradation of land in arid, semi-arid, and other areas with a dry season caused primarily by over-exploitation and inappropriate [land] use interacting with climate variance" (FAO and NDMC 2008). Potential indirect impacts include: (i) reduced income for farmers and agro-businesses; (ii) increased prices for food and other primary products; (iii) rural unemployment; (iv) lower tax revenues; (v) increased crime and insecurity; and (vi) increased migration to urban areas and elsewhere.

Developing countries are more vulnerable than higher income ones to droughts' adverse effects. Among the reasons for this is that dryland populations tend to live in developing countries and employed in the agricultural sector. This is the case for many low- and lower-middle-income countries in South Asia, Sub-Saharan Africa, and the MENA region. In these regions, agriculture has a high share of total freshwater extraction that also varies by country income level (Table 5.1). Drought-related economic losses tend to be higher as a proportion of Gross National Income (GNI) in the developing world (FAO, n.d.). In general, developing nations and their poor, rural populations are comparatively less well prepared to confront droughts.

TABLE 5.1 Per Capita Gross National Income, Share of Rural Population, and the Share of Water Withdrawal for Agriculture in Select Countries, Regions, and Income Groups

Country/Region	Per Capita GNI (US$) (World Bank Atlas Method)	Rural Population Share (%)	Agriculture as a Share of Total Freshwater Withdrawal (%)
United States	55,230	18.6	40
Spain	29,390	20.6	64
Australia	64,600	10.7	66
India	1,570	67.6	90
Mexico	9,870	21.0	77
Brazil	11,790	14.6	60
Iran	7,120	27.1	92
Lebanon	10,030	12.3	60
Morocco	3,070	40.3	88
Tunisia	4,230	33.4	80
North America	54,879	18.5	38
Europe & Central Asia	26,424	29.3	36
Latin America & Caribbean	9,912	20.4	72
East Asia & Pacific	9,731	44.3	72
Middle East & North Africa	8,722	36.3	85
Sub-Saharan Africa	1,646	62.8	81
South Asia	1,496	67.4	91
Low Income	628	70.2	90
Lower Middle Income	2,018	61.5	88
Upper Middle Income	7,926	38.2	49
High Income	38,301	19.3	43

Source: World Bank 2016.
Note: FNI = gross national income.

MENA

The countries in the MENA region are also experiencing more frequent and intense droughts. MENA is the most arid region in the world and this is expected to be compounded by climate change (Verner 2012). Most of the MENA region relies on rainfed agriculture, so any increase or intensification of drought only makes the water scarcity challenges for untenable. Eighty-five percent of water withdrawals in MENA are dedicated to agriculture (Table 5.2). This is the highest rate in the world behind only South Asia.

MENA is a volatile region. Growing populations, political unrest, economic dislocation, ineffective water management, and the lack of international agreements over shared water resources all pose threats to the MENA region. These threats are multiplied against a background of predicted meteorological and climatological changes in the region (Gleick 2014). Table 5.3 shows how natural conditions, like aridity

TABLE 5.2 Selected Characteristics of Lower and Upper Middle Income Countries in MENA

Country/Item	Area (1,000 km^2)	Population (millions)	GNI per Capita US$	Urbanization (%)	Agriculture Share of Water Withdrawals (%)	Average Annual Precipitation (mm/year) and (rank out of 176)
Algeria	2,382	38.9	5,490	70.1	59	89 (170)
Djibouti	23	0.876	NA	77.3	16	220 (160)
Egypt	995	89.6	3,210	43.1	86	51 (176)
Iran	1,629	78.1	7,120	72.9	92	228 (158)
Iraq	434	34.8	6,530	69.4	79	216 (161)
Jordan	89	6.6	5,160	83.4	65	111 (168)
Lebanon	10	4.5	10,030	87.7	60	661 (114)
Libya	1,760	6.3	7,820	78.4	83	56 (175)
Morocco	446	33.9	3,070	59.7	88	346 (149)
Syria	184	22.2	NA	57.3	88	252 (155)
Tunisia	155	11.0	4,230	66.6	80	207 (162)
West Bank/Gaza	6	4.3	3,060	75.0	45	402 (147)
Yemen	528	26.2	1,300	34.0	91	NA
MENA	11,236	417.5	8,722	63.7	85	NA

Source: World Bank 2016.
Note: The high-income MENA countries also have among the very lowest average annual rainfall levels in the world. In 2011, Oman, Kuwait, Bahrain, the United Arab Emirates, Qatar, and Saudi Arabia ranked 166, 167, 171, 172, 173, and 174 out of 176 countries. GNI = gross national income; km^2 = square kilometers; MENA = Middle East and North Africa; mm/year = millimeters per year; NA = not available.

and drought, and social factors, like poor decision-making and management practices, cause increased water scarcity and desertification in the region.

LEBANON

Like the rest of the region and much of the world, Lebanon faces increased drought risk. Various sources affirm this. The Lebanese Agricultural Research Institute (LARI) reports a 40 to 50 percent decrease in rainfall in the country compared with an average year. The head of the Land, Water, and Environment Department, said 2013–14 was the driest winter on record (Farajalla, n.d.). In May 2014, Lebanon's meteorological service reported there were just 431 millimeters of rainfall since September 2013. This was less than half the previous year's total of 905.8 millimeters and well below the yearly average of 812 millimeters. One source said the observed precipitation level in late 2013–early 2014 was the lowest since 1932, but "the increase in the country's population since then makes this

TABLE 5.3 Type of Dry Conditions Caused by Short-, Medium-, and Long-term Social and Natural Conditions

	Short-Mid Time Scale or Temporary	Long Time Scale or Quasi-Permanent
Natural	Drought	Aridity
Human-made	Water Scarcity	Desertification

Source: Pereira, Oweis, and Zairi 2002; Van Loon and Van Lanen 2013.

year's drought far more serious" (Middle East Eye 2014). The impact was particularly strong on agriculture. In normal years, Lebanese farmers irrigate their fields by digging channels that divert water from wells or local rivers. However, in dry years "the rain and snow that usually fill the rivers and wells never arrived," and, as a result, farmers were forced to pump groundwater, a rapidly diminishing supply (Middle East Eye 2014).

One source explained the challenge in more detail. It said, "the severe drought in (. . .) Lebanon during the winter of 2013–14 resulted from rains less than 35 percent of the long-term average values . . . Dams held less than 50 percent of their usual volumes going into the summer dry season and rain-fed agriculture was already affected with slow growth or dieback. The lack of rainfall exacerbated the already highly stressed water and food supply resulting from political, economic, and social stressors" (USAID, n.d.).

Climate change exacerbates drought risk in Lebanon. The Dubai-based International Center for Biosaline Agriculture (ICBA) and Oxford University claimed 2014 was "the most extreme" drought on record for this sub-region, and that "it was made about 45 percent more likely due to climate change" (USAID, n.d.). In 2011, the Lebanese Government's Second National Communication to the UNFCCC, made a similar argument. They said, if trends continue, climate change will decrease precipitation by 10 to 20 percent by 2040 and 25 to 45 percent by 2090. Farajalla (n.d.) described this situation as "common to the entire Middle East." Verner (2012) says, "despite sparse observational data, the projections are that most of the Arab region is becoming hotter and drier."

But, Lebanon also faces challenges unique to the rest of the MENA region. First, its land mass is much smaller than most other countries in the region. This is especially true about arid zones. Whereas large areas of the Middle East and North Africa are arid, only a sliver of Lebanon could be described the same. This is relevant because natural water availability is affected by aridity and droughts in humid and semi-arid areas. In most of these areas, agriculture relies on rainfall, not irrigation, for its water needs. This can be a challenge, because the small arid region means fewer people identify drought as a risk.

Second, Lebanon's population is smaller, but wealthier and more urban than most other MENA countries (Table 5.2). This growing urbanization presents different challenges from other MENA countries, putting pressure on urban water supplies and relatively less on agricultural water supplies (Table 5.1). Over the last decade, population growth has increased water pressures. These population changes—both natural migration and the forced migration of refugees—create water demand challenges associated with urbanization, agricultural expansion, and energy and industrial activities. Challenges are compounded by the contamination of urban water supplies and limited investment in water infrastructure.

RECENT OBSERVED EVENTS

Lebanon and surrounding areas have experienced several damaging weather events over the past decade. Since weather events do not follow political boundaries, we will look at events not only in Lebanon, but also nearby countries. We refer to the Eastern Mediterranean as Israel, Cyprus, Syria, Palestine, and Lebanon. The Middle East refers to the entire region. Information is extracted from the Bulletin of the American Meteorological Society (BAMS 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016), the most comprehensively peer reviewed updates on annual climates. Table 5.4 provides a list of how these various events impacted Lebanese agriculture, specifically.

TABLE 5.4 Climatic Events in Lebanon that Impacted Agriculture

Date	Location	Region	Climate Event	Damage Description
March 31, 2014	Central and Northern Bekaa Valley	Inlands	Frost	■ Fruit trees affected during budding and flowering ■ Greenhouse agriculture was damaged ■ Wheat was burned for the first time ever ■ Irrigation networks were damaged ■ Domestic water networks were damaged
March 31, 2014	North Lebanon	Akkar, coastal area	Frost	■ Potato season was ruined in Akkar
Rainy season, 2013–2014	Lebanon	Country level	High temperatures	■ Crops and fruit trees were damaged ■ Fruit trees flowered early
Rainy season, 2013–2014	Lebanon	Country level	Dry year, low rainfall	■ Rainfed agriculture affected ■ Groundwater sources did not replenish ■ Surface water sources dried up ■ Bekaa potato farmers lost crops or did not cultivate potatoes
September 26, 2010	Over the Bekaa Valley	Inlands	Heatwave	■ Entire grape production season was lost ■ Greenhouse tunnels were damaged
January 16, 2015	South Lebanon	Coastal area, south Lebanon	Wind storm and frost damage	■ Wind storm damaged citrus and banana trees; ripened fruits fell and rotted ■ Bananas broke open ■ Protected agriculture was damaged; plastic covers tore away ■ Low temperature affected protected agriculture
March 27, 2016	North Lebanon, Akkar area	Northern coast	Hail storm	■ Potato crops were damaged
March 7, 2015	Mount-Lebanon	Aley, Metin area in Mount Lebanon	Snow, wind and frost	■ Protected agriculture was damaged
February 22, 2015	Akkar area	North Lebanon	Flood of Nahr El Kabir	■ Damaged crops near the river
September 30, 2014	Mount-Lebanon	Aley, Metin area in Mount Lebanon	Heat, water shortages	■ Dried leaves and loss of olives on olive trees ■ Fruit dropped before ripening
September 30, 2011	■ North Lebanon ■ South Lebanon	Akkar and Danieh-Hasbni area	Flood damage	■ Flood damaged most field crops
November 16, 2013	North Bekaa, East Lebanon	Eastern inlands	Flash floods	■ High erosion; broken terraces

2007: Severe heat waves hit Cyprus, Syria, and Lebanon. Temperatures in each country exceeded the 90th percentile during the summer months. Heat waves reached temperatures above 40°C for five days in June and seven days in July. This led to large local forest fires. Rainfall was also 50 percent lower that summer.

2008: During the winter, the Middle East experienced well-below-average temperatures and drier-than-average conditions. For Cyprus, it was its second-driest year since 1901.

2009: Warmer-than-average temperatures prevailed throughout the region. At the same time, rainfall levels returned to normal in Cyprus, which ended a three-year drought. Severe rainfall was recorded in northern Israel in February. This caused flooding and extensive damage to agriculture. Cyprus also experienced flooding.

In Syria, severe drought conditions, which began in 2006, affected eastern Syria during the summer of 2009. Because of the two years of drought and failed crops, thousands of Syrians were forced to move to cities. Some have argued that this precipitated the conditions that would lead to the civil war (Al Jazeera 2015). In September, high rainfall finally ended the drought.

2010: Warm temperatures affected much of the Middle East. The average air temperature ranged from 2°C to 4°C higher than normal. In Israel, it was the warmest and driest year on record since the middle of the 20th century. November was again very dry for the entire Middle East. Lebanon received less than 40 percent of normal precipitation levels.

In December, an extratropical cyclone brought heavy rainfall and strong winds to the eastern Mediterranean. Along the coast of Lebanon, waves reached ten meters tall.

2011: Temperatures and rainfall levels were normal.

2012: Middle East temperatures were 1°C to 2°C above normal. Summer was significantly warmer than normal throughout the area with anomalies between <1°C and +3°C, reaching +4°C on the eastern border of the Mediterranean.

Despite some extreme precipitation events, 2012 was slightly drier than normal, especially during the warm season. Recurrent troughs of low pressure led to a very wet January in the eastern Mediterranean. The precipitation surplus resulted in a wetter-than-normal winter with rainfall reaching 125 percent to 140 percent of long-term mean precipitation. Spring was dominated by mostly dry conditions. Lebanon received 50 millimeters less precipitation than normal, or 40 percent of the long-term mean.

2013: The Middle East was +1° to +2°C warmer than normal. Cyprus was +2.3°C warmer than the long-term mean. Winter 2012–13 was +1° to +2°C warmer than normal across the eastern Mediterranean. In the wider Middle East, persistently high pressure led to a warmer-than-normal summer. The summer saw heatwaves exceeding 40°C. The highest daytime temperatures were measured in the eastern Mediterranean region.

Precipitation in 2013 was mostly lower than normal in the Middle East—60 to 80 percent of the average. In March, the eastern Mediterranean received only 20 percent of normal precipitation levels. In May, conditions changed dramatically with the region receiving 250 percent of normal precipitation levels.

In the first days of January, snow, frost, and thunderstorms affected parts of Lebanon and surrounding areas. In March, a heatwave hit Lebanon; with maximum temperatures reaching nearly 40°C.

2014: Middle Eastern temperatures were 1°C to 2°C above the long-term mean. Israel and the Palestinian territories experienced its second warmest year (cooler than 2010 but slightly warmer than 2008, 2009, and 2012) over the last 60 years.

Annual precipitation in the Middle East was below normal. The 2013–14 winter was drier than the long-term mean. Most of Syria received only 40 percent of normal precipitation levels. Israel and Palestine had a record dry winter, receiving only 25 percent of normal rainfall totals. Spring was drier than normal in most areas.

During May, the eastern Mediterranean countries (except northern Syria) experienced wetter-than-normal conditions—over 250 percent of normal. Cyprus measured precipitation totals of 320 percent of normal and Israel and Palestine reported its wettest May since records began in the 1920s. This was followed by a dry summer. Precipitation totals in eastern areas were well below average—about 40 percent of normal levels.

Israel experienced flooding associated with heavy rainfalls in May. This led to road closures and agricultural damage. In many parts of Israel, there was 20 to 50 millimeters of rain daily, some areas received 40 to 80 millimeters per day. In August, heavy rainfall led to landslides in Cyprus. Several roads were closed.

2015: In the Middle East, temperatures were +1°C to +2°C warmer than the long-term mean. Except for Cyprus, where near-normal conditions prevailed. During summer and fall, prevailing anticyclonic conditions induced positive temperature anomalies across the entire region. The eastern Mediterranean experienced temperatures +3°C warmer than average.

The region saw near-normal precipitation totals. But, the 2014/15 winter was drier than normal, reaching only 60 percent of normal precipitation levels. During the summer dry season, the eastern Mediterranean received surplus rainfall, exceeding 500 percent of the average in some areas.

DROUGHT IMPACTS ON CROPPING SYSTEMS

The 2014 drought led to more people realizing drought was a danger in Lebanon. During 2016 interviews with Lebanese stakeholders, they described drought impacts as a relatively recent phenomenon. War and political conflict, both in Lebanon and in surrounding countries, dominated the conscience of people over last several decades. As a result, droughts seemed relatively inconsequential. The perception that Lebanon is water-rich and does not experience drought is widespread among farmers, civil society and government stakeholders. In 2016, stakeholders compared drought impacts to any other weather event, but less severe than agricultural export challenges caused by Syria's border closing.

Droughts disproportionately impact the poorest communities in Lebanon. When taking account of the entire agricultural value chain, agriculture is an important livelihood. This is especially true in the poorest governorates of Akkar and Baalbek-Hermel, where agriculture is a primary source of income and employment. Drought impacts these areas, first, because of the limited capacity of the communities to manage drought risk, second because of these areas' dependence on agriculture, and third because Syrian refugees are relatively more concentrated in these areas, placing greater demand on local water and natural resources.

Drought's impacts on agricultural finance were described as wide-reaching. Smallholders predominantly receive loans from local agricultural input shops. So, when drought occurs, input prices become higher as retailers absorb the risk of fewer loan repayments. As such, when drought impacts production, prices can increase even for unrelated agricultural equipment.

Drought's impacts on groundwater usage are considerable. Drought has direct repercussions on groundwater recharge in Lebanon. This is especially true when it is caused by less snowfall or a changing period of snow cover, which feed the springs and streams that meet agricultural water demands in summer months. Most crops in Lebanon require supplemental irrigation, and droughts increase irrigation demand, which is met almost entirely by groundwater abstraction. Also, utilities and organizations that provide water for refugee settlements face water shortages during drought periods, which is also met with groundwater utilization. Increased groundwater pumping, the need to deepen or drill new wells, and water purchases for refugee relief are major cost burdens for all stakeholders. Moreover, blackouts are frequent in Lebanon, meaning pumps can fail for hours at a time.

Drought has important impacts on water quality. Numerous stakeholders mentioned this as an issue, especially in the Bekaa and South Lebanon areas of the Litani River Basin. The concentration of chemical and biological pollutants in groundwater and surface-water increases during drought. Stakeholders described this as a major challenge for human health, irrigation, and municipal water supplies.

Drought can lead to conflict or illegal behavior. Large agricultural areas in Lebanon depend on spring systems. The discharge of these springs fluctuates in response to changing snow cover and precipitation. According to stakeholder consultations, spring failures lead to conflicts within and between villages as reduced water supply must meet competing demands. Likewise, in densely populated areas with more piped water and wastewater infrastructure, farmers frequently tap these water lines illegally. This leads to leakages, water pressure drops, and, in the case of tapped sewage lines, major health risks.

CHAPTER
SIX

ENSO, TELECONNECTIONS, AND OTHER DRIVERS OF DROUGHT

Large scale atmospheric dynamics, like teleconnections, impact drought. The El Niño Southern Oscillation (ENSO) assuredly impacts drought in certain parts of the world, but it is unclear how much it impacts droughts in Lebanon. In the years of a strong El Niño or La Niña there also tends to be drought in the Middle East, however the causal link has not been confirmed. The North Atlantic Oscillation (NAO), on the other hand, seems to be the most relevant teleconnection for winter precipitation in Lebanon.

ENSO

It is unclear if ENSO contributes to droughts and other extreme weather events in Lebanon. The winter of 2015–16 saw the co-occurrence of a strong ENSO and drought conditions in Lebanon. A monthly breakdown over several years shows that during strong El Niño or La Niña years, there is also irregular precipitation patterns (see Figure 6.3). Hence, it was hypothesized that ENSO is an early warning mechanism for drought. But, after examining long-term climate records, this linkage cannot be confirmed.

El Niño is a natural climatic phenomenon of unusually warm water along South America's west coast and in the tropical parts of the Pacific Ocean. It is a natural process that affects marine currents and atmospheric circulation every two to seven years. In Spanish, El Niño means boy or, in certain contexts, baby Jesus. It got its name because it typically occurs along the Peruvian and Ecuadorean coast around Christmas time. The phenomenon has been known for centuries among local fishermen. But, only in recent decades has it been attributed with unusual weather occurrences all over the planet. Its official name is El Niño Southern Oscillation, or ENSO, where "Southern Oscillation" refers to the atmospheric changes associated with El Niño.

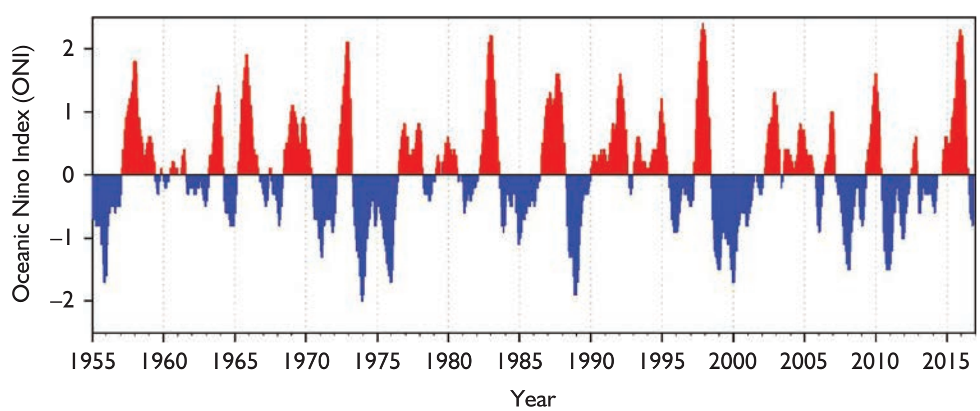
La Niña is the opposite process of El Niño. After an El Niño, the sea in the eastern Pacific cools again. Often, but not always, the water temperature drops below its normal levels. When this occurs, it is called La Niña, or "the girl." The Oceanic Niño Index (ONI) was created to determine when conditions merit an El Niño or La Niña classification. An El Niño is defined by an ONI greater than +0.5°C, that is, a 3-month mean temperature at least 0.5°C above the 30-year mean. Similarly, a La Niña is defined by an ONI lower than—0.5°C. Temperatures between plus or minus 0.5°C are considered normal, and not El Niño or La Niña. A moderate El Niño has an ONI above 1°C and a powerful El Niño has an ONI greater than 1.5°C. The same range applies to La Niña only in negative ONI values. Figure 6.1 shows ONI ranges since the 1950s. As can be seen, ocean temperature fluctuations are normal and only in some years do they classify as El Niño or La Niña.

ENSO affects weather patterns in the Central Pacific, but its farther-reaching impacts are uncertain. ENSO-related weather impacts are strongest in countries bordering the tropical Pacific. On the west coast of South America, it leads to heavier-than-usual rainfall, while in Australia, Indonesia, and the Philippines, it leads to drier conditions. But, it may also impact weather in countries outside of the central Pacific. Droughts and floods are often linked with stronger ENSO events, though it is difficult to attribute remote weather events with the phenomenon's influence. Remote weather events are impacted by a combination of climate phenomena. Climate change, for example, adds an additional layer of uncertainty. The far-reaching impact of ENSO is, therefore, a longstanding research topic in the scientific climate community. For example, the World Climate Research Programme's Climate and Ocean—Variability, Predictability, and Change (CLIVAR) mission studies the dynamics, interactions, and predictability of these various ocean-atmosphere systems.

Having said this, there are simple ways to measure if ENSO influences far-reaching countries. This is done by looking at long-time observed variations and correlating them with ENSO phases. Figure 6.2 and Figure 6.3 do this. Figure 6.2 displays the geographical correlation of temperature anomalies with the ONI. When the correlation is positive (shown in red), temperatures tend to be warmer than normal during El Niño and cooler than normal during la Niña. Negative correlations (in blue) means the opposite.

From these maps, it is evident that the Middle East and North Africa (MENA) regions are only marginally influenced by ENSO. Possible exceptions to this rule are a weak-to-moderate positive correlation in Northwest Africa from December to May and a weak positive correlation in Northern Africa from June to August. For precipitation, there is a weak (possibly even moderate) negative

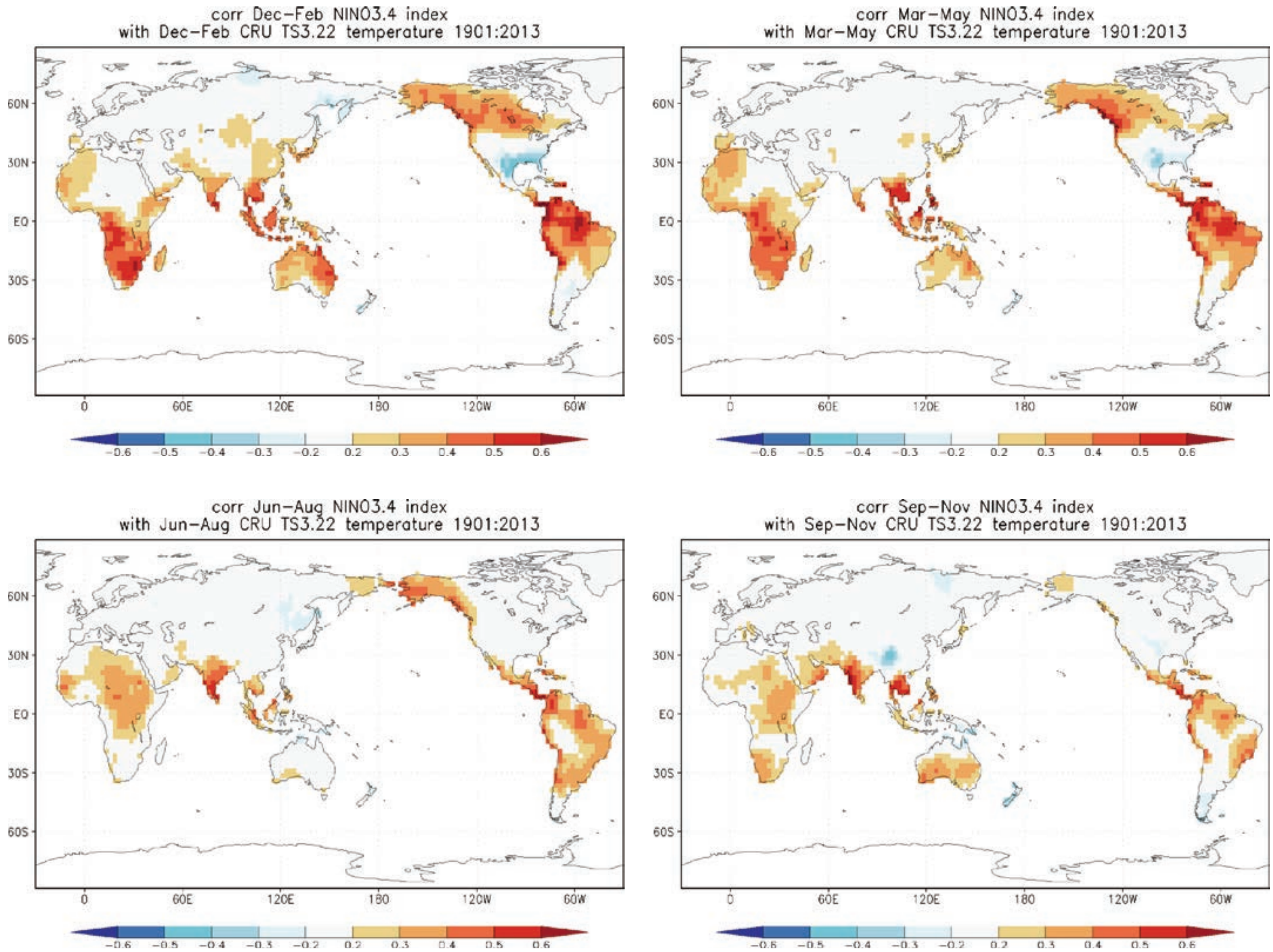
FIGURE 6.1 Values of ONI from 1955 to the Present



Source: NOAA, https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/cb-mei.cfm.

Note: Red bars indicate warm conditions in the equatorial Pacific and blue bars indicate cool conditions in equatorial waters. Large and prolonged El Niño events are indicated by large, positive index values: note the > +2 value associated with 1972, 1983, 1998, and the recent strong event in 2015–2016. Recent cool anomalies (La Niña) occurred in 1999–2002, 2007–2009, and 2010–2012.

FIGURE 6.2 Temperature Correlation Maps



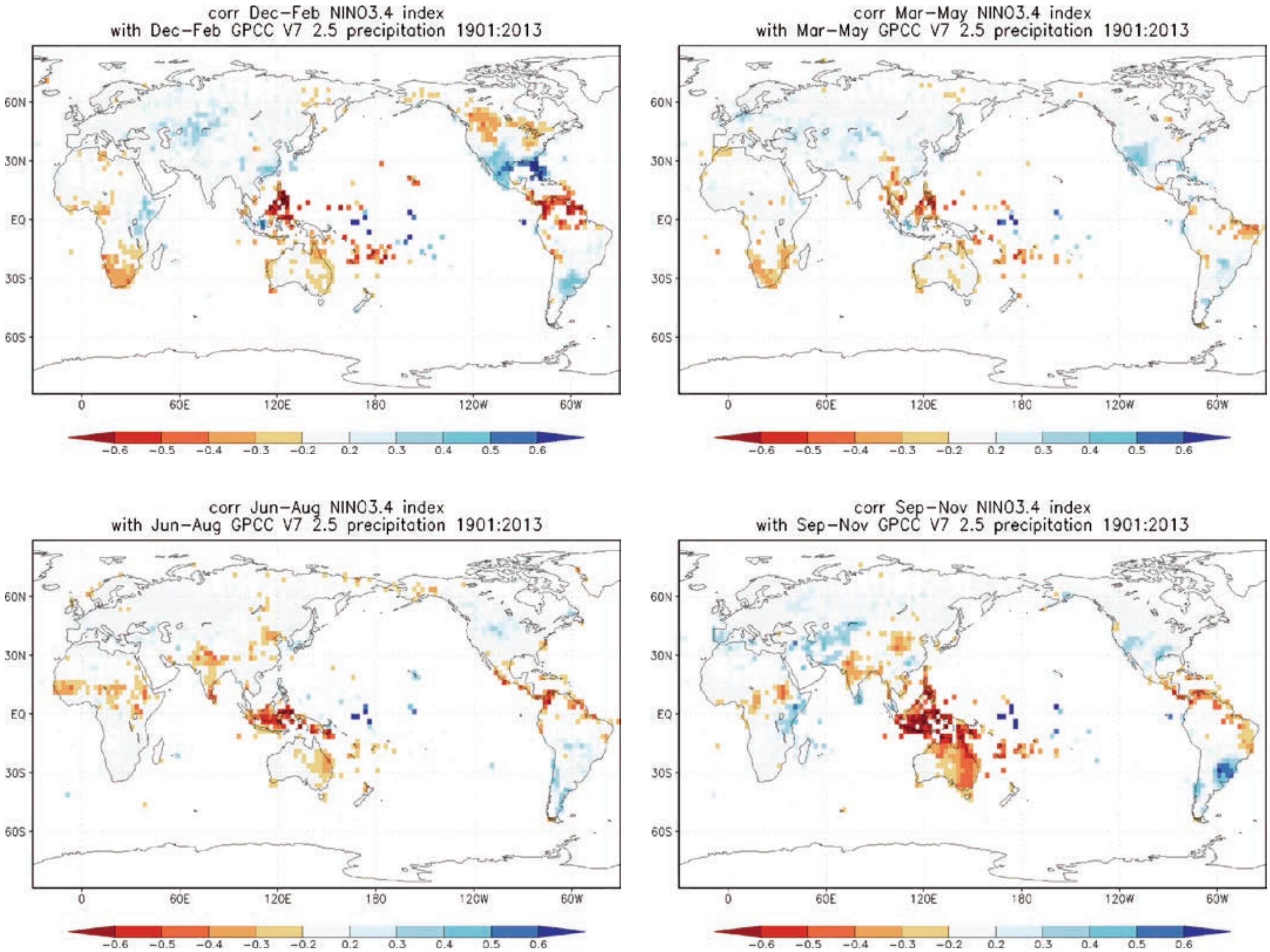
Source: KNMI Climate Explorer, https://climexp.knmi.nl/start.cgi.

Note: Red denotes locations that are warmer on average during El Niño and cooler during La Niña. Blue denotes locations that are colder during El Niño and warmer during La Niña. In North America, the effects are often non-linear, or La Niña is not always the opposite of El Niño.

correlation in North and Northwest Africa from December to May and a weak positive correlation in North Africa and, possibly, in parts of the Middle East from September to November. But in all cases, it is speculative to solely attribute temperature or precipitation anomalies to ENSO. Only weak correlations appear at the country level. Christensen et al. (2012 and 2013) argue the most dominant climate phenomena in the Mediterranean region is the North Atlantic Oscillation (NAO), during northern hemisphere winters.

Other researchers maintain that ENSO plays a much stronger role in global weather events. Barlow et al. (2016) reviewed drought occurrence in the Middle East and southwest Asia and showed that large-scale climate variability, particularly La Niña, appears to play an important role in region-wide droughts. This includes the two most severe droughts of the last 50 years, the first from 1999 to 2001 and the second in 2007 and 2008. They also predict that significant temperature

FIGURE 6.3 Precipitation Correlation Maps



Source: KNMI Climate Explorer, https://climexp.knmi.nl/start.cgi.
Note: Blue indicates that during El Niño there was, on average, more rain than normal. Red indicates drought during El Niño. La Niña has the opposite effect in almost all locations.

increases and drying of the eastern Mediterranean will continue. But, researchers identified other influences besides ENSO that contribute to these trends. These influences include orography, storm-track changes, moisture transport, vertical motion thermodynamics, and feedback mechanisms from reduced vegetative growth.

Even with the demonstrated relationship between strong La Niña events and widespread drought, the predictive capacity of this model remains low. The statistical basis for claiming a direct link between La Niña and Middle East precipitation remains speculative. Models would have to consider many more factors that can influence drought. These factors include drought's regional coherence, data uncertainty, the role of temperature, regional storm track dynamics, a range of dynamic drought mechanisms, the stability of remote influences, the predictability of crop yields and vegetation, and the relationship between drought and synoptic-scale mechanisms.

It is possible to establish a link between drought and ENSO teleconnections. Many research centers are working on seasonal-to-decadal scale prediction systems. This involves large computations with data assimilation elements from the entire climate system, which includes oceans, the atmosphere, the cryosphere, and land surfaces. These efforts produce large databases with synthetic climate records that span many centuries and even millennia. Using models, it is therefore possible to establish a statistically sound correlation between ENSO and drought.

DROUGHT AND TELECONNECTIONS IN MENA

Understanding teleconnections is an important step for being able to predict drought. Teleconnections are causal connections among meteorological or environmental phenomena that occur long distance apart. Large-scale high pressure systems that prevent low pressure rain-bearing frontal systems from moving into an area or allow convectional uplift conditions cause drought. The atmospheric dynamics that cause these conditions are poorly understood, but known as teleconnections (from the Greek word "faraway," and the English word "connection"). Teleconnections are recurring and persistently large-scale patterns of pressure and atmospheric circulation anomalies over vast geographical areas. In simple terms, they are atmospheric interactions between widely separated regions of Earth (Glantz 1994).

Teleconnections are diverse. They can occur over time periods of weeks to months at a time. They can also appear for consecutive years and play in inter-annual and inter-decadal atmospheric variability. Teleconnections can affect storm tracks, temperature, precipitation, jet stream location and intensity, and abnormal weather patterns that simultaneously affect distant areas (Barnston and Livezey 1987; Barnston and Livezey 1991; Mo and Livezey 1986). The different teleconnections are defined by different teleconnection indices.

ENSO is the most well-known teleconnection. It causes global climate variability on seasonal to inter-annual time scales (Wolter and Timlin 2011). ENSO clearly influences areas in Asia, Africa, and North and South America, but its influence in Europe, North Africa, and the Middle East is weak. Simulations that use a fully coupled climate model (Merkel and Latif 2002), suggest that El Niño could weaken the North Atlantic mean meridional pressure gradient, causing a southward shift of the North Atlantic storm-track. In turn, this weakens the NAO and leads to wetter conditions over central Europe and the western Mediterranean (Hurrell and van Loon 1997). Research has shown possible links between El Niño and drought in Morocco and a possible negative correlation between ENSO and precipitation in northeastern Tunisia (Mariotti, Zeng, and Lau 2002). Other research shows possible links between ENSO and European and Mediterranean climates (Lloyd-Hughes and Saunders 2002; Shaman 2014). Still, evidence remains sparse on ENSO's effects on Lebanon and ENSO's relationship with other teleconnections impacting the region.

The NAO is a prominent teleconnection in the MENA region (Barnston and Livezey 1987). The NAO consists of a north-south dipole of air pressure anomalies, with one center located south of Iceland and the other located over the Azores Islands (between 35°N and 40°N). The positive phase of NAO is below-normal pressure across the high latitudes of the North Atlantic and above-normal pressure over Western Europe, the eastern United States, and the central North Atlantic. The negative phase indicates the opposite pattern of pressure anomalies over these regions.

Long-term observations suggest NAO is a dominant influence on weather in the Middle and Near East. Most notably, it impacts river flows, surface temperatures, and winter precipitation. NAO also drives western and southern Mediterranean precipitation. For example, winter rainfall over southern Europe and North Africa has declined since the 1970s because of a positively phased NAO.

The North Atlantic Oscillation Index (NAOI) is calculated by the Rotated Principal Component Analysis (RPCA) (Barnston and Livezey 1987). This applies to monthly, mean, standardized, 500-millibar height anomalies obtained from the Climate Data Assimilation System (CDAS) between 1950 and 2000. Each month, teleconnection indices, which include NAO and other relevant modes, are calculated to explain the spatial variance of height anomaly fields.[4]

The Mediterranean Oscillation (MO), another teleconnection, shows the presence of synchronized, but opposing, atmospheric behavior in the eastern and western sub-basins (Conte et al., 1989). The MO's low-frequency pattern produces opposed anomalies, which affects pressure, temperature, and precipitation regimes. The influence of the MO on Mediterranean climate variability has been studied by many researchers (Baldi et al. 2004; Corte-Real, Zhang, and Wang 1995; Kutiel and Paz 1998; Maheras, Xoplaki, and Kutiel 1999; Palmieri et al. 2001; Palutikof et al. 1996; Piervitali, Colacino, and Conte 1997; Xoplaki et al. 2003). Research shows the MO is the most important low-frequency driver of precipitation (Douguedroit 1998; Dünkeloh and Jacobeit 2003; Kutiel, Maheras, and Guika 1996; Maheras, Xoplaki, and Kutiel 1999). Several methods are used to measure the MO. The Mediterranean Oscillation Index (MOI) (Conte, Giuffrida, and Tedesco 1989; and Palutikof et al. 1996) measures the normalized pressure difference between Algiers (36.4°N, 3.1°E) and Cairo (30.1°N, 31.4°E). MOI data is calculated using the Bessel interpolation of pressure data provided by the Climate Research Unit (CRU).

The Western Mediterranean Oscillation (WeMO) is a regional teleconnection pattern (first proposed by Martin-Vide and Lopez-Bustins (2006)). The WeMo was initially used to explain the poor relationship between the NAO and eastern Iberian Peninsula weather patterns. It is defined as the pressure difference between the north Italian peninsula and the southwest Iberian Peninsula. The WeMO index is used to explain convective rainfall (López-Bustins and Azorín-Molina 2004), winter rainfall trends (Lopez-Bustins et al. 2008; Oliva et al. 2006), urban heat islands (Lopez-Bustins et al. 2006), sea-breeze occurrences (Azorin-Molina and Lopez-Bustins, 2008), heavy rainfall events (Martin-Vide and Lopez-Bustins 2006; Martin-Vide et al. 2008), and sunshine variability (Lopez-Bustins and Sanchez-Lorenzo 2006).

ANALYZING DROUGHT AND TELECONNECTION LINKS

Droughts result from abnormal atmospheric conditions that lead to high-pressure systems remaining over an area. These systems suppress rainfall because of the descending, warming air associated with these pressure types. Oscillations in large-scale atmospheric systems can change wind, pressure, temperature, and precipitation patterns. The causes of these natural variations are not always known, but they are often attributed to abnormal land or ocean warming and cooling.

[4] For more information on the RPCA technique, see: www.cpc.ncep.noaa.gov/data/teledoc/teleindcalc.shtml.

We analyze correlations between droughts and teleconnections in Lebanon. We do this since there are no in-depth analyses on drought climatology in Lebanon and its connections to atmospheric variations. We focus on Lebanese droughts from 1990 to 2014. This period was selected because meteorological station data was available. We analyze this data for correlations with ENSO,[5] NAO,[6] MO,[7] and WeMO.[8] This data set goes back long enough to include several El Niño and La Niña events, but only a few of these events could be considered major (for example see Figure 6.1).

There are two main difficulties in assessing links between teleconnections and droughts in Lebanon. The first is the need for high resolution data. There are only a few operable stations that provide data on the country's complex topography and various microclimates. The second is the lack, or disruption, of meteorological records. These disruptions were mainly a consequence of the civil war from 1975 to 1990. For these reasons, we use regular, gridded satellite data rather than the sparse and disrupted station data. Preliminary tests show Tropical Rainfall Measuring Mission (TRMM) data are the most reliable in the region. Specifically, we use monthly TRMM data at 25-kilometer resolution for the period from 1998 to 2014.w

We used a seasonal Pearson correlation to assess the relationship between teleconnections and precipitation. We calculated the Pearson correlation of each teleconnection index with each gridpoint's standard precipitation index (SPI). Although a monthly correlation would provide better temporal resolutions, the limited history of TRMM records (less than 20 years) and the high-resolution geographical focus area, compelled us to use seasonal data. We achieved a 0.2 confidence level, which means there is 80 percent confidence that the numerical correlation reflects a relationship between observed phenomena.

TABLE 6.1 Correlation Values Between the ENSO ONI Index and Lebanon's SPI Values, with at Least an 80 Percent Confidence Interval and 0.4 Correlation

ONI				
Months	JJA	SON	DJF	MAM
Tripoli	■ (blue)			
Minieh	■ (blue)			
Jbail	■ (blue)			
Baalbek	■ (blue)			■ (red)
Beirut	■ (blue)			
Zahle	■ (blue)			■ (red)
Chouf	■ (blue)			
W Bekaa	■ (blue)			
Nabatiye	■ (blue)			
Marjaayoun	■ (blue)			
Sour	■ (blue)			
Bent Jbail	■ (blue)			

LEGEND	
positive correlation	negative correlation
■ 0.4	■ 0.4
■ 0.6	■ 0.6
■ 0.8	■ 0.8
■ 1.0	■ 1.0

Source: ICBA (2017). "Drought, atmospheric systems, impacts and management in Lebanon," International Center for Biosaline Agriculture.
Note: Correlation values for ENSO ONI, NAOI and MOI with Lebanon SPI values, with at least 80% of confidence interval and 0.3 correlation. Positive correlation, resulting in increased positive precipitation anomaly, is indicated in blue; negative correlation in red. The size of the squares indicates the correlation value (see Legend).

Table 6.1, Table 6.2, and Table 6.3 show the results from twelve representative Lebanese districts. Table 6.1 shows that ONI is an important influence on precipitation in the summer months. The monthly breakdown shows that the strongest correlation, and most of the precipitation, is in August. This suggests ENSO plays a role since a positive El Niño phase can influence heavy August showers. This can replenish water resources but also have a negative, disruptive impact on soils. Hence, by this measure, it seems that all of Lebanon is influenced by ENSO, regardless of geographical area. In

[5] The Oceanic Nino Index (ONI) was used to capture the variations and phases in ENSO.
[6] NAO Index (NAOI) was used to capture the variations and phases in NAO.
[7] MO Index (MOI) was used to capture variations and phases in MO.
[8] WMEO Index (WMEOI) used to capture variations and phases in WEMO.

TABLE 6.2 Correlation Values Between the NAO Index and Lebanon's SPI Values, with at Least an 80 Percent Confidence Interval and 0.3 Correlation

NAOI				
Months	JJA	SON	DJF	MAM
Tripoli			■	
Minieh			■	
Jbail			■	
Baalbek			■	
Beirut			■	
Zahle			■	
Chouf			■	
W Bekaa			■	
Nabatiye			■	
Marjaayoun			■	
Sour			■	
Bent Jbail			■	

LEGEND	
positive correlation	negative correlation
■ 0.4	■ 0.4
■ 0.6	■ 0.6
■ 0.8	■ 0.8
■ 1.0	■ 1.0

Source: ICBA (2017). "Drought, atmospheric systems, impacts and management in Lebanon," International Center for Biosaline Agriculture.

Note: Positive correlation, resulting in an increased positive precipitation anomaly for positive NAO phase (and vice versa for the negative phase) is indicated in blue. The size of the squares indicates the correlation value and ranges from 0.3 to 0.42. DJF = December, January, February; JJA = June, July, August; MAM = March, April, May; NAOI = North Atlantic Oscillation Index; SON = September, October, November.

Baalbek and Zahle, certain effects occur in the spring months when a positive ENSO phase limits precipitation.

The NAO is the most relevant teleconnection for winter precipitation, while the MO's relevance is inconclusive (Table 5.4 and Table 6.1). Like ENSO, NAO's correlation with rainfall is significant and its effects are felt all over Lebanon. For the Mediterranean Oscillation, the main difficulty was establishing significant correlation values. Most Lebanese grid points show only a 0.4–0.5 correlation, with significant correlations found in only two areas during the winter months: Zahle and Bent Jbail. This was not included in the table because of the low significance. More long-term data is needed to establish the statistical significance of the MOI.

The SPI shows high precipitation variability in Lebanon. An SPI, used by the World Meteorological Office to establish moisture availability for agriculture, was generated for Lebanon. Figure 6.4 plots the results. The figure shows clear variability in Lebanon's rainfall patterns (with zero representing average rainfall). The figure shows that during drought years—such as 1972–73, 1994–95, and 1999–2000—not all stations show low precipitation levels. This implies that seasonality and land surface moisture are also relevant for determining if a drought occurs. The SPI for the Ksara Obsy station, located in the Bekaa Valley, has the highest negative values for known drought events. This is likely a result of topography and associated rain shadows during these low rainfall periods. In later years, when data is only available for Beirut and Tripoli, the figure shows more wet years than dry, reflecting decadal scale variability. The drought years in 1994–95 and 1999–2000 are not apparent in the SPI values. This suggests precipitation variations were less in coastal areas and that the droughts may not have been as wide spread as perceived.

To gain greater insight into precipitation variability we used regular, gridded satellite data. As mentioned above, station data from Beirut and Tripoli was missing or unreliable. Several gridded sources are available. These include: CHIRPS[9] data from 1981 to 2015; TRMM data from 1998 to 2013;[10] and E-OBS[11] data from 1901 to 2015 (Funk et al. 2015). The TRMM and E-OBS data was compared to data from 28 stations across the Levant (because of spatial and temporal limitations with Lebanese stations).[12]

[9] Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) generated at the University of California Santa Barbara.

[10] Tropical Rainfall Mapping Mission (TRMM) from National Aeronautic and Space Administration.

[11] ENSEMBLES daily gridded observational dataset for precipitation, temperature and sea level pressure in Europe called E-OBS.

[12] This data was available through KNMI's Climate Explorer website.

This helped determine which dataset best captured recent drought events. The data varied among the three datasets.

The three datasets also gave some comparable results. The datasets showed comparable correlations and root mean square errors (RMSE) when tested against station data for accumulated precipitation during the 9-month growing season in Lebanon. The analysis was further refined by removing stations where mean annual precipitation was below 300 millimeters per year. These areas are arid or semi-arid and, therefore, not typical of Lebanon's climate. This brought the testing down to 23 stations (from 28).

Testing correlations and RMSE showed that the CHIRPS and TRMM datasets were similar and comparable, but not as much when testing SPI data (Figure 6.5). SPI data is more relevant to drought monitoring than accumulated precipitation value. But, testing 3-month SPI data expanded the study from 23 to 159 stations over the same timeframe.

In general, CHIRPS showed smoother data. This suggests precipitation extremes were not captured well in CHIRPS. But, CHIRPS data, available at a 5-kilometer resolution, is more useful for a small country like Lebanon, than is TRMM and E-OBS data, which are available only at a 25-kilometer resolutions. This is much too coarse a resolution for drought monitoring. To generate data that best represents the conditions in Lebanon, the TRMM's temporal variability was combined with CHIRPS' spatial variability. By doing this, we could downscale TRMM to a 5-kilometer resolution. Thus, TRMM's 25-kilometer resolution provided average values for a 5 by 5 grid of 5-kilometer grid points. This downscaled precipitation data is shown as CHIRPS-TRMM in Figure 6.5. The CHIRPS-TRMM downscaling has an error of 0.79 compared to CHIRPS' 0.87. These results were encouraging enough for us to use only downscaled data in Figure 6.6 and Figure 6.7, though more validation of the downscaling method could still be undertaken. For these figures, precipitation anomalies were calculated as percentages of normal values for three time-periods. These periods include: spring (March 1st to May 31st); autumn (September 1st to November 30th); and the 9-month growing season (September 1st to May 31st). This allowed us to analyze timing and precipitation anomalies within those timeframes.

Figure 6.5 captures variability both within and between years. It shows there have been seven autumns with below average precipitation since 1998. There have also been four seasons with drought, where the negative anomaly is more than 30 percent. The most severe autumn droughts were in 2011 and 2014. The 2016 drought had the highest negative anomaly for the entire agricultural season. There were wet seasons during the early 2000s and in 2012–13 that recharged reservoirs and groundwater systems. Figure 6.5 also shows that recent droughts are more severe than older droughts. But, drawing this conclusion is difficult because it is based on historical data spanning less than 20 years.

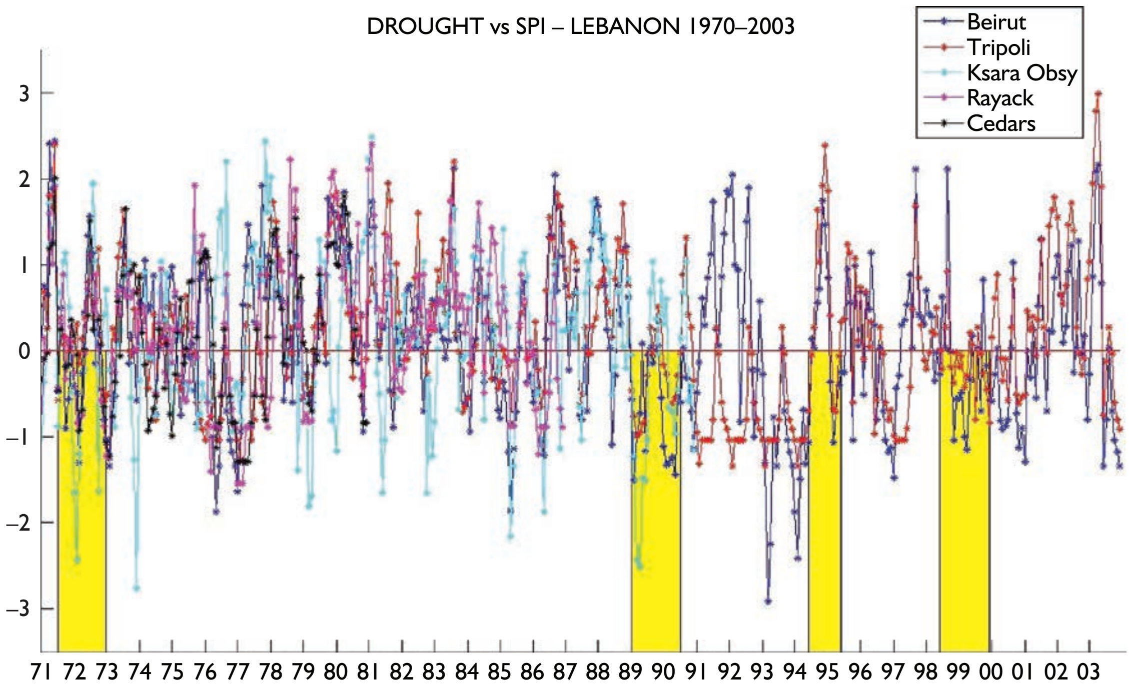
TABLE 6.3 Correlation Values Between the MOI and Lebanon's SPI Values, with at Least an 80 Percent Confidence Interval and 0.3 Correlation

MOI				
Months	JJA	SON	DJF	MAM
Tripoli				
Minieh				
Jbail				
Baalbek				
Beirut				
Zahle			■	
Chouf				
W Bekaa				
Nabatiye				
Marjaayoun				
Sour				
Bent Jbail			■	

LEGEND	
positive correlation	negative correlation
■ 0.4	■ 0.4
■ 0.6	■ 0.6
■ 0.8	■ 0.8
■ 1.0	■ 1.0

Source: ICBA (2017). "Drought, atmospheric systems, impacts and management in Lebanon," International Center for Biosaline Agriculture.
Note: Positive correlation, resulting in an increased positive precipitation anomaly during positive MOI phase (and vice versa during a negative MOI) is indicated in blue. The size of the squares indicates the correlation value and ranges from 0.3 to 0.52. DJF = December, January, February; JJA = June, July, August; MAM = March, April, May; MOI = Mediterranean Oscillation Index; SON = September, October, November.

FIGURE 6.4 SPI Values for Beirut, Tripoli, Ksara Obsy, Rayack, and Cedars



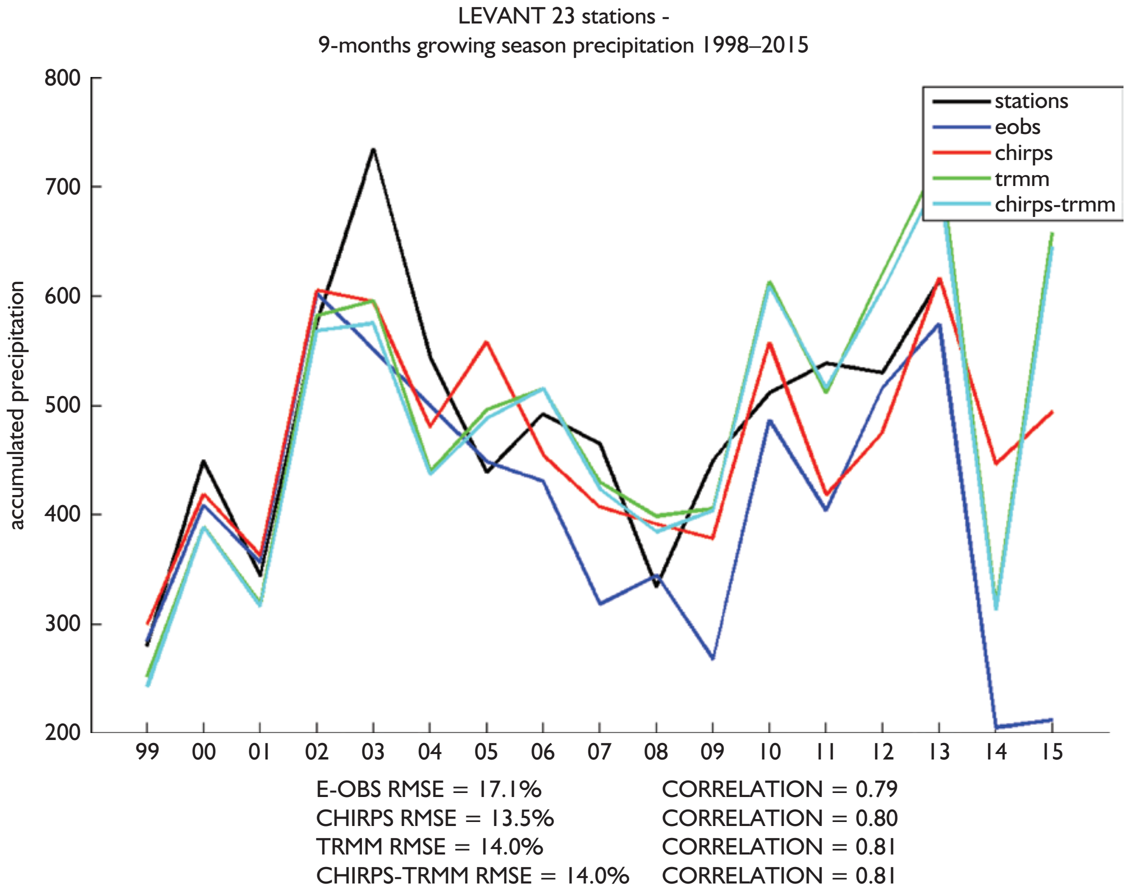
Source: ICBA (2017). "Drought, atmospheric systems, impacts and management in Lebanon," International Center for Biosaline Agriculture.

Note: Agricultural drought years are highlighted in yellow. SPI = standard precipitation index.

Figure 6.7 shows the variability between spring precipitation and precipitation during the entire agricultural season. It shows that a dry spring does not always mean there will be a drought that year. In some years, spring sowing in wet conditions can make up for losses from autumn droughts. During the period analyzed, there were four wet springs where the precipitation was 100 percent more than average conditions. There were seven years when spring was more than 50 percent drier than average. Droughts in 1999, 2014, and 2016 were the most severe for entire seasons. Over the short timeframe, the data does not show droughts becoming more frequent, but show lower precipitation in spring and autumn.

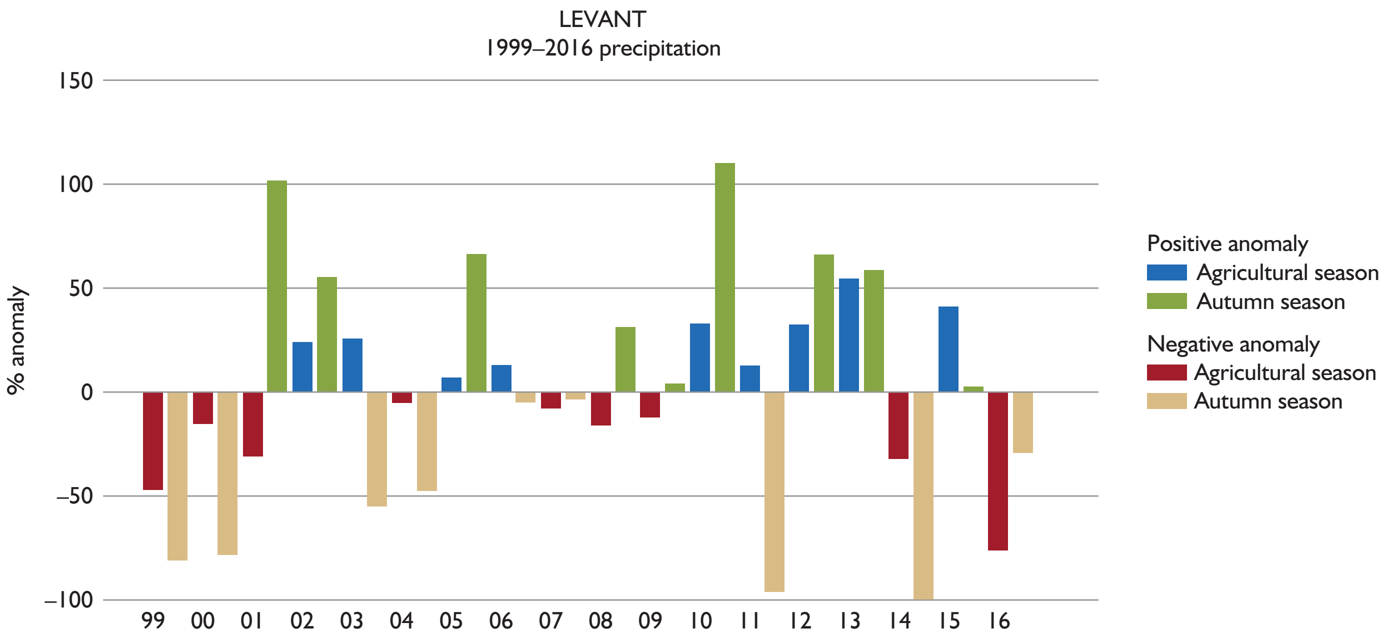
This analysis shows the timing of dry periods determines longer-term impacts on crops. For example, droughts occurring later in the year—and following a wet, normal, or slightly-less-than-normal autumn—affect cereal production values less. Some of the impacts of dry periods are offset by irrigation expansions, especially for fruit trees, potatoes, and vegetables. Stakeholders in Bekaa and the Akkar plains said potatoes require adequate fall precipitation for planting and then substantial spring rains; whereas fruit trees are more reliant on fall rains. Therefore, the use of supplementary irrigation during dry periods helps reduce negative consequences on crops.

FIGURE 6.5 Comparison of Observed Precipitation for the 9-Month Agricultural Season (September to May), with RMSE and Correlation



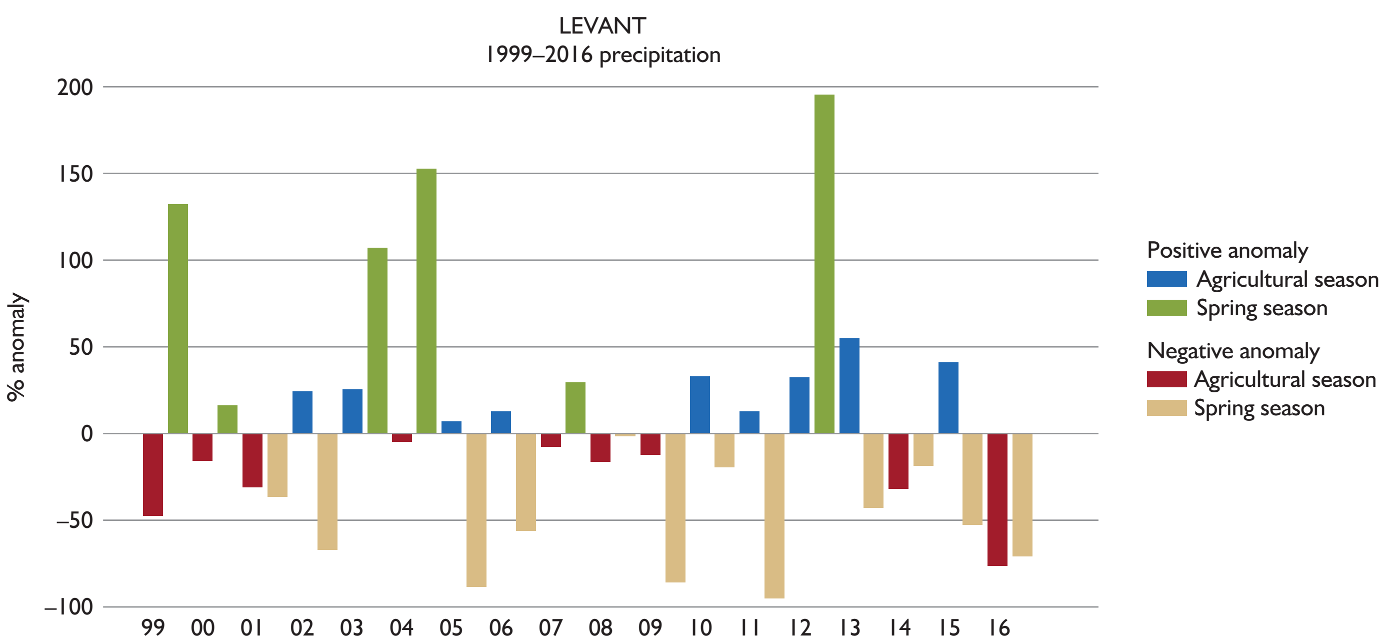
Source: ICBA (2017). "Drought, atmospheric systems, impacts and management in Lebanon," International Center for Biosaline Agriculture.
Note: Data are from 23 Lebanese weather stations (black line), CHIRPS (red line), CHIRPS/TRMM (cyan line) and E-OBS (blue line). CHIRPS = Climate Hazards Group InfraRed Precipitation with Station; E-OBS = ENSEMBLES daily gridded observational dataset for precipitation, temperature and sea level pressure in Europe; RMSE = root mean square error; TRMM = Tropical Rainfall Mapping Mission.

FIGURE 6.6 Percentage Precipitation Anomalies in Lebanon for Autumn and the Agricultural Seasons



Source: ICBA (2017). "Drought, atmospheric systems, impacts and management in Lebanon," International Center for Biosaline Agriculture.

FIGURE 6.7 Percentage Precipitation Anomalies in Lebanon for Spring and the Agricultural Seasons



Source: ICBA (2017). "Drought, atmospheric systems, impacts and management in Lebanon," International Center for Biosaline Agriculture.

CHAPTER
SEVEN

PREDICTING FUTURE WEATHER PATTERNS

Climate projections indicate Lebanon is warming and will experience more frequent droughts in the future. Estimations show that warming will be well above the global mean warming rate. It is predicted that winter precipitation will also decrease. But, even if precipitation levels do not change, soil moisture will continue to decrease because of evaporation from higher temperatures. This will decrease water availability for human or agricultural needs as reservoirs and mountain streams become more depleted. Taken together, chances are high that drought conditions will spread and occur more frequently. Lebanon will also face increased risk of other extreme events, like heavy rains and flash floods.

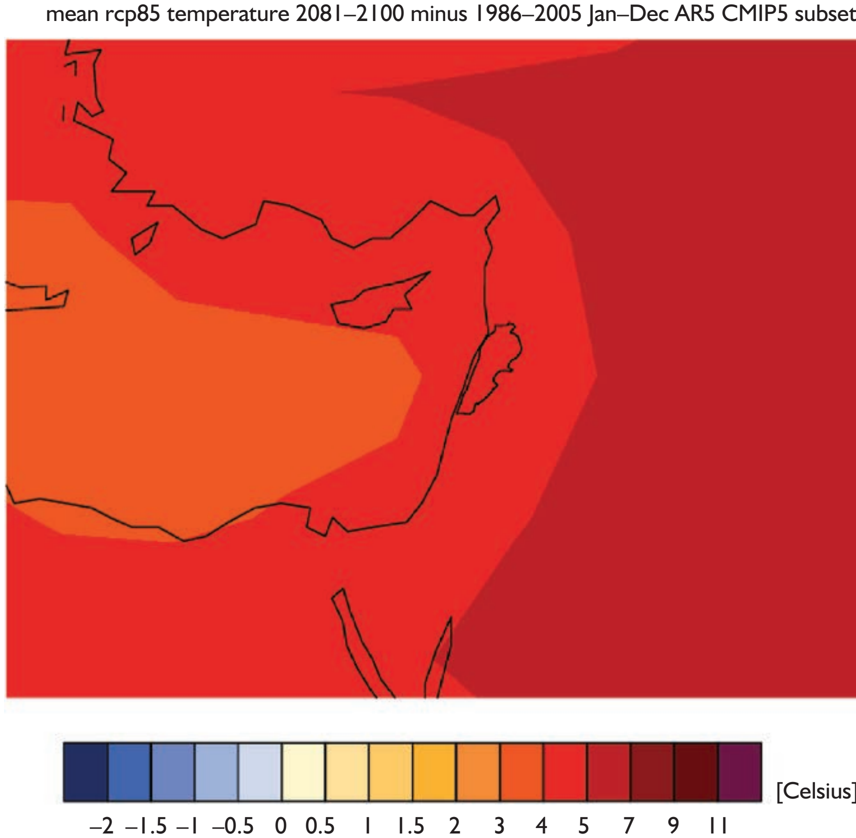
Below we look at drought and climate projections through two approaches. The first is to look at the Intergovernmental Panel on Climate Change (IPCC) data and apply it to Lebanon. The second is to look at the European Coordinated Regional Climate Downscaling Experiment (CORDEX-Europe) data and apply those models to Lebanon.

IPCC PROJECTIONS

IPCC projections are expressed as differences between future scenarios and the reference period of 1986 to 2005. Therefore, predicted changes are relative to the climate changes that have already occurred since the pre-industrial period. IPCC models are made available through the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor 2012) database. KNMI Climate Explorer (https://climexp.knmi.nl) developed an online data store to produce maps on a country-by-country basis. We used same procedures as the IPCC to access data for this report. As such, these maps are meant for global climate models so do not contain much detail for individual countries. Despite this, the maps can be indicative of future scenarios for specific countries.

The IPCC (2013a) maps four different future scenarios. These include: RCP2.6, RCP4.5, RCP6.0, and RCP8.5. RCPs, or Representative Concentration Pathways are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its fifth Assessment Report (AR5) in 2013. The four RCPs are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively). RCP2.6 is a strongly mitigated scenario that keeps projected temperature increases below 2.0°C. RCP8.5 is a non-mitigated scenario where temperature rise projections are in line with the current (high) emission levels.

FIGURE 7.1 Mean Annual Temperature Change for 2081–2100 versus 1986–2005, as Projected by the CMIP5 Models for the RCP8.5 Scenario

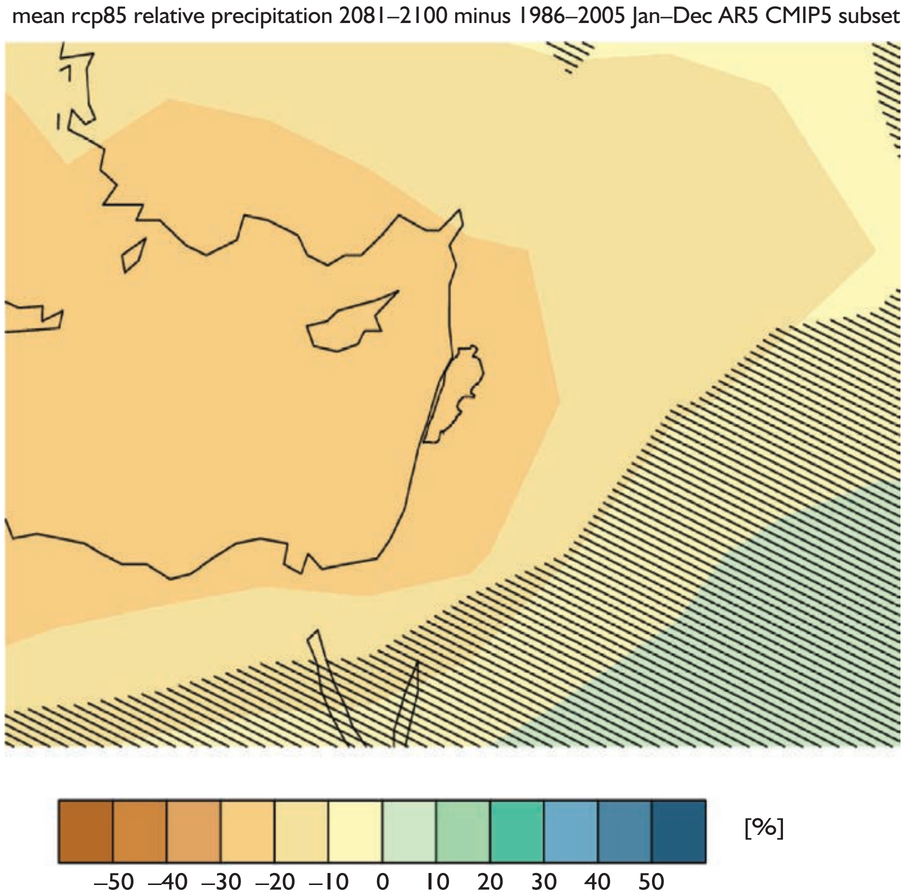


Source: KNMI Climate Explorer; https://climexp.knmi.nl/start.cgi.

According to IPCC data, temperatures are projected to increase for all seasons. Figure 7.1 and Figure 7.2 show the CMIP5 subsets for temperature and precipitation.[13] Specifically, Figure 7.1 shows the annual mean, end-of-century temperature changes for Lebanon under the RCP8.5 scenario. Figure 7.2 shows the mean annual relative precipitation change. In both cases, the values represent the model's median values based on all available simulations. In summary, the CMIP5 models indicates that for the RCP8.5 scenario by the end of the 21st century, country-scale temperatures could increase by 3–6°C during winter, 3–6°C during spring, 4–7°C during summer, and 3.5–6°C during fall. Precipitation amounts may be reduced by 10 to 30 percent in the wet season (October–April), 10 to 40 percent in the dry season (May–September), and 10 to 40 percent annually.

[13] For each modelled grid point, the 25th, 50th, and 75th percentiles of the CMIP5 distribution were shown. Here only the 50th percentile is shown and results compare the timeframes of 2081–2100 to those of 1986–2005. This includes both inter-model spread and natural variability. Hatching denotes areas where the mean 20-year differences in percentiles are less than the standard deviation of model-estimated present-day natural variability of the mean 20-year differences. This provides a measure of robustness to the results. Hatching indicates that the change is not statistically significant, yet the sign and magnitude may still be relevant given the geographical pattern of the overall changes. For other scenarios or other time slices, projected changes are scaled back and the information can be extracted from IPCC (2013). To summarize all these different scenarios is beyond the scope of this document.

FIGURE 7.2 Mean Annual Relative Precipitation Change During 2081–2100 versus 1986–2005, as Projected by the CMIP5 Models for the RCP8.5 Scenario



Source: KNMI Climate Explorer; https://climexp.knmi.nl/start.cgi.

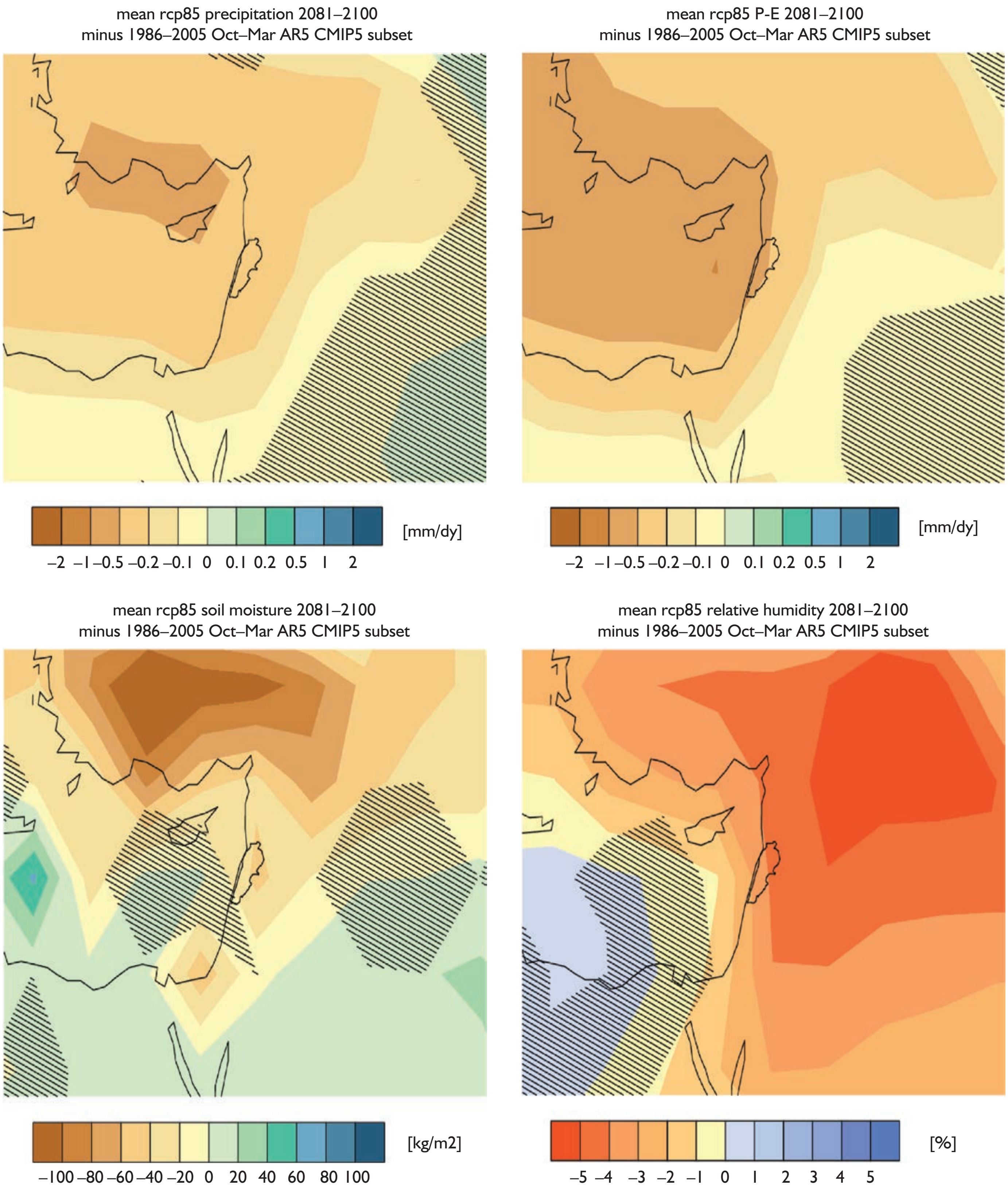
The Hydrological Cycle

IPCC projections all point to significantly drier future conditions in Lebanon. Figure 7.3 displays projected changes for the end of the century. Or, 2081–2100 versus 1986–2005 for winter months under the RCP8.5 scenario for precipitation, net water flux (precipitation minus evaporation), near surface soil moisture, and near surface relative humidity. It shows that precipitation will decline by about a half millimeter per day, and that if you include evaporation, the water flux will decline by between a millimeter and a half millimeter. Figure 7.3 shows that soil moisture and relative humidity will also decrease.

CORDEX-EUROPE PROJECTIONS

The CORDEX-Europe database shows much of the same as the IPCC database. Namely, that Lebanon will get warmer and drier. This data is available at a 0.11 × 0.11-degree resolution. Table 7.1 lists the models used to build the projections.

FIGURE 7.3 Mean Projected Changes for Winter (October–April)



Source: KNMI Climate Explorer; https://climexp.knmi.nl/start.cgi.

Note: Upper left: precipitation (mm/day); upper right: net water flux (precipitation minus evaporation) (mm/day); lower left: near surface soil moisture (kg/m^2); lower right: relative humidity (%). (2081–2100) vs. (1986–2005) as projected by the CMIP5 models for the RCP8.5 scenario. kg/m^2 = kilograms per square meter; mm/day = millimeters per day.

The next three figures all show rainfall in Lebanon will decrease. These are projected changes under different RPC scenarios (see Box 7.1 below on the difference between predictions and projections). Figure 7.4 shows the spatial distribution of precipitation anomalies in Lebanon for the RCP4.5 and RCP8.5 scenarios. It shows there will likely be a 20 percent decline in rainfall in the Bekaa valley and southern Lebanon. These are important agricultural areas that are already feeling water stress from urbanization and limited infrastructure. Figure 7.5 shows the increasing precipitation anomalies going forward for both the RCP4.5 and 8.5 scenarios. The downward spikes in the graph shows that droughts will likely be more intense and more frequent. Figure 7.6 shows that the number of consecutive dry days will increase. This is especially the case in the Bekaa Valley and northern-most and southern-most parts of the country.

These projections indicate that Lebanon will experience substantially drier conditions with enhanced drought risk. This is the case for both strongly-mitigated and unmitigated scenarios. With a reduced hydrological cycle, water reserves and runoff from the mountains will also be influenced making the dry season even more difficult to manage. Water for irrigation will be considerably less abundant. And, taking year-to-year variability into account, suggests that drought conditions will occur regularly. Taken together, the general trend over the next 20 years will be towards higher exposure to drought conditions. This is not only true for Lebanon, but for the wider region. This suggests wide-spread drought conditions will be more severe and occur more frequently. This will challenge local agriculture.

TABLE 7.1 List of the CORDEX-Europe Regional Models Used

Modeling Center Name	Global Model	Regional Model
CNRM-CERFACS	CNRM-CM5	CCLM4-8-17
CNRM-CERFACS	CNRM-CM5	ALADIN53
ICHEC	EC-EARTH	CCLM4-8-17
ICHEC	EC-EARTH	RACMO22E
ICHEC	EC-EARTH	HIRHAM5
IPSL	IPSL-CM5A-MR	WRF331F
MOHC	HadGEM2-ES	CCLM4-8-17
MOHC	HadGEM2-ES	RACMO22E
MPI-M	MPI-ESM-LR	CCLM4-8-17
MPI-M	MPI-ESM-LR	REMO2009

Source: http://www.euro-cordex.net/index.php.en.
Note: CERFCAS = European Centre for Research and Advanced Training in Scientific Computation; CNRM = National Centre for Meteorological Research; ICHEC = Irish Centre for High-End Computing; IPSL = Institut Pierre Simon Laplace; MOHC = Met Office Hadley Centre; MPI-M = Max Planck Institute for Meteorology.

Other Extreme Events

Lebanon also faces the risk of more flash floods. We have already seen that Lebanon has experienced a high number of severe rainfalls over the past decade. And, it is totally possible, even likely, that an area subject to drying conditions would also experience more flooding. When a heavy rainfall happens during dry conditions, the land is not equipped to absorb the excess moisture, and as a result, flooding occurs. For this reason, drought risk management and flood risk management reinforce one another; protecting against one protects against the other.

Figure 7.7 summarizes this on a global scale. It shows that as the planet warms, the intensity of rainfall is also likely to increase over short periods. Based on a multi-model analysis, the figure simulates 5-day rainfall intensity increases between now and the end of the 21st century (upper panel). The lower panel shows a snapshot of the pattern of change towards the end of the century (2081–2100 versus 1986–2005). For Lebanon, the statistical signal is weak but indicates there will be both increased rainfall intensity and more frequent droughts or dry spells.

Collins et al. (2013) states that it is also very likely that heat waves will occur more frequently and for longer because of seasonal mean temperature increases. Changes in the absolute value of temperature extremes are very likely in Lebanon. They are expected to exceed global temperature

BOX 7.1 Predictions versus Projections

There are large data variations for future climate trends. And, even with the Paris agreement, future greenhouse gas emission scenarios are uncertain. At large spatial scales, the data is more reliable, but for small countries, like Lebanon, the data is indicative at best and not predictive. As such, the IPCC (2013a) distinguish between climate *predictions* and *projections*:

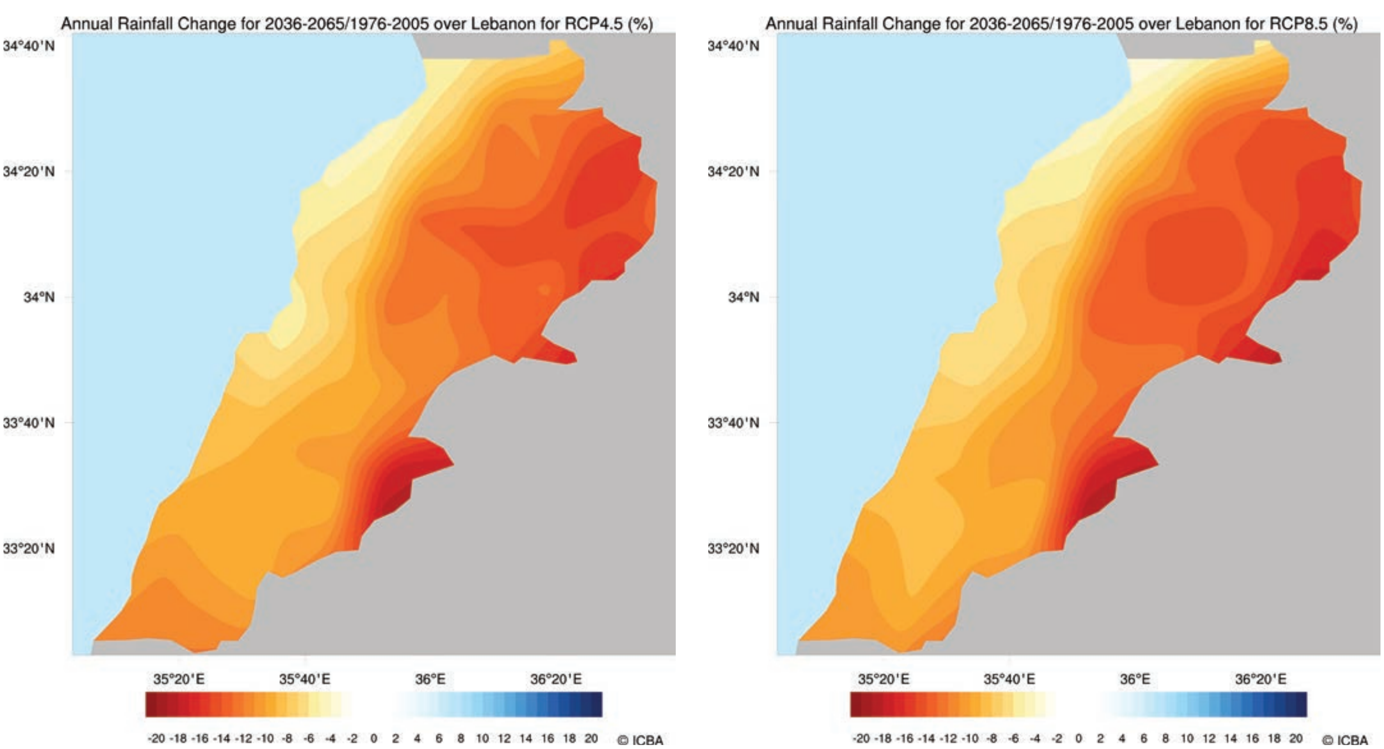
Predictions: A climate prediction or climate forecast is an estimate of the climate's evolution in the future, for example, at seasonal, interannual, or decadal time-scales. The climate system's evolution is highly sensitive to initial conditions; therefore, predictions are usually probabilistic in nature.

Projection: A climate projection is the simulated response of the climate system to a scenario of future emissions of greenhouse gases or aerosol concentrations, generally derived using climate models. Climate projections are distinguished from climate predictions in that they depend on emission, concentration, or radiative forcing scenarios. These, in turn, are based on assumptions of future socioeconomic conditions, technological developments, or other scenarios that may or may not be realized.

The line distinguishing these two terms is often blurred and there is an interest to make predictions over projections. It is much simpler for policy makers to work in certainties not probabilities. Predictions allow them to do that. For this reason, studies on ENSO and other largescale drivers intensified in recent years. There is a hope that droughts or flashfloods can be predicted with acceptable credibility. This explains why large international funding programs, like the EU's Horizon 2020, are directed towards predictive research needs.

But, to be able to make predictions, one requires a large amount of easily accessible, quality controlled, observational records that represent the local climate accurately. For most countries, and certainly for Lebanon, this data does not exist. Lebanon has reasonable climate data for Beirut and Tripoli, but the country's large variance in microclimates makes future climate predictions that cover the entire country nearly impossible. As such, large-scale projections will continue to be relied upon.

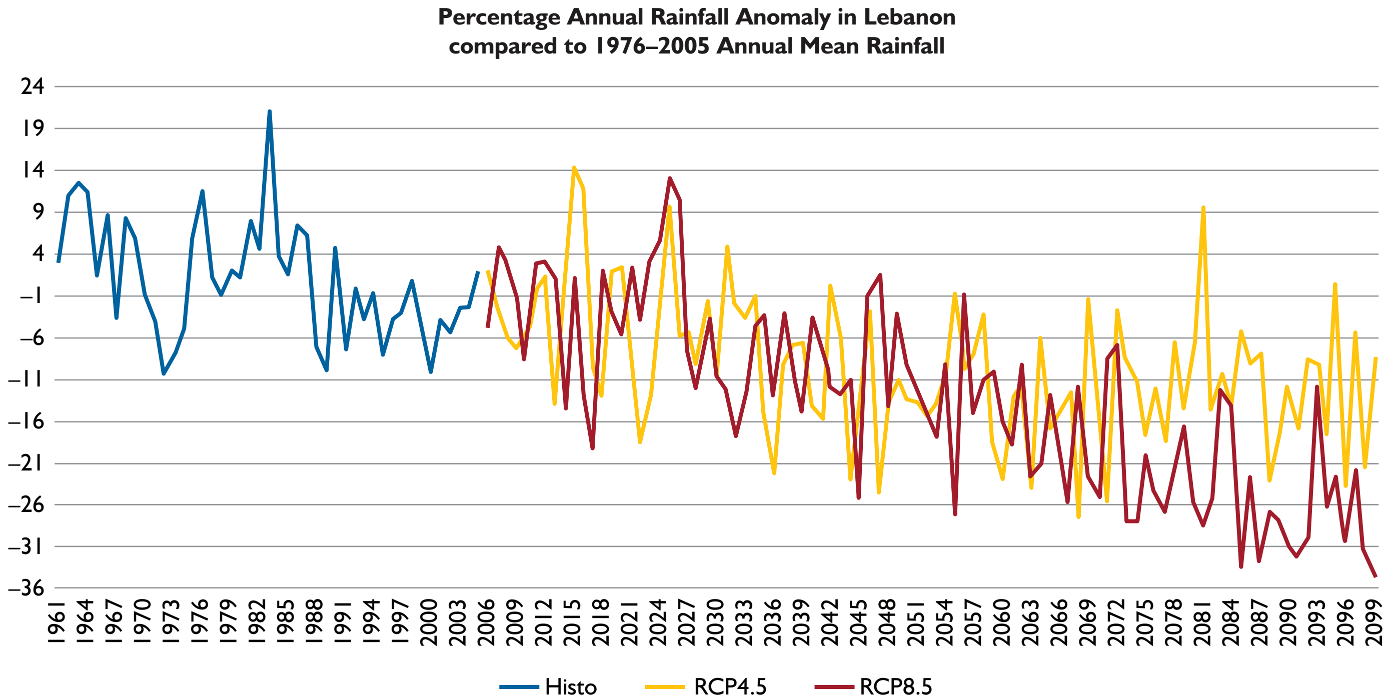
FIGURE 7.4 Annual Total Rainfall Change Calculated as a Percentage Difference Between 2031–2050 and 1976–2005



Source: ICBA (2017). "Drought, atmospheric systems, impacts and management in Lebanon," International Center for Biosaline Agriculture.

Note: The left panel is the RCP4.5 scenario and the right panel is the RCP8.5 scenario.

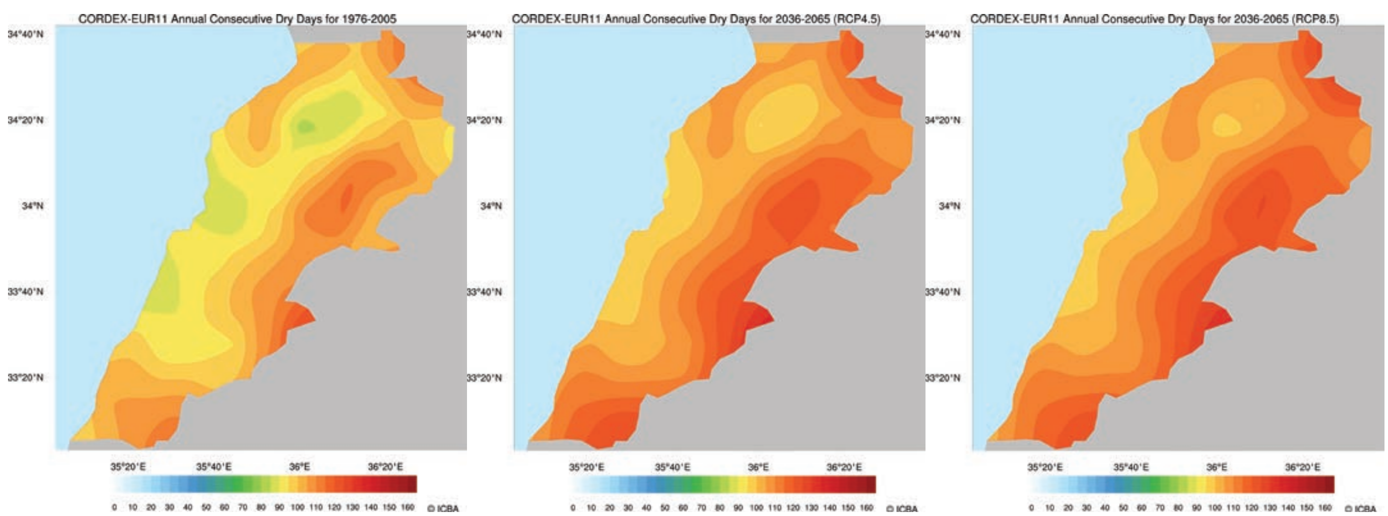
FIGURE 7.5 Annual Rainfall Anomaly in Lebanon Compared to the Mean Annual Total Rainfall for the Period of 1976 to 2005



Source: ICBA (2017). "Drought, atmospheric systems, impacts and management in Lebanon," International Center for Biosaline Agriculture.

Note: The blue line is the models' average for the oldest period, the yellow line is the models' average for the RCP4.5 scenario, and the red line is the models' average for the RCP8.5 scenario.

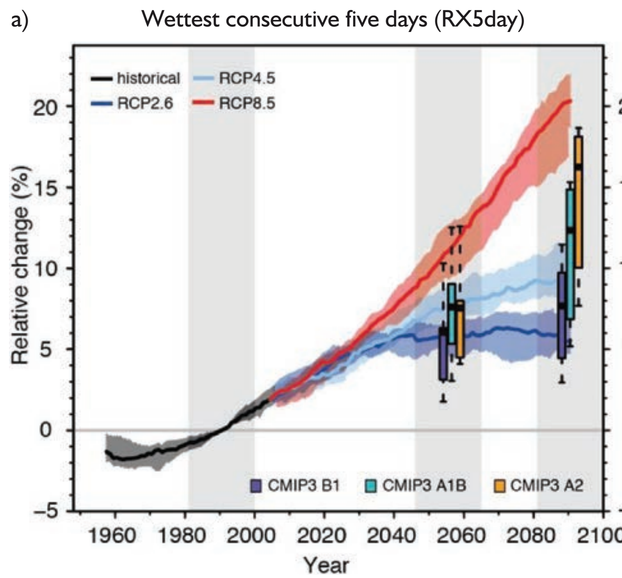
FIGURE 7.6 Spatial Distribution of Annual Consecutive Dry Days in Lebanon

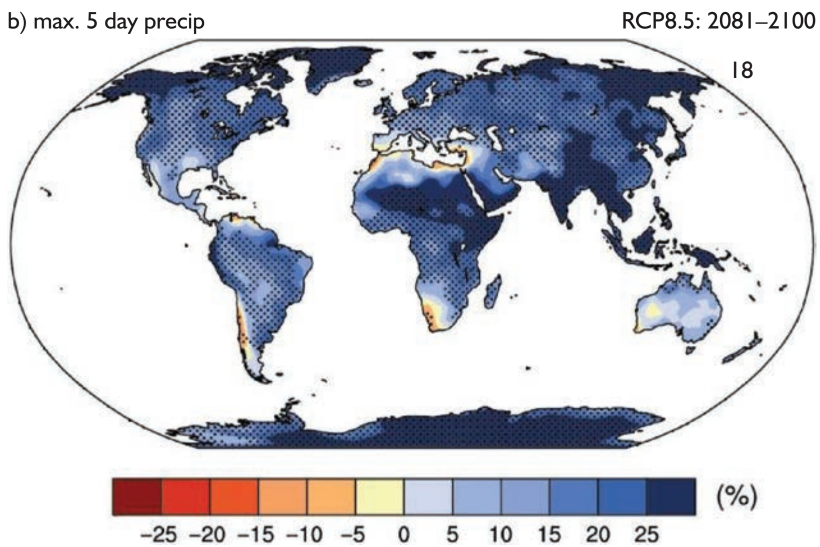


Source: ICBA (2017). "Drought, atmospheric systems, impacts and management in Lebanon," International Center for Biosaline Agriculture.

Note: The left panel is for the period of 1976 to 2005, the middle panel is for the period of 2031 to 2050 under RCP4.5, and the right panel is for the period of 2031 to 2050 under RCP8.5.

FIGURE 7.7 Projected Percentage Change in 5-Day Extreme Rainfall (relative to the 1981–2000 reference period) from the CMIP5 Models on the Maximum Annual 5-Day Precipitation Accumulation





Source: Collins et al. 2013.

Note: (a) Average global percentage change for the RCP2.6, RCP4.5, and RCP8.5 scenarios. Shading in the time series represents the interquartile ensemble spread (25th and 75th quantiles). The box-and-whisker plots show the interquartile ensemble spread (box) and outliers (whiskers) for 11 CMIP3 model simulations of the SRES scenarios A2 (orange), A1B (blue), and B1 (purple) globally averaged over future time periods (2046–65 and 2081–2100) as anomalies from the 1981–2000 reference period. (b) Percentage change from 2081 to 2100 under the RCP8.5 scenario.

increases by far, with substantial changes in hot extremes even for moderate or average warming levels—less than 2.5°C above present day levels.

Lebanon is also likely to see an increase in warm temperature extremes and a decrease in cold temperature extremes. AR5 says, "it is virtually certain that there will be more hot extremes and fewer cold extremes as global temperature increases" (Collins et al. 2013). Figure 7.8 shows changes in the absolute temperature indices of the coldest and the hottest day of the year and the threshold-based indices of frost days and tropical nights. This data comes from the CMIP5 ensemble. It shows a robust increase in warm temperature extremes and a decrease in cold temperature extremes by 2100. The magnitude of these changes will increase as anthropogenic forcing also increases. The coldest night of the year undergoes larger increases than the hottest day in the globally averaged time series (Figure 7.8a and d). This tendency is consistent with older (CMIP3) models. Similarly, the frequency of warm nights increases more than the frequency of warm days. Regionally, the largest increases in the coldest night of the year are projected under the RCP8.5 scenario (Figure 7.8a). The subtropics and mid-latitudes exhibit the greatest projected changes in the hottest day of the year. Whereas changes in the frequency of warm days and warm nights are largest in the tropics. Frost days increase significantly in the Mediterranean and central Asia, and therefore, likely in Lebanon too.

FIGURE 7.8 CMIP5 Multi-model Mean Geographical Changes (relative to a 1981–2000 reference period in common with CMIP3) under RCP8.5 and a 20-Year Smoothed Time Series for RCP2.6, RCP4.5, and RCP8.5

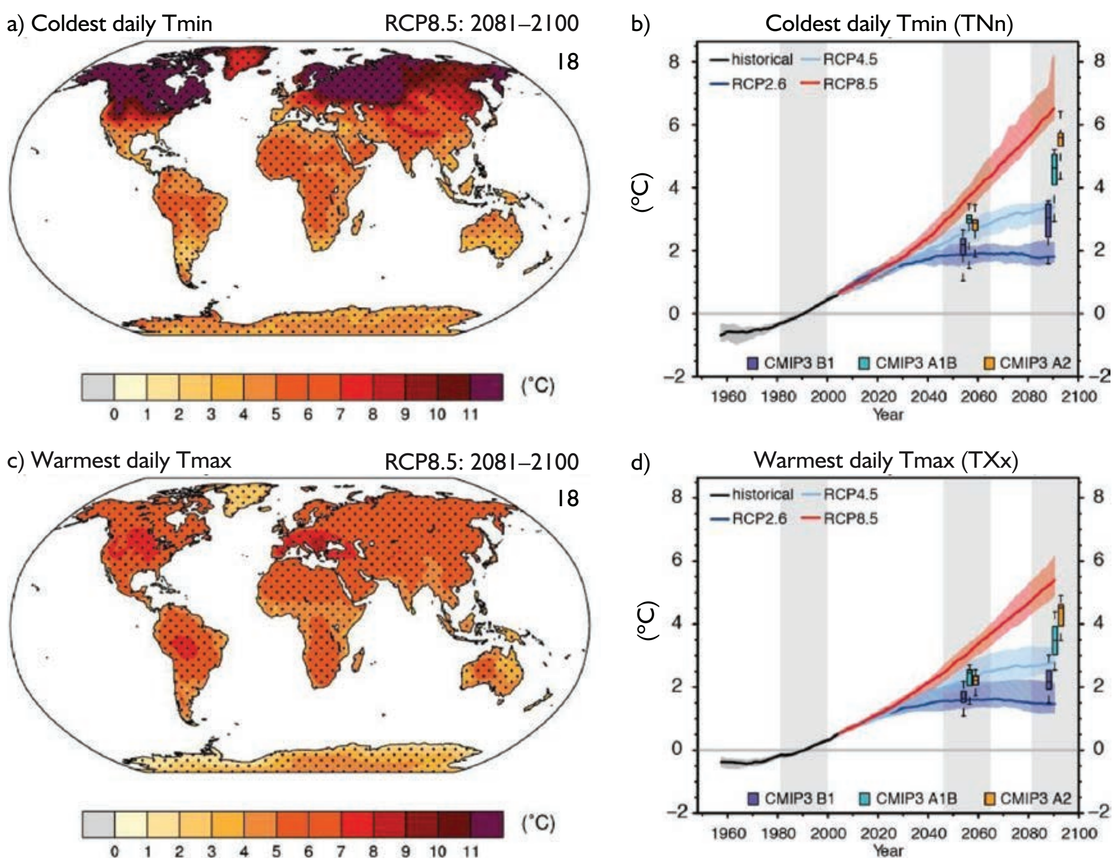


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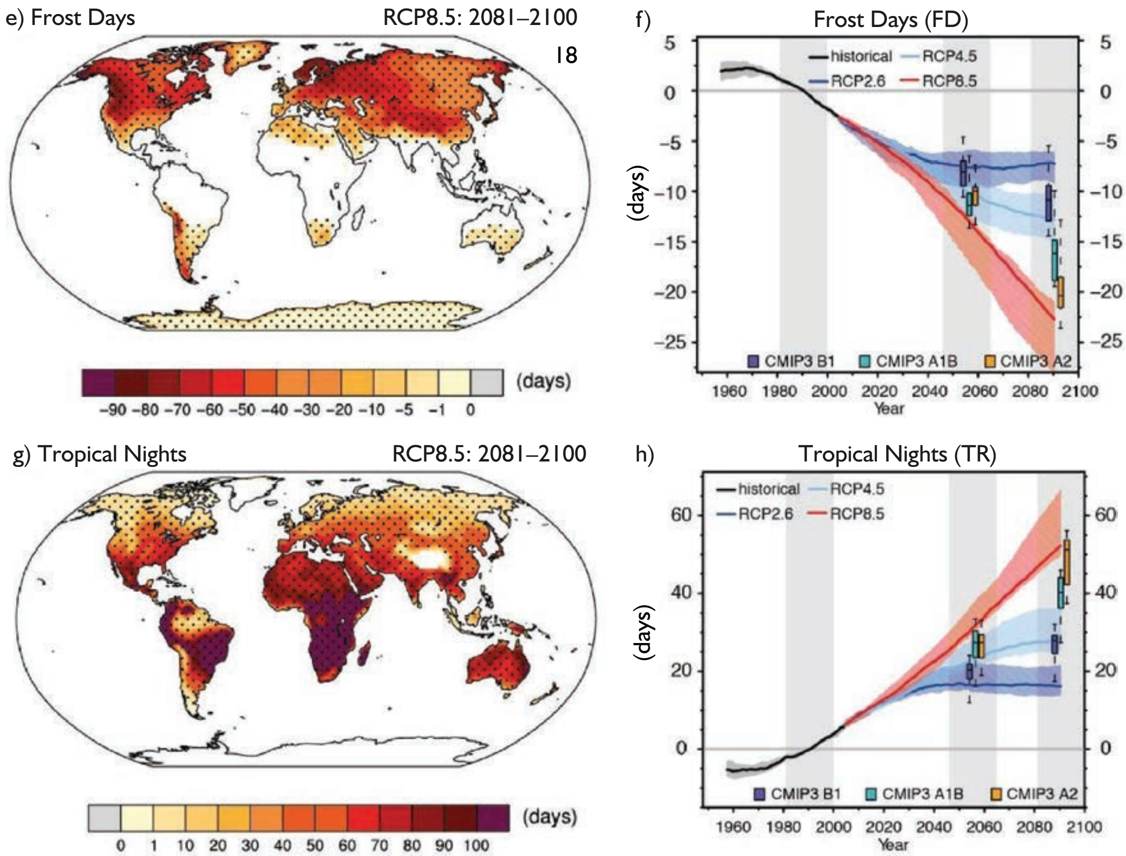
FIGURE 7.8 *(Continued)*



Source: Collins et al. 2013.

Note: (a, b) the annual minimum of daily minimum temperatures, (c, d) annual maximum of daily maximum temperatures, (e, f) frost days (number of days below 0°C), and (g, h) tropical nights (number of days above 20°C). White areas are regions where the index is not valid. Shading in the time series represents the interquartile ensemble spread (25th and 75th quantiles). The box-and-whisker plots show the interquartile ensemble spread (box) and outliers (whiskers) for 11 CMIP3 model simulations of the SRES scenarios: A2 (orange), A1B (cyan), and B1 (purple) averaged over future time periods (2046–65 and 2081–2100) as anomalies from the 1981–2000 reference period.

CHAPTER
EIGHT

DROUGHT MANAGEMENT CHALLENGES AND POTENTIAL INTERVENTIONS

Lebanon has not been successful in drought risk management, but some important efforts should be acknowledged. Generally, the public and private spheres lack a coherent and coordinated drought strategy. There is no central drought authority or coordinating body. Often drought management efforts take place at the subnational level, with some notable achievements at the municipal level, but nothing sustained. When interventions occur on a wider scale, they are to build resilience, an important contribution, but they do not specifically target droughts or manage drought risk. Other challenges include a lack of drought monitoring, poor knowledge exchange, weak extension services, unstable land and water rights, and more generally a dysfunctional government drought management framework. This chapter describes these challenges and some of the efforts that are being made to rectify them. It also will examine two new technologies—a drought Early Warning System (EWS) and hydroponic farming—that demonstrate the potential for Lebanon to improve drought risk management efforts. This Chapter looks at the many challenges to drought management in Lebanon and some innovated responses to the problem, like EWSs and hydroponics.

CHALLENGES

There are several challenges related to drought risk management in Lebanon. Through stakeholder consultations and a literature review we classified these challenges into four main types. These include: weak institutional frameworks, a lack of scope and focus on drought, the poor collection and exchange of information, and poor subnational capacity.

Weak Institutional Framework

In Lebanon, drought management is not centralized. Drought is managed by individual institutions through their own frameworks. There is not a guiding national strategy for drought management and efforts are not coordinated. The Ministry of Environment (Farajalla, n.d.) characterized the country's drought response as "weak" because of "the lack of legislation that would have enabled the Government to declare a water emergency but also due to the fact that there is no drought emergency plan." Government stakeholders said institutional roles in drought management are not clear. For example, in response to the 2014 drought, according to stakeholder interviews, the central government's ability to develop an action plan was hampered by each agency not knowing its role. As a result, institutional focus was lost after the drought abated in 2015. In another example, local Departments of Agriculture cannot act independently but must take directives from the central government. This created blockages down the drought management line.

To improve drought coordination, an inter-ministerial committee was established to deal with the increasing water shortages from the 2013–14 drought. The Parliamentary Committee of Public Works and Energy and Water proposed this committee, which comprised various ministerial stakeholders. It proposed that the Council of Ministers manage water shortages. It created a Water Scarcity Task Team within the MoE to help respond to the water crisis.

Another effort was made to coordinate through the Disaster Risk Management (DRM) unit in the Prime Minister's Office (PMO). In theory, the DRM unit could coordinate activities among each ministry, but currently this system is not operational for droughts. Moreover, some government and civil society stakeholders are skeptical of the long-term sustainability of the DRM units since they operate under the aegis of the United Nations. Once the UN ceases these efforts there is a strong likelihood that these units will fall away.

Overall, the country lacks regulatory enforcement for water management. For example, water utilities are often unable to collect tariffs, with local elites pressuring them not to cut services as a result. Likewise, illegal pipe connections cause leakages, decrease water pressure in pipes, and are costly to repair. Moreover, the various water utilities do not have sufficient resources or security capabilities to protect infrastructure and enforce legal and regulatory codes.

At a broader level, government dysfunction was another challenge, according to stakeholders. One source said, "corruption, bureaucracy, and the country's perennial political paralysis make the prospects for (drought management) changes uncertain" (Middle East Eye 2014). A decade passed without an elected government or an approved budget, causing instability. While institutions continue to function according to their historical roles, progress is stalled because of a lack of a cohesion, clear mandates, coordination, and a strong central authority. Connected to this, local leaders commonly have major influence over local development strategies and legal and regulatory regimes. Compounding these problems, security concerns limit government agencies' access to some areas of the country. Regional stakeholders mentioned some villages had not had visits from extension agents in over two years. In the semi-arid Northeastern areas of Lebanon, rangeland degradation and the livestock impacts from drought have not been tracked because of security concerns.

Lack of Scope and Focus

Lebanon drought management efforts lack a concerted effort. In stakeholder consultations, only one nationally-coordinated relief effort was mentioned. This effort, called the Higher Relief Fund and is used to mitigate the financial impacts from war and natural disasters. The army leads this fund because they have the personnel and equipment to access remote and insecure areas and are the only institution trusted to distribute relief funds. They survey impacted areas and manage payouts if necessary. Unfortunately, staff who undertake surveys are not sufficiently trained in the technical components of drought impact assessments. This can contribute to inefficiencies. For example, in the only instance when payouts were made after a drought, funds did not arrive for two years, much too late to mitigate negative impacts. These delays were caused by inefficiencies and slow allocation from the Cabinet.

The country does not focus on drought risk management. While Lebanon possesses a National Water Sector Strategy (NWSS), issued by the Ministry of Environment (MOE), this strategy does not specifically address drought management. In the example of the Higher Relief Fund, it was not created to provide support for droughts, but to relieve war and natural disasters more generally. In consultations, stakeholders often described resiliency building measures when asked to describe how they managed drought. Building resilience to disasters and other potential disruptions is very important. These efforts include increasing water storage and improving irrigation efficiency. For example, the Ministry of Energy and Water is building dams to capture seasonal runoff and the Green Plan (a semi-autonomous agency of the Ministry of Agriculture) is implementing a comprehensive program to construct hill lakes and water reservoirs to expand rainwater harvesting. But, these measures do not target drought specifically, only the consequences of drought.

Poor Information

One of the limits to the current drought management system is there is no drought monitoring mechanism. Monitoring systems act as information sources to trigger action. Lebanon's relatively advanced meteorological network was severely disrupted and degraded during the civil war. This network was never fully rebuilt so there is limited data available. Moreover, there is a financial charge associated with accessing data from these stations. Recent efforts spearheaded by the Lebanese Agricultural Research Institute (LARI) have improved coverage and the sharing of climatological information (See section below on EWS). But, the dearth of climatological data and the non-centralized nature of water resource data management are major stumbling blocks for monitoring drought since there are no commonly-accessible data repositories. Efforts by the Ministry of Energy and Water to establish a Water Information Center to collect data and make it available have not yet materialized.

Stakeholders described other challenges to drought-related information-sharing. These include:

A. The need for personal relationships: Stakeholders described the necessity of personally knowing someone in the institution to receive data. Government stakeholders receive regular weather reports from LARI or directly from the Meteorological Department. But, requests for additional analyses or information are often met with delays if the information comes at all.
B. Low demand for data: Stakeholders expressed relatively little demand for more meteorological and climatological information. Hydrological information, which is spread between multiple institutions, is in higher demand because it more directly links irrigation to municipal water supply management. One problem is many individuals who would benefit from this information lack the capacity and technical know-how to utilize it.
C. A lack of metering: Government stakeholders emphasized there is a lack water metering information, making water management challenging. Even water utilities do not meter all wellfields. The absence of farm-level metering, for both surface and groundwater, makes it difficult to develop irrigation guidelines for droughts or produce estimates of water demand fluctuations caused by drought.
D. Poor flow of information: Even when data is available, the flow of information is problematic. Information sharing from government agencies to farmers and civil society stakeholders is

limited except for LARI's EWS. If it happens at all, it often arrives too late to be useful. Acquiring information on surface water irrigation or water levels remaining for irrigation, for example, were described as useful but hard to attain.

To help overcome some of these data constraints, USAID funded a three-year regional technical assistance project called, "the MENA Regional Drought Management System." The project was implemented by the International Center for Biosaline Agriculture (ICBA) and the National Drought Mitigation Center (NDMC) at the University of Nebraska in partnership with FAO. The objective was "to empower decision-makers to manage drought impacts on food and water security under current and future climate conditions" (USAID, n.d.). But, part of this work entails validating drought indicators for Lebanon. These indicators could be used to create maps and Composite Drought Indices and support decision-making by organizations tasked with mitigating drought impacts. This data would also improve predictive capabilities.

Weak Subnational Capacity

Weak subnational land and water rights are major issues during droughts. Progress has been made in Lebanon to codify, unify, and rationalize land and water regimes over the past decade. This includes the October 2017 ratification by parliament of a new Water Law, which provides a legal framework for Water User Associations, but there is still lots to do. Many laws date back to the Ottoman era and simply evolved into current laws. Government and civil society stakeholders described this as a barrier to developing coordinated management plans. There are also legal difficulties to creating local water user associations, which are typically a part of effective water management. Most agree that providing some degree of local user management over water resources would be effective, especially during droughts. In stakeholder consultations only one example was given of a water user association being formed. This was in Southern Lebanon.

There are few efforts to empower the subnational level to manage drought risk. In cases where local municipalities control water resources for irrigation, there have been notable successes in drought management. Civil society stakeholders said responses to drought are effective when municipalities are well-organized, have respected leaders, and control water resources. As such they can plan for local needs and take necessary steps to regulate annual crop plantings and irrigation timings.

Weak extension services were another subnational problem for drought management. Governmental extension services are under-staffed with personnel responsible for a range of duties under the regional departments of agriculture, not just extension activities. In the areas without public-sector extension services, agricultural input suppliers become the primary "extension" agents in Lebanon. But, suppliers have vested interests in the advice they provide. For example, stakeholders said suppliers frequently promote products regardless of their effectiveness.

INNOVATIVE INTERVENTIONS

This section looks at two innovative interventions currently taking place in Lebanon. These include the development of drought EWSs and hydroponic farming. Both interventions are in their early stages but both also appear promising. Both systems are described in detail below.

Early Warning Systems

LARI has created weather forecasting facilities and developed a nationwide drought EWS for Lebanese growers. These services necessitate daily monitoring, recording and forecasting. LARI's experts analyze the gathered weather data and develop information services before dissemination to farmers and to the public.

The unit within LARI that manages the EWS is the Irrigation and Agrometeorology department. LARI was established in 1957 and this unit shortly thereafter. Agrometeorology is the study of weather and climate information to enhance agricultural crops and increase production. Understanding crop water requirements, soil water retention traits, crop coefficient parameters, and evapotranspiration computations are priorities of the department. These agrometeorlogical services were upgraded through the EU-funded Agriculture Development Project (EU Agriculture Development Project, MED/2003/57/ADP). This included the initial expansion of the automated weather stations from four to 25 (described below) and helped develop pest and disease models for several crops. These crops include grapes, apples, cherries, tomatoes, and potatoes. Using agrometeorology, two pilot projects were established in the Bekaa Valley to create water harvesting reservoirs and pressurized irrigation systems.

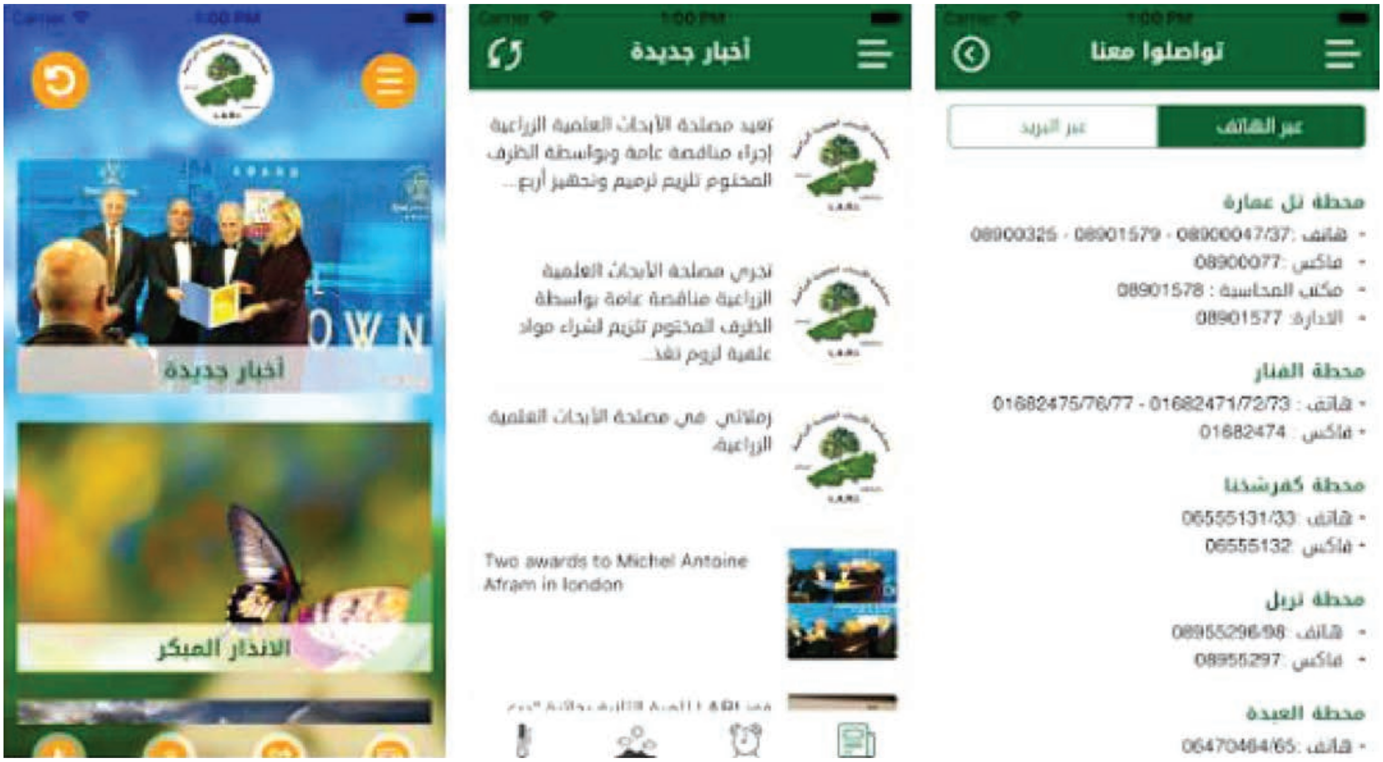
In 2008, LARI established a Short Message Service (SMS), or text messaging, which sent farmers weather forecasts, extreme event warnings, and important agricultural updates. By 2015, the number of registered beneficiaries reached more than 5,000 farmers. Despite many operational challenges and rising costs, LARI has sustained the system continuously since its establishment. In early 2015, LARI developed a smart phone application called "LARI-LEB" that runs on both Android and Apple systems.[14] The "LARI-LEB" application replaced the costlier SMS system and increased the pool of farmers registered in the system. The "LARI-LEB" application now has between 15,000 and 50,000 beneficiaries. It also expanded the types of information it shared to include, sowing dates, irrigation efficiency information, and pest and disease management. It has a tab that provides 10-day weather and rainfall rates for specific regions and compares this data to the previous year and to long-term averages. Figure 8.1 provides screenshots of the application.

The application serves as an EWS for farmers. This developed out of necessity after a series of extreme weather events in Lebanon led to production losses. A functional EWS has several important benefits. These include: helping farmers cope and prepare for extreme weather events and climate change; improved food security and fewer production losses by protecting crops and informing about ideal planting conditions; informing about proper chemical and pesticide use; and informing farmers about available water levels and irrigation strategies.

Rainfed agriculture has benefited from LARI's EWS. Lebanese farmers typically cultivate rainfed crops in the fall without planning for the coming rainy events. The EWS advises farmers on the ideal time to cultivate. The timing is determined by forecasting rainfall rates and calculating crops' water needs to withstand twenty consecutive dry days. This leads to better water management and maximized production. The total area of cultivated rainfed wheat land ranges from 25,000 to 40,000 hectares. Early crop growth requires about five to ten millimeters of irrigated water for the first watering. To irrigate a hectare of wheat requires between 100 to 500 cubic meters of water depending on many factors. As such, managing irrigation through the EWS can save millions of cubic meters of fresh water in Lebanon.

[14] https://play.google.com/store/apps/details?id=com.moussawi7.lari&hl=en

FIGURE 8.1 The LARI-LEB Smartphone Application



EWS also informs farmers on frost and heat wave warnings and pruning, spraying, and harvesting times. The EWS also minimizes pesticide application.

But, implementing a functional EWS in Lebanon has proven difficult. First, Lebanon's rugged topography and multiple agro-climatic zones makes it difficult to target farmers. Second, to achieve that level of accuracy, Lebanon would need many more long-term weather stations. As shown in Figure 4.1b, there are five meteorological stations in Lebanon, three of which have sufficiently long recording histories to properly identify weather anomalies. These stations include Beirut (1888–2003), Ksara Obsy (1921–90), and Tripoli (1931–2003). But, this information is less helpful for the rest of the country and building and maintaining new weather stations is expensive. And third, Lebanon's homogenous agricultural zoning does not properly delineate different agricultural areas. So, EWS information in certain zones may not be relevant for many farmers.

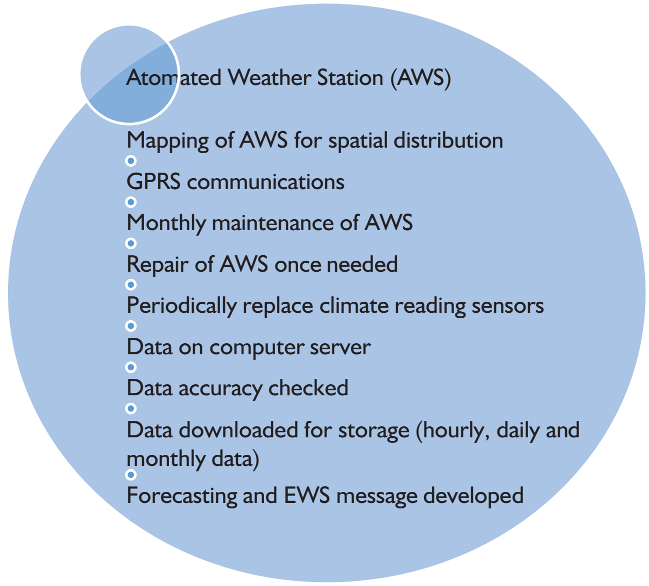
Recognizing these challenges, LARI created an Automated Weather Station Network (AWSN). The AWSN generates climate data on most of the country's micro-climates for agro-meteorological services. The AWSN serves agricultural industries, researchers, and other public and private organizations. The AWSN covers much of Lebanon, and expands greatly on the five existing Koninklijk Nederlands Meteorologisch Instituut (KNMI) stations. Moreover, data is available for free to anyone. The AWSN started in 2009 with 25 stations and gradually expanded to sixty stations by 2016 (see Figure 8.3). Observational climate data is transferred through GPRS technology to centrally-located computer servers. Automated Weather Stations (AWSs) are inspected monthly and repaired when needed. Climate sensors are replaced as specified by manufacturer recommendations.

The climatic data is checked for accuracy by comparing it to trough graphical illustrations. The AWSN is not ideal for monitoring climate changes because, as we discussed, a longer historical record would be needed. But, over time, these stations will be essential. These processes are shown in Figure 8.2.

The AWSN measures several climatic elements. These include rainfall rates, atmospheric pressure, total radiation, wind speed and direction, relative humidity, and maximum and minimum temperatures. This information informs forecasting, EWSs, crop water requirements, irrigation scheduling, pest and diseases monitoring, and potential evapotranspiration. The network was designed to cover most of the national territory (Figure 8.3). The AWSN covers many altitudes from sea-level to 1,900 meters above sea-level at Ehden.

Despite this progress, several areas are still not covered. Lebanon's many microclimates make it difficult to assess all of them. This is especially true for the Anti-Lebanon mountains, which border Syria. Eastern Lebanon, which is often affected by torrential rainfall, is the closest to Syria and not covered by the AWSN because of persistent insecurity in the region.

FIGURE 8.2 Automated Weather Station Network Process



Note: EWS = Early Warning System.

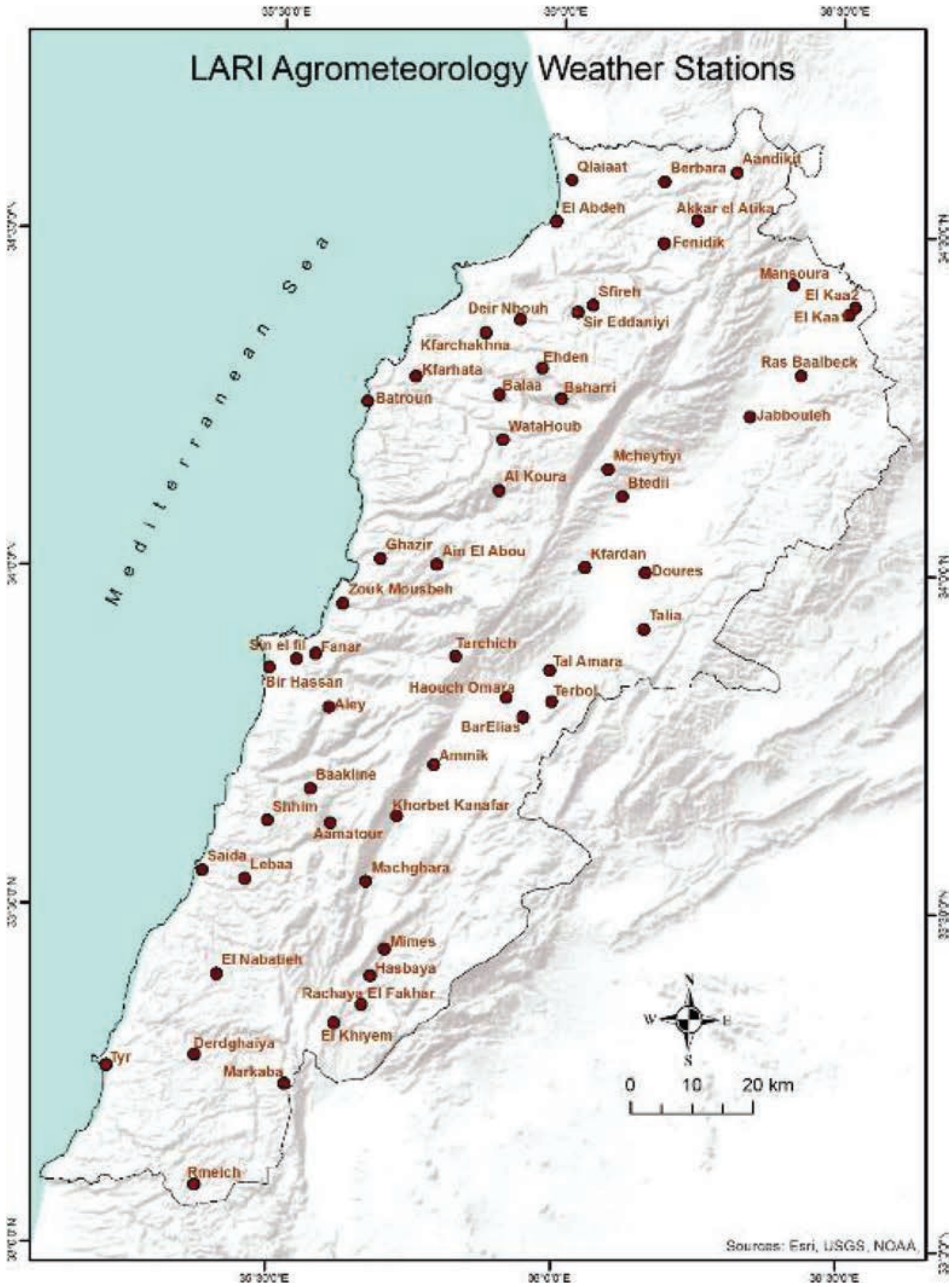
LARI estimates that about 200 AWS would be needed to cover the country. These 200 AWS could report observations from almost every Lebanese micro-climate. The current cost for 60 stations is about US$60,000 per year and the estimated cost for 200 stations is between US$150,000 and US$200,000 per year. Currently, LARI covers these costs from its own budget, while the service it provides is free. New technologies could help stem some of these costs. For example, the World Bank Group's Agriculture Observatory and its private sector partner (aWhere) produce high-resolution (9 kilometer × 9 kilometer), near-real-time weather data based on about 300 virtual meteorological stations. This data is created using a combination of existing ground stations and artificial intelligence algorithms. This could be applied in Lebanon to supplement existing stations.

A rapid appraisal was carried out in Spring 2016 by ClimaSouth,[15] an EU-funded project, to gain farmers' perspectives on the app. Sixty percent of users were satisfied with the app and found it useful. Farmers specifically reported the app helped decrease production risks and improve climate change resilience, but farmers still expressed some concerns. For example, some farmers expressed their wish that the application would be expanded to include more agricultural practices.

There are several ways the EWS and LARI-LEB can be improved. This includes: building more AWSs to better capture subregional micro-agroclimates, expanding the amount of agriculture practices it covers, evolving with newer technologies, modifying the structure of the application for improved user-friendliness, and linking the EWS to political advocacy, socioeconomic conditions, and agricultural institutions and their corresponding organizational structures (Pelling 2010). To make the app more user-friendly, several things could be improved upon. First, it could include maps where farmers can easily register their crops and exact field location. Second, each EWS message would be specific to

[15] http://www.climasouth.eu/.

FIGURE 8.3 Distribution of LARI's Automated Weather Stations



Source: LARI 2016.

the farmer's exact microclimate. And third, farmers could enter cultivation specifics and the app would generate an agricultural program specific to his or her locality.

Hydroponics

Hydroponic agriculture is a fledgling industry that presents many opportunities in Lebanon, particularly in improving water productivity and drought management. This is especially true in urban areas, small or fragmented lands, and among refugee communities that lack land, livelihoods, and food security. Hydroponics is the method of growing plants in a nutrient-rich water solvent, without using soil (Cooper 1979). Not all soil-less growing methods, like aeroponics, are hydroponics, but for the purposes of this report we use the term hydroponics as an umbrella term for all soil-less techniques (FAO 1990). Hydroponic systems range from small home setups to large enterprises. As such, the process can be relatively cheap or very expensive. It also requires a high level of technical skills to operate.

Hydroponic agriculture requires professional experience to implement. Though hydroponic technologies have been known for many years, those technical skills are not widely understood or utilized. In 1937, the principles of hydroponics were published in *Science* Magazine by W.F. Gericke (Gericke 1940; Hoagland and Arnon 1950; Jones 2005). Despite this long history, according to the US Environmental Protection Agency, total US crop production is worth US$143 billion, but US hydroponic revenue is worth only US$607 million (Pilloni 2014). In Lebanon, the hydroponic industry is even smaller and more nascent. An important reason that hydroponics has not become more widely used is that it requires advanced technical capacities to monitor the process and carry out detailed analyses.

Hydroponics are also expensive. According to farmer estimates (Jomaa and Massad 2017), hydroponics cost about US$175 per square meter in Lebanon. The cost for medium- to large-size hydroponic farms ranges from US$100 to US$200 per square meter. Most of these costs are dedicated to up-front expenses, making short-term profits difficult to achieve. This high capital investment in hydroponic systems largely goes towards purchasing equipment.

Hydroponic systems require a minimum level of equipment. This includes (1) a growing chamber, (2) a water reservoir, (3) a submersible pump, (4) a delivery system of pipe networks (5) timers, regulator, and sensors, (6) an air pump, (7) growing lights, (8) inert or organic substrates, and (9) a drainage and water recycling system. Precise salt and nutrient concentrations are determined according to plan requirements. The main hydroponic systems are (1) water-only solutions, (2) mixed air and water solutions, and (3) substrates. With water solutions, nutrients can be moved to the plant using pumps in an "active hydroponic system" or by gravity in a "passive hydroponic system."

Hydroponic systems can be either open or closed. Open systems do not reuse solutions, but allow these solutions to flow through the system only once. Closed systems recycle the solutions, reusing unabsorbed nutrients (Jensen 1997; Nederhoff and Stanghellini 2010). Open systems have the advantage of: (1) eliminating water solution maintenance, and (2) reducing the risk of plant infection. But, open systems are also more wasteful. Closed systems, by contrast, have the advantage of conserving water and nutrients. By some estimates, it conserves resources by 20 to 40 percent over open systems (Nederhoff and Stanghellini 2010). Closed system solutions are monitored for nutrient compositions (Spensley, Winsor, and Cooper 1978) and discarded after a fixed amount of time, usually a week or two. The discarded solutions can then be applied to traditional agriculture as a supplemental fertilizer (Lykas et al. 2006; Nederhoff and Stanghellini 2010).

There are six common types of hydroponic systems. These include: Drip, Wick, Ebb and Flow, Aeroponics, Water Culture, and Nutrient Film Technique (NFT). Systems are chosen depending on the plant type, plantation size, connecting water network, and water availability. These systems are summarized in Table 8.1.

Despite these high equipment and maintenance costs, there are ways to save or recover costs in the longer-term. For example, small-scale hydroponic systems for individual households could have lower investment costs. Also, a more experienced grower might find ways to limit costs by building the system alone and not hiring a specialized company or by maintaining the system with cheap, manual, simple tools. If the initial investment is minimized, the system's rapid plant

TABLE 8.1 Hydroponic System Summary

Hydroponic Group	Hydroponic System	Year	Technical Specifics	Advantages	Disadvantages
Water solution only, water based systems	Gerike's system	1929	Litter suspended, concrete tank, aerated solution		
	Floating systems		Plants supported on rafts, aerated solution		
	Deep re-circulating water culture system		Kyowa semi-deep system: storage tank, pump, aerated solution		
			M-system: pump, air mixer		
			Ein Gedi system: aerated solution		
Water solution/air	Nutrient Film Technique (NFT) (mainly closed system)	1966	Shallow film of water (1 cm to 2 inches), slow flow of 1 to 2-liters per minute	Save water and nutrients	■ High level of technical skills ■ High risk of disease ■ Continuous solution monitoring ■ Water flow blocked by roots ■ High initial and operational costs
	Root misting, aeroponic				High initial and operational costs
Substrate, media systems	Intermittent subirrigation				
	Ebb-and-flow or flood and drain	1940s	Rooting bed with inert substrate, pump, reservoir or sump, closed		Disease infection risk, periodic rooting replacement
	Drip/pass through inorganic medium systems		Perlite or rockwool slabs, open	Could be vertical cultivation system	
	Wick system		Vermiculite, pro-mix, perlite, coconut fiber	Passive: water moves through wicks	Large plants absorb most of the solution
	Natural organic substrate				

Sources: Brooke 1990; Donnan 1998; Eastwood 1947; FAO 1990; Graves 1980; James 1993; Jones 2005; Morgan 2003.

production can recover costs relatively quickly. For example, a hydroponics project in the Adloon area of southern Lebanon, established by the Debbane group, is producing 30 to 35 kilograms of tomatoes per square meter. By contrast, greenhouse cultivation produces a maximum of 16 kilograms of tomatoes per square meter. Rainfed areas produce even less. For other crops, hydroponic production is also high. It is 20 kilograms per square meter for strawberries, 20 for eggplant, and 30 for cucumbers. These yields are much higher than traditional farms, making investment recoupment relatively quick. LARI (2017) estimates that initial costs can be recovered within the first year.

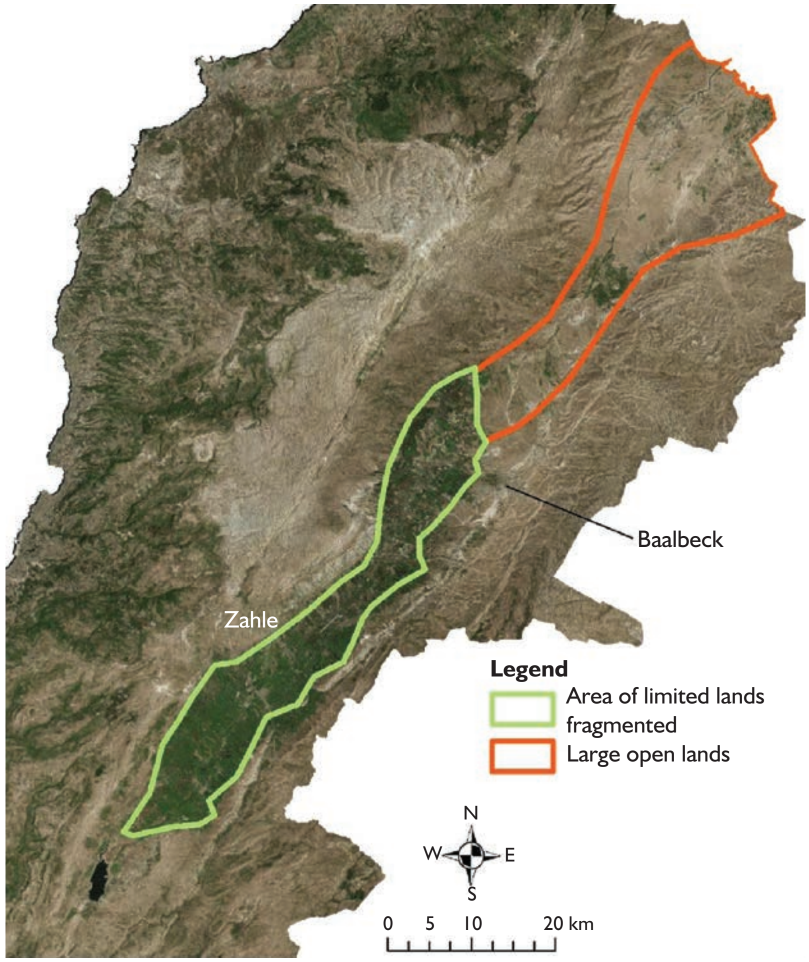
There are many advantages to implementing hydroponic agriculture. These include the following: hydroponics can be applied anywhere. It does not require large swaths of land or nutrient rich land to produce crops like traditional agriculture; crop rotation and other soil conservation techniques are not required; the equipment and solvents used to grow crops can be re-used and recycled, limiting waste; hydroponics can produce all year long, there are no growing seasons; hydroponic plants are grown in a controlled environment and, therefore, have high pest and disease resistance; plants grow more quickly with higher yields; pesticides are not necessary; and growers can control for a plant's nutrient uptake, eliminating unwanted elements, like nitrates, and making crops more nutritious.

In terms of drought, the greatest benefit of hydroponics is its water-saving capability. Despommier (2010) estimates that hydroponics use between 70 and 95 percent less water than open field cultivation (Despommier 2010). It minimizes loss from water runoff and evaporation. This makes it an agricultural system ideally suited for dry or drying regions. Population growth, agricultural intensification, industrial expansion into agricultural areas, and other factors are putting pressure on land and water resources. Hydroponics is applicable in these and other types of marginalized lands that are no longer suitable for traditional agriculture (Nelkin and Caplow 2007).

There are other specific characteristics about Lebanon that make hydroponics a useful option. These characteristics include:

1. The diverse topography of Lebanon causes dramatically changing climatic conditions. For example, abrupt temperature changes over the course of a single day. Hydroponics controls the growing environment, neutralizing challenges from microclimate variability.
2. Lebanon's sloping terrain makes soil erosion a frequent challenge to agriculture. Hydoponics, a soil-less technology, is unaffected by soil erosion or the general nutrient depletion of soils.
3. As mentioned earlier, several regions of Lebanon are arid. Others are becoming arid. Moreover, it is predicted that the country is drying and water resources are becoming scarcer. Hydroponics, especially closed systems, very efficiently uses water resources.
4. Lebanon is a small country with limited lands available for agriculture. Hydroponic plots can be created in small areas. They can even be built vertically to further save space.
5. Lebanese farms also tend to be small or fragmented (see Figure 8.4). Making small land plots more productive can benefit small-scale farmers. Hydroponic growers interviewed by LARI say hydroponics can increase output by a factor of 15.
6. Lebanon is more urban than most countries in the region. Hydroponics can be implemented on small urban plots. This can provide livelihoods and food security for poor urban populations.
7. For similar reasons, hydroponics can benefit refugee communities in Lebanon. Large numbers of refugees have fled the war in neighboring Syria and temporarily settled in Lebanon. Many came from rural areas in Syria and many possess agricultural skills. LARI (2017) estimates the agricultural labor force doubled in Lebanon because of the Syrian conflict.

FIGURE 8.4 Bekaa Valley's Land Availability



Source: LARI 2016.

> When refugees arrive to Lebanon they often live in crowded conditions in informal, tented settlements or cities. In both cases, they have limited access to lands. Moreover, they are often unemployed and rely on humanitarian assistance. Implementing hydroponics in refugee communities would put people to work, increase food security, and utilize the agricultural skills that many refugees possess. It would also make overcrowded areas with little or no available land productive.

Currently, hydroponic cultivation in Lebanon is limited. Recently, 400 square meters of land was set aside in northern Lebanon for hydroponics crop farming (The Daily Star 2017). This was commissioned by the Hyundai Startup Company in 2015. Still, there are only four larger-sized hydroponic producers in the country. Two of these are located on the southern coast, and two along the northern coast. Previously there was one in the Bekaa Valley, but it was forced to shut down after a fungal outbreak, brought on by unseasonably warm temperatures, destroyed the crop. Also, since hydroponics require freshwater to maintain nutrient solutions, saltwater infiltration on the coast makes many of those areas unsuitable for hydroponics.

CHAPTER

NINE

MANAGING DROUGHT IN LEBANON—TODAY AND TOMORROW

Drought will continue to negatively affect agriculture and water resource systems in Lebanon. Future climate scenarios show that aridity will continue to increase as will the severity and frequency of droughts, particularly in central Lebanon. These changes are important for Lebanon's agricultural sector and the populations that depend on it. Droughts can have social, economic, and environmental impacts on the agricultural sector. Table 9.1 shows many of the ways this occurs. This Chapter outlines immediate and longer-term steps to improve Lebanon's drought management system.

Traditionally, Lebanon has relied on short-term emergency relief measures to manage droughts. These *ad hoc* responses are a result of drought not historically being viewed by policymakers and the wider public as a major threat to Lebanon. But, *ad hoc* emergency assistance measures are "seriously flawed from the perspective of vulnerability reduction since the recipients of assistance are not expected to change behaviors or resource management practices as a condition of the assistance." A researcher at American University of Beirut (AUB) concurred (Jabar 2014, 1), saying, "most of the Arab countries' approach to drought management is reactive." Thus, there is a need to "push to proactive approaches where actions are planned in advance . . . [because] preparing for drought is less costly than managing a crisis when it actually hits."

Long-term drought risk management can be difficult to advance when current droughts heighten the focus on immediate crisis response. However, it is often a severe drought crisis that provides the best opportunity and impetus to implement longer-term drought risk management measures. Because drought risk management involves a long-term commitment, it is acceptable and not uncommon for initial efforts to be comparatively simple. The expectation is this commitment will become more sophisticated and continue to evolve. A prime illustration of this is the United States Drought Monitor (USDM), which was a much simpler process when it started in 1999. There are similar expectations for the recently established Drought Monitor for Northeast Brazil.

As we have seen in previous chapters, the severe drought in 2014 raised awareness about the severity of drought in Lebanon and began to move the country towards more proactive drought programs. These efforts include: creating synergies among public institutions and civil society organizations, investing in climate data collecting stations, developing Early Warning Systems (EWSs), and exploring new technologies, like hydroponics. But, much more needs to be done to reduce drought risk. Fortunately for Lebanon, other countries have struggled with drought challenges for many years, so it is understood what steps could be taken to reduce drought risk.

TABLE 9.1 Drought Impacts on Agriculture

Social	Economic	Environmental
■ Reductions in nutrition, stress-related dietary deficiencies ■ Increased conflicts, such as water disputes ■ Inequity in drought impacts ■ Reduced quality of life, changes in lifestyle in rural areas ■ Population migration from rural areas	■ Losses from crop production ■ Losses from dairy and livestock production ■ Losses from forest products ■ Income losses for farmers ■ Employment from production declines ■ Decline in food production and disrupted food supply ■ Increased groundwater depletion, land subsidence ■ Decreased land prices	■ Damage to plant species ■ Increased number and severity of forest fires ■ Wind and water erosion of soils ■ Lake and reservoir drawdown ■ Water quality effects, such as high salt concentration, increased water temperature, and others

Source: WMO and GWP 2014.

Successful drought risk management requires both short-term emergency assistance and longer-term policy, structural, and institutional interventions. Drought risk management requires longer-term interventions because the complex nature of droughts and their social vulnerabilities change over-time. These longer-term projects often focus on water resource management, agricultural technology improvements, and water-related infrastructure developments. These use scarce water supplies more efficiently and productively. Short-term projects, by contrast, often meet with limited success. This should be understood as different from short-term emergency assistance, which minimizes drought's worst impacts by helping protect people's livelihoods and protect drought-impacted families and communities. The World Bank (Redwood, 2017) recommended this dual, short-and-long-term approach for both Northeast Brazil and Sub-Saharan Africa, two areas long affected by drought, but is also applicable to other drought-prone parts of the world.

Effective drought risk management would also benefit from recognizing overlapping challenges and integrating management efforts for each complementary challenge. For example, proactively managing both surface and sub-surface water stocks and flows is essential to build drought resilience. Well-stocked sub-surface water stocks, or aquifers, are important for mitigating drought, especially for future drought, but so are sufficient surface water resources. As such, Lebanon could develop landscape-scale specifications for both surface and sub-surface storage and water capture. Also, depleted aquifers are vulnerable to seawater intrusion because of expected seal level rise. Other areas that could be better integrated are climate change adaptation with drought risk management and flood risk management with drought risk management. One approach is to use a Managed Aquifer Recharge (MAR) system (Jordan 2016). Such a system integrates many of these themes. For example, it replenishes aquifers, which mitigates the risk of both drought and surface flooding.

IMMEDIATE STEPS

To help build long-term drought risk management, two first steps could be taken. First, set up a national drought monitoring system and, second, develop national drought plans. These steps will establish clear and practical actions, like water allocation prioritization, that can be implemented quickly once droughts are identified.

Improving drought monitoring capacity and the timely communication of monitoring data are important steps in initiating any drought response. For this purpose, the experience with "Drought Monitors" in the United States and, more recently, in Northeast Brazil, is of direct relevance. One output from these experiences is the production and widespread dissemination of weekly or monthly drought maps. These could be disseminated to affected areas and communities but also to local and national policymakers. This dissemination can occur through the Internet or by other means, such as smart phone technologies. Drought maps were very useful tools in the US and Brazil for increasing awareness and speeding up government responses to evolving drought conditions. In robust systems, better drought monitoring leads to better planning as improved information enters the decision-making process at both the national and subnational levels. This was recognized by the US, Brazil, and other countries surveyed, although achievements to date have been mixed (Redwood 2017).

To help supplement a shortage of hydrometeorological ground stations in Lebanon, the country could harness state-of-the-art agricultural meteorology services. The World Bank Group's Agriculture Observatory in partnership with aWhere has created such a service. This service produces high-resolution (9 kilometers × 9 kilometers), near-real-time weather data based on about 300 virtual meteorological stations. The data is generated using a combination of existing ground stations and artificial intelligence algorithms. For a fee, Lebanon could use this service to buttress data shortages stemming from limited ground stations. Some capacity building would need to take place to properly implement this service and integrate the data into monitoring systems. Alternatively, Lebanon could consider investing in historical data collection to make better use of the Lebanese Agricultural Research Institute's (LARI) Automated Weather Station Network, but an analysis of the costs and benefits of such research should be carried out first.

The other immediate step that can be taken to build long-term drought resilience is to develop a drought management plan. In fact, this was the main recommendation coming out of the discussion on *Drought Policy, Governance, and Management Systems in the MENA Region* (Jabar 2014). In some countries, such as Iran, Mexico, and Morocco, developing a National Drought Policy helped break inertial attitudes in the government. This illustrates the importance of having strong "top-down" support for any drought management plan.

These plans could focus on risk reduction. They could include organizational frameworks and operational arrangements and be "developed in advance of drought and maintained between drought episodes by governments or other entities." They should carry with them the complementary objectives of "improved coordination and collaboration within and between levels of government, stakeholders in the primary impact sectors, and the plethora of private organizations with a vested interest in drought management (i.e., communities, natural resource or irrigation districts or managers, utilities, agribusinesses, farmers' organizations, and others)" (WMO and GWP 2014).

Drought management programs can build off previous work. The World Meteorological Organization (WMO), the Global Water Partnership (GWP), and the National Drought Mitigation Center (NDMC) at the University of Nebraska, established an Integrated Drought Management Program (IDMP). This program soon published guidelines for developing National Drought Policy (NDP). This document lays out a ten-step plan for countries to follow to prepare a NDP. This is summarized in Table 9.2.

TABLE 9.2 Proposed Steps in the National Drought Policy and Preparedness Plan

1. Appoint a national drought management policy committee.
2. Define the goals and objectives of a risk-based national drought management policy.
3. Seek stakeholder participation; define and resolve conflicts between key water use sectors, considering also transboundary implications.
4. Inventory data and financial resources available and identify groups at risk.
5. Write out the key tenets of the national drought management policy and preparedness plans, including the following elements: monitoring; early warning and prediction; risk and impact assessment; and mitigation and response.
6. Identify research needs and fill institutional gaps.
7. Integrate science and policy aspects of drought management.
8. Publicize the national drought management policy and preparedness plans and build public awareness and consensus.
9. Develop education programs for all age and stakeholder groups.
10. Evaluate and revise national drought management policy and supporting preparedness plans.

Source: WMO and GWP 2014.

LONGER-TERM ACTIONS

Besides these immediate steps, other longer-term steps could be initiated. The first of which is acknowledging that drought is a challenge in Lebanon. Despite the 2014 drought and the level of awareness this raised on drought risk, most Lebanese still do not view drought as a major national challenge. During stakeholder consultations, they urged a shift in discourse on drought and water management. They said drought and water scarcity had hardly entered the public lexicon, despite Lebanon reaching extreme water scarcity in some areas. There is a hope among stakeholders that the Regional Drought Monitoring System (MENA-RDMS), funded by USAID, will provide the base of evidence to shift perceptions of drought and water resource availability.

To codify this shift in thinking, drought risk management could be embedded within Lebanon's National Adaptation Plan (NAP). NAPs are national strategies by countries to adapt to climate change and are submitted periodically to the United Nations Framework Convention on Climate Change (UNFCCC). In Lebanon's most recent NAP (UNFCCC 2015), drought was not acknowledging as an important challenge. Rather, the focus was to improve water availability and decrease water usage. By only focusing on water use and availability, Lebanon is not taking steps to identify and classify drought, and as a result, are will not be prepared for drought. Also, climate change adaptation and drought risk management require many of the same actions, so plans should be fully consistent and integrated (Engle 2013).

The local level also requires embedding drought. This would come in the form of vulnerability assessments. The diverse bioclimatic and agrometeorological zones in Lebanon requires local assessments of drought risk. This will help national and international efforts to properly target interventions and give communities the support they require. Assessments can lead to more efficient ways of approaching cropping, food storage systems, water resource management, or infrastructure development. Understanding local vulnerabilities can help build systems that directly respond to conditions, not impacts, so decisions can be made before impacts occur.

Lebanon could continue to engage with international organizations for technical cooperation. In other drought-prone countries, continuous engagement with international experience has been beneficial both for the development of more dynamic risk management approaches and the infusion of updated knowledge and research findings into these approaches (Redwood 2017). Current technical cooperation activities in MENA are capitalizing on such exchanges at the regional level and are likely to have positive results. Ongoing technical assistance by the International Center for Biosaline Agriculture (ICBA), United Nations Department of Economic and Social Affairs (UNDESA), and other international organizations supports drought risk management. Other institutions, including the World Bank, UN agencies, and bilateral donors can help strengthen agricultural policy, drought risk management, disaster risk management, and integrated water resource management (IWRM). These institutions stand ready to help finance the ensuing interventions.

- Develop proactive drought planning, prevention, and mitigation projects. These can include elements of modern science, risk and resource management, innovation and new technologies, among many other possible components.
- Promote greater collaboration to enhance the quality of local, national, regional, and international delivery systems and observation networks.
- Improve public awareness about drought risk management.
- Consider economic instruments and financial strategies, including risk reduction, risk sharing, and risk transfer tools in drought management plans.
- Establish emergency response plans based on sound management of natural resources.
- Integrate drought management plans with local and national development policies (HMNDP 2013).
- Provide tax and other financial incentives on the purchase and import of water saving technologies. These include dual flush toilets, automatic water dispensers, low flow shower heads, low water use washing machines and dishwashers, and equipment to establish hydroponic farms.
- Enact laws that require water saving accessories in new buildings and those undergoing renovation.
- Adopt green building codes that require rainwater harvesting for new buildings and encourage the same for older buildings.
- Encourage green infrastructure so storm water runoff is captured, treated, and reused.
- Require that modern irrigation technologies and management practices are implemented (Farajalla, n.d.).

The principal responsibility for the eventual achievement of these changes lies with Lebanon. They must successful develop and implement these policies, strategies, instruments, and institutional capacity building measures. For this purpose, strong government commitment and civil society participation at all levels, especially in the drought-prone areas themselves, are necessary.

In Lebanon, there is a strong need for an integrated, cross-ministerial, multi-stakeholder approach to drought management that reflects the new realities of politics and government. Generally, this will require establishing an empowered central authority on drought risk management and institutional coordination. This coordination must first take place within the government, but also eventually with the private sector and civil society. Combining this improved communication and collaboration among governmental agencies and non-governmental organizations with active participatory decision-making is effective in reducing drought risk (Redwood 2017).

Greater coordination can also lead to a more open exchange of knowledge and information. As previously discussed, Lebanon lacks sufficient data to forecast and prevent droughts. Efforts have been made in recent years to expand on this data. For example, LARI's establishment of a network of automated weather stations, and leveraging this data to create an EWS is a good start. But, to fully understand and respond to both the underlying causes and the social, economic, and environmental impacts of droughts, more could be done. This includes understanding the relationship among short-term atmospheric dynamics and phenomena, like El Niño Southern Oscillation (ENSO), and longer-term, more gradual but progressive dynamics, like climate change and climate variability. Generally, the adequacy of drought responses depends on the quantity and quality of available data and the ability to feed this information into local communities and decision-making processes.

Another important tool for managing drought risk, is establishing innovative financial mechanisms. Financial incentives and mechanisms like crop insurance and national drought contingency funds—or natural disaster funds more generally—could be considered. Effective drought management requires both supply side—like expanding water availability—and demand side measures—like price controls or water use restrictions. These measures conserve and allocate water during periods of water shortages according to pre-defined priorities. These mechanisms are being applied in places as different as Australia, California, and Morocco (Redwood 2017). Incentives for farmers to participate in these financial mechanisms should avoid moral risks and added fiscal costs.

Finally, there is an opportunity to expand hydroponics. The previous chapter shows the many ways that Lebanon is ideally suited for an expansion of hydroponics, including increasing water pressures, large urban populations, small land holdings, and large refugee communities. But, it also has logistical conditions that are helpful. Lebanon has been engaged in protected cultivation, like greenhouse cultivations for decades. These started along the coast in the late 1980s and early 1990s, and have lately become popular inland as well. Protected crops are gateways for growers to enter hydroponic schemes. After all, hydroponics is simply an advanced, more productive form of protected cultivation, so a transition is not such a giant leap. This is not to say a transition is simple. It will still require investment, albeit less, and still requires high technical capacity. Even small-scale hydroponics require demonstrations, awareness raising, technical training, and field investigations.

BIBLIOGRAPHY

Abi-Saleh, B., and Safi, S. (1988). "Vegetation map of Lebanon." *Ecologia Mediterranea*, France.

Abi Saleh (1978). Abi Saleh B. Etude phytosociologique, phytodynamique et écologique des peuplements sylvatiques du Liban. Thèse Univ. Droit Econ. Sciences Aix-Marseille III, 184 p.

Abi Saleh, B. 1982. Attitudinal Zonation of vegetation in Lebanon. Ecol. Medit, VII, pp. 355–364.

Abi Saleh B., Nasser N., Hanna R., Safi N., Safi S., Tohme H. 1996. Lebanon Country Study on Biological Diversity. Terrestrial Flora. Republic of Lebanon, Ministry of Agriculture (MoA) and United Nations Development Programme. Lebanon.Vol. 3.

A. Chehade, A. El Bittar, E Choueiri, A Kadri, R. Nabbout, H. Youssef, M. Smeha, A. Awada, Z. Al Chami, I. Cavoski, A. Trani, A. Aly, L. Piscitelli, G. Bruno, F. Caponio, G. Gambacorta, F. Famiani, D. Mondelli, E. Dubla, (2012). "Characterization of the main Lebanese olive germplasm," published by the project "Social and economic support for the families of producers in the olive-growing marginal regions in Lebanon (L'olio del Libano)," funded by the Italian government and implemented by IAM-Bari, Italy with Ministry of Agriculture of Lebanon (MOA) and the Lebanese Agricultural Research Institute (LARI), ISBN: 2-85352-493-0. pp. 72

Adel Modhej, Rozbeh Farhoudi, Ali Afrous (2015). "Effect of post-anthesis heat stress on grain yield of barley, durum and bread wheat," *Journal of Scientific Research and Development* 2 (6): 127–131, 2015

Al Jazeera (2015). "Syria's civil war linked, in part, to global warming," Al Jazeera online, March 2, available at: http://america.aljazeera.com/articles/2015/3/2/syrias-civil-war-linked-partly-to-drought-global-warming.html.

Al Monitor (2017), "Lebanon's budding hashish business brings high returns," Fernande Van Tets, Al Monitor, May 9, available at: http://www.al-monitor.com/pulse/originals/2017/05/lebanon-hash-marijuana-production-rise.html#ixzz4jhwimJK9

Alexander, L. V., X. Zhang, T. C. Peterson, J. Caesar, B. Gleason, A. M. G. Klein Tank, M. Haylock, D. Collins, B. Trewin, F. Rahimzadeh, A. Tagipour, K. Rupa Kumar, J. Revadekar, G. Griffiths, L. Vincent, D. B. Stephenson, J. Burn, E. Aguilar, M. Brunet, M. Taylor, M. New, P. Zhai, M. Rusticucci, and J. L. Vazquez-Aguirre (2006). "Global observed changes in daily climate extremes of temperature and precipitation," *J. Geophys. Res.*, 111, D05109, doi:10.1029/2005JD006290.

American Meteorological Society (AMS) (2004). "Statement on meteorological drought," *Bull. Am. Meteorol. Soc.* 85, 771–773.

Aoubouazza M., Rajel R., Essafi R. (2013). "Impact of Extreme Climate Events on Water Resources and Agriculture and biodiversity in Morocco," *J Climatol Weather Forecasting* 1: 104. doi:10.4172/2332-2594.1000104

Attri S.D., Rathore L.S., Sivakumar M.V.K., Dash S.K. (2011). *Challenges and Opportunities in Agrometeorology*, Springer.

Austin, P.T. and Hall, A.J. (2001). "Temperature Impacts on Development of Apple Fruits," VII International Symposium on Orchard and Plantation Systems.

Azorin-Molina, C. and Lopez-Bustins, J.-A. (2008). "An automated sea breeze selection technique based on regional sea-level pressure difference," *WeMOi, Int. J. Climatol.*, 28, 1681–1692, doi:10.1002/joc.1663, 2008.

Balasubramanian, T.N. et al., (2016). "Designing Agromet Advisories for Selected Weather Windows Under Automated Weather based advisory system in Tamil Nadu – A case Study," *Journal of Agrometeorology*, (18) (1): 34–40.

Baldi M., Cesarone F., Carella F., Crisci A., Dalu G.A. (2004). "Mediterranean winter and fall climate: trends and mechanisms," *EMS Annual Meeting Abstracts* 1: 00266.

BAMS (2008). "State of the Climate in 2007," Levinson, D. H., and J. H. Lawrimore, Eds., *Bull. Amer. Meteor. Soc.*, 89, S1–S179.

BAMS (2009). "State of the Climate in 2008," Peterson, T. C., and M. O. Baringer, Eds.,*Bull. Amer. Meteor. Soc.*, 90, S1–S196.

BAMS (2010). "State of the Climate in 2009," Arndt, D. S., M. O. Baringer, and M. R. Johnson, Eds., *Bull. Amer. Meteor. Soc.*, 91 (7), S1–S224.

BAMS (2011). "State of the Climate in 2010," Blunden, J., D. S. Arndt, and M. O. Baringer, Eds., *Bull. Amer. Meteor. Soc.*, 92 (6), S1–S266.

BAMS (2012). "State of the Climate in 2011," Blunden, J., and D. S. Arndt, Eds., *Bull. Amer. Meteor. Soc.*, 93 (7), S1–S264.

BAMS (2013). "State of the Climate in 2012," Blunden, J., and D. S. Arndt, Eds., *Bull. Amer. Meteor. Soc.*, 94 (8), S1–S238.

BAMS (2014). "State of the Climate in 2013," Blunden, J., and D. S. Arndt, Eds., *Bull. Amer. Meteor. Soc.*, 95 (7), S1–S257.

BAMS (2015). "State of the Climate in 2014," Blunden, J. and D. S. Arndt, Eds., *Bull. Amer. Meteor. Soc.*, 96 (7), S1– S267.

BAMS (2016). "State of the Climate in 2015," Blunden, J. and D. S. Arndt, Eds., *Bull. Amer. Meteor. Soc.*, 97 (8), S1–S275.

Barbera, G. (1991). "Programme de recherche Agrimed," le câprier (Capparis spp), Commission des communautés européennes, Direction Générale de l'Agriculture, Luxembourg. 62 p.

Barlow, M., Zaitchik, B., Paz, S., Black, E., Evans, J., & Hoell, A. (2016). "A review of drought in the Middle East and Southwest Asia," *Journal of Climate*, *29*(23), 8547–8574, doi:10.1175/JCLI-D-13-00692.1.

Barnston, A. G. and Livezey, R. E. (1987). "Classification, seasonality and persistence of low-frequency atmospheric circulation patterns," *Monthly Weather Review*, 115, 1083–1126.

Barnston, A. G., Livezey, R. E., and Halpert, M. S. (1991). "Modulation of Southern Oscillation-Northern Hemisphere mid-winter climate relationships by the QBO," *J. Climate*, 4, 203–217.

BBC (2016). "Illicit cannabis farming thrives in Lebanon," by Venetia Rainey, BBC News, October 26, available at: http://www.bbc.com/news/business-37616921.

Beals E.W. (1965). The remnant cedar forests of Lebanon. *J. Ecology*, 53, 679–694.

Bean WJ, Clarke DL (1991). *Trees and Shrubs: Hardy in Great Britain*, Vol 1 - 4 and Supplement, 8th edition, John Murray Pubs Ltd.

Bois, J.F., Winkel, T., Lhomme, J.P. and Rocheteau, A. (2016). "Response of some Andean cultivars of quinoa to temperature, effect of germination, phenology, growth and freezing," *European Journal of Agronomy*, 25, 299–308.

Bosch, A. P., F. S. Martos, J. L. M. Vidal, and F. Navarrete (1992). "Groundwater problems in a semiarid area (low Andarax river, Almeria, Spain)," *Environ. Geo. Water Sci.* 20:195–204.

Brooke, L.L. 1990. Hydroponics: a growing technology for the 1990s. *The Growing Edge* 1(1):21–23.

Cervigni, Raffaello and Michael Morris (eds.) (2016). *Confronting Drought in Africa's Drylands: Opportunities for Enhancing Resilience*, World Bank, Washington D.C.

Chalak L., Chehade A., Elbitar A., Cosson P., Zanetto A. Dirlewanger E. And Laigret F. (2006). "Morphological and molecular characterization of peach accessions (*Prunus persica* L.) cultivated in Lebanon," *Lebanese Science Journal*, vol. 7, No. 2.

Chalak L., Chehade A., Elbitar A., Youssef H., Nabbout R., Elhaj A., Bassal A., Selman M., Smaha M., Awada A. Bouaram G. (2008). Final Report of Olive RESGEN project in Lebanon.

Chalak L., Chehadé A., Kadri A. (2007). "Morphological characterization of cultivatedalmonds in Lebanon," *Fruits* 62 (3): 177–186.

Chalak L., Chehade A., Kadri A., Cosson P., Zanetto A., Dirlewanger E. And Laigret F., (2006). Preliminary characterization of cultivated almonds (Prunus dulcis L.) in Lebanon by morphological traits and microsatellite markers. Biologia Tunisie, N0 4: 5–11.

Chalak L., Chehade A., Mattar E and Khadari B. (2008). "Morphological characterization of fig accessions cultivated in Lebanon," *Acta hort*., 798, ISHS.

Chalak L., Noun J., El Haj S., Rizk H., Assi R., Attieh J., Maalouf F., Abi Antoun M., Sabra N. (2011). "Current Status of Agro-biodiversity in Lebanon and Future Challenges," *Geneconserve* 10(39): 23–41.

Chalak L., Perin A., Elbitar A. and Chehade A. (2007). "Phenotypic diversity and morphological characterization of *Capparis spinosa* L," *Lebanon Biologia tunisie*, N0 4 bis, 28–32.

Chalak L.and Sabra N. (2007). *Second Country Report on Plant Genetic Resources for Food and Agriculture*, pp.61, available through: www.pgrfa.org.

Chalak L., A. El Bittar and A. Chehade (2014). "Diversity of Wild Prunus in the Bekaa Province, Lebanon, Proc. Ist IS on Fruit Culture and Its Traditional Knowledge along silk road countries, *Acta Hort.* 1032, ISHS: 207–213.

ChalakL., H. Achtak, A. Chehade, A. Elbitar, S. Santoni and B. Khadari (2009). "Genetic structure of spontaneous and cultivated fig in Lebanon indicating a local selection," Fourth International Symposium on Fig, Meknes, September 29–October 3.

Chamoun R., Baalbaki R., Kalaitzis P., Talhouk S.N. (2009). "Molecular characterization of Lebanese olive germplasm tree," Genetics and Genomes, 5(1): 109–115.

Chandniha S.K. and Kansal M.L. (2016). "Rainfall Estimation Using Multiple Linear Regression Based Statistical Downscaling for Piperiya Watershed in Chhattisgarph," *Journal of Agrometeorology*, 18 (1): 106–112.

Chang, F.C., Wallace, J.M., (1987). "Meteorological conditions during heat waves and droughts in the United States great plains," *Mon. Weather Rev.* 115 (7), 1253–1269.

Chéhadé A., Chalak L., Elbitar A., Cosson P., Zanetto A., Dirlewanger E. (2005). "Caractérisation préliminaire morphologique et moléculaire de clones de cerisier cultivés au Liban (*P. avium* L.)," *Lebanese Science Journal*, Vol. 6, No.1.

Chéhadé A.,Elbitar A., Chalak L. (2001) Caractérisation morphologique de la diversité du genre *Prunus* dans la plaine de la Békaa. Magon 1: 4–17

Chehade Ali, Ahmad ElBitar, Aline Kadri, Elia Choueiri, Rania Nabbout, Hiyam Youssef, Maha Smeha, Ali Awada, Ziad Al Chami, Eustachio Dubla, Antonio Trani, Donato Mondelli and Franco Famiani (2015). In-situ evaluation of the fruit and oil characteristics of the main Lebanese olive germplasm, *J.Sci.Food.Agric.*

Chehade Ali, Chalak Lamis, Elbitar Ahmad, Anne Zanetto and Patrick Cosson (2010). "Characterization of almond diversity in Lebanon by microsatellite markers," Primer congresso peruano de mejoramiento genético y biotecnologia agricola, 17–19 May, La Molina Peru: 27–29.

Chehade, Ali and Ahmad Bitar (2017). "Crops and Plants Adapted to El Niño and Climate Change," Background Paper for *The Cures, Causes, and Consequences of Drought in Agricultural Lebanon*, unpublished.

Chmielewski, F.M., Müller, A., Bruns, E. (2003). "Climate changes and trends in phenology of fruit trees and field crops in Germany, 1961–2000." *Beiträge zur,* Klima- und Meeresforschung, Berlin und Bayreuth: 125–134.

Chouchani B., Khouzami A., Quezel P. 1974. A propos de quelques groupements forestiers du Liban. Biol. Ecol. Med. Marseille, 1, 63–77.

Christensen, J. H. and Christensen, O. B. (2007). "A summary of the PRUDENCE model projections of changes in European climate by the end of this century," *Climatic Change*, 81, 7–30, doi:10.1007/s10584-006-9210-7.

Christensen, J. H., K. Krishna Kumar, E. Aldrian, S.-I. An, I. F. A. Cavalcanti, M. de Castro, W. Dong, P. Goswami, A. Hall, J. K. Kanyanga, A. Kitoh, J. Kossin, N.-C. Lau, J. Renwick, D. Stephenson, S.-P. Xie and T. Zhou (2013). "Climate Phenomena and their Relevance for Future Regional Climate Change," *Climate Change 2013: The Physical Science Basis,* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1217–1308, doi:10.1017/CBO9781107415324.028.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton (2007). "Regional Climate Projections," *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)], Chapter 11, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Christensen, J.H., M. Stendel, and S. Yang (2012). "Ways Forward for Climatology," *Adaptation to a Changing Climate in the Arab Countries - A Case for Adaptation Governance in Building Climate Resilience* [Ed. D. Verner], Chapter 2, The World Bank, Washington DC, USA.

Clark, Liat (2017). Syria returns its mass of seeds to the Arctic 'Doomsday vault'. Wired UK. February 23. Available online at: http://www.wired.co.uk/article/svalbard-seed-bank-syria.

Clausen, B., Pearson, C.P., (1995). "Regional frequency analysis of annual maximum stream flow drought," *J. Hydrol*, 173, 111–130.

Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner (2013). "Long-term Climate Change: Projections, Commitments and Irreversibility," *Climate Change 2013: The Physical Science Basis*, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Conte, M., Giuffrida, A., and Tedesco, S. (1989). "The Mediterranean Oscillation. Impact on precipitation and hydrology in Italy Climate Water," *Publications of the Academy of Finland*, Helsinki.

Cook, B.I., Anchukaitis, K.J., Toucham, R., Meko, D.M., Cook, E.R. (2016). "Spatiotemporal drought variability in the Mediterranean over the last 900 years," *Journal of Geophysical Research*: Atmospheres, 121, 5, 2060–2074

Cooper, A., (1979). "The ABC of NFT," *Grower Books*, London, 181 pp.

Corte-Real J, Zhang Z, Wang X (1995). "Large-scale circulation regimes and surface climatic anomalies over the Mediterranean," *Int J Climatol* 15: 1135–1150

Cosmulescu, Sina, Adrian Baciu, Mihai Cichi, Marius Gruia (2010). "The Effect of Climate Changes on Phenological Phases in Plum Trees (Prunus domestica L.) in South Western Romania," *South Western Journal of Horticulture, Biology and Environment*, pp: 9–20.

Dai, A. (2011). "Drought under global warming: a review," *Climate Change*, 2, 45–66, doi:10.1002/wcc.81.

Daliakopoulos I.N., Pappa P., Grillakis M.G., Varouchakis E.A., Tsanis I. K, (2016). "Modeling soil salinity in greenhouse cultivations under a climate with SALTMED: Model modification and application in Timpaki, Crete," *Soil Science*, V 181, 6: 241–251.

Davis, G.W., and Richardson, D.M. (1994). *Mediterranean- Type Ecosystems: The function of biodiversity*, Ed. Springer-Verlag, p. 366.

Davis, P.H. (1965). *Flora of Turkey and the east Aegean Island*, University of Edimburgh, p. 576.

De Nys, Erwin, Nathan. L. Engle, and Antonio Rocha Magalhaes (eds.) (2017). *Drought in Brazil: Proactive Management and Policy*, CRC Press, Taylor & Francis Group, Boca Raton, Florida.

Despommier D. (2010). *The vertical farm: Feeding the world in the 21*st *Century*, New York, NY: ST. Martins Press.

Develle, A. L., Herreros, J., Vidal, L., Sursock, A., & Gasse, F. (2010). "Controlling factors on a paleo-lake oxygen isotope record (Yammoûneh, Lebanon) since the Last Glacial Maximum," *Quaternary Science Reviews*, 29(7), 865–886.

Donnan R. 1998. Hydroponics Around the World. *Practical Hydroponics and Greenhouses*, vol. 41, p. 18–25.

Douguedroit, A. (1998). "Que peut-on dire d'une Oscillation Mediterraneenne?" *Climate and Environmental Change*, Proceedings of the Meeting of the Commission on Climatology of the IGU, Evora, Portugal, pp. 135–136.

Dracup, J.A., Lee, K.S., Paulson, E.G., (1980b). "On the definition of droughts," *Water Resour. Res.* 16 (2), 297–302.

Dunkeloh, A. and Jacobeit, J. (2003). "Circulation dynamics of Mediterranean precipitation variability 1948–98," *International Journal of Climatology*, 23, 1843–1866.

Eastwood, T. (1947). *Soilless Growth of Plants*. 2nd Edition. Reinhold Publishing, New York.

Elleuch, M. (1994). *Stratégie de développement de la recherche en oléiculture*, FAO (1994) Liban.

Eltahir, E.A.B., Yeh, P.J.F., (1999). "On the asymmetric response of aquifer water level to floods and droughts in Illinois," *Water Resour. Res.* 35 (4), 1199–1217.

Engle, Nathan (2013). "The Role of Drought Preparedness in Building and Mobilizing Adaptive Capacity in States and Their Community Water Systems" in *Climate Change*, Volume 118, Issue 2, May.

Estrela, M.J., Penarrocha, D., Millan, M., (2000). Multi-annual drought episodes in the Mediterranean (Valencia region) from 1950–1996: a spatio-temporal analysis," *Int. J. Climatol*, 20, 1599–1618.

Fakhry, K. 2004. Chestnut planting suitable zones in Lebanon. Memoire de fin d'etude M2, Universite Libanaise.

FAO (1983). "Guidelines: Land evaluation for Rainfed Agriculture," *FAO Soils Bulletin* 52, Rome.

FAO (1990). "Soilless culture for horticultural crop production," Plant production and protection, Paper 101.

FAO (2000). "Deficit Irrigation Practices," FAO water reports 22.

FAO (2002). Global Agriculture Census in Lebanon.

FAO (2006). "Agricultural Homogeneous Zones: Support to the Agricultural Census," Direction of studies and coordination. Ministry of Agriculture, Lebanon. pp. 234.

FAO (2009). FAO Lebanon country profile, UN's Food and Agriculture Organization, Rome.

FAO (2011). Quinoa (Chenopodium quince), available at: http://www.fao.org/docrep/t0646e/T0646E0f.htm.

FAO (2011). *Second Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture*, Food and Agriculture Organization of the United Nations, available at: http://www.fao.org/docrep/015/i2624e/ i2624e00.htm.

FAO (N.D.). *Drought Facts*, Rome.

FAO and National Drought Mitigation Center (NDMC) (2008). *The Near East Drought Planning Manal: Guidelines for Drought Mitigation and Preparedness Planning*, Rome.

FAO and National Drought Mitigation Center (NDMC) (2008). *The Near East Drought Planning Manal: Guidelines for Drought Mitigation and Preparedness Planning*, Rome, pg. 5.

FAO, (2015). *National strategy for conservation and management of plant genetic resources for food and agriculture in Lebanon*, pp. 38.

FAO/UNDP (1971). "Report to the government of Singapore on production and marketing of vegetables, Ochids and other flowers, including Hydroponics," TA 2997, p17.

FAOstat (2011). http://faostat.fao.org/site/375/default.aspx.

Farajalla, Nadim (2015). *Drought in Lebanon: The Past Year Was One of the Driest on Record*, SETS.

Fereres E. and Soriano M.A. (2007). "Deficit Irrigation for reducing agriculture water use," *Journal of Experimental Botany*, Vol 58: 147–158.

Fischer, G., M. Shah, F.N. Tubiello, H. Van Velhuizen (2005). Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080.

Flato, G., J. Marotzke, B. Abiodun, P. Braconnot, S.C. Chou, W. Collins, P. Cox, F. Driouech, S. Emori, V. Eyring, C. Forest, P. Gleckler, E. Guilyardi, C. Jakob, V. Kattsov, C. Reason and M. Rummukainen (2013). "Evaluation of Climate Models," *Climate Change 2013: The Physical Science Basis*, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Fraedrich (1994). "An ENSO impact on Europe? A review," *Tellus*, 46 A, 541–552.

Gerike, W.F. (1940). *Soilless Gardening*, New York, NY: Prentice Hall.

Gibbs, W.J., (1975). "Drought, its definition, delineation and effects," Drought: Lectures Presented at the 26th Session of the WMO, Report No. 5. WMO, Geneva, pp. 3–30.

Glantz, M.(ed.) (1994). "Usable Science: Food Security, Early Warning, and El Niño," Proceedings of the Workshop on ENSO/FEWS, Budapest, Hungary, October 1993, UNEP, Nairobi; and NCAR, Boulder, Colorado.

Gleick, P. H. (2014). "Water, Drought, Climate Change, and Conflict in Syria," *Weather, Climate and Society*, 6, 331–340.

Graves, C.J. (1980). "The nutrient film technique," *Horticultural Reviews*, 5:1–44.

Gray, Erin, Norbert Henninger, Chris Reij, Robert Winterbottom, and Paola Agostini (2016). *Integrated Landscape Approaches for Africa's Drylands*, World Bank, Washington D.C.

Gregorio E. Fernandez J., Alcon, F. (2017). "Financial assessment of adopting irrigation technology for plant-based deficit irrigation scheduling in super high-density olive orchards," *Agriculture Water Management*, V. 187: 47–56.

Hamzé M. and Lacirignola C. (2008). *Local Genotypes Present in Lebanon: Apple, Pear, Cherry, Peach, Table Grapes and Olive*, CNRS.

Hanlon, R. J., & Christie, K. (2016). *Freedom from Fear, Freedom from Want: An Introduction to Human Security*, University of Toronto Press.

Harlan, J.R. (1970). "Evolution of cultivated plants." Pages 19–42 *in Genetic Resources in Plants: their Exploration and Conservation* (O.H. Frankel and E. Bennett, eds.), Blackwell, Oxford, UK.

Harlan, J.R. (1971). "Agricultural origins centers and noncenters," *Science (*174): 468–474.

Hartmann, D. L., A. M. G. Klein Tank, M. Rusticuci, L. V. Alexander, S. Bronnimann, Y. Charabi, F. J. Dentener, E. J. Dlugokencky, D. R. Easterling, A. Kaplan, B. J. Sodern, P. W. Thorne, M. Wild, and P. M. Zhai. (2013). "Observations: Atmosphere and Surface." In *Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley, 159–254. Cambridge, United Kingdom, and New York, NY: Cambridge University Press.

Hesselbjerg Christensen, Jens (2017). "Climate and climate change in Lebanon – an update," Background Paper for *The Cures, Causes, and Consequences of Drought in Agricultural Lebanon*, unpublished.

High-Level Meeting on National Drought Policy (HMNDP) (2013). *Final Declaration*, Geneva, March 15, pp. 2–3.

Higton R. N., Akeroyd, J. R. (1991). "Variation in Capparis spinosa L. in Europe," *Botanic Journal of Linnean Society*, 106: 104–112.

Hirich, A., Choukr-Allah, R. and Jacobsen, S.-E.(2014). Quinoa in Morocco-Effect of Sowing Dates on Development and Yield. Journal of Agronomy and Crop Science, 200, 371–377.

HMNDP (2013). *Final Declaration*, High-Level Meeting on National Drought Policy (HMNDP), Geneva, March 15, 2013, pp. 2–3.

Hoagland, D.R. and Arnon, D.I. (1950). "The water-culture method for growing plants without soil." *Circular. California agricultural experiment station* 347, no. 2nd edit.

Hoerling, M., Eischeid, J., Perlwitz, J., Quan, X., Zhang, T., and Pegion, P. (2012). "On the increased frequency of Mediterranean drought," *J. Climate* 25, 2146–2161.

Hurrell, J. W. and Van Loon, H. (1997). "Decadal variations in climate associated with the North Atlantic Oscillation," *Climatic Change*, 36, 301–326, doi:10.1023/A:1005314315270.

Huxley A.J., Griffiths, M., Levy, M. (1992). *The New Royal Horticultural Society Dictionary of Gardening*. London, UK; New York, USA: Macmillan Press

ICBA. (2017). "Drought, atmospheric systems, impacts and management in Lebanon," International Center for Biosaline Agriculture.

IPCC (2013). "Annex I: Atlas of Global and Regional Climate Projections," [van Oldenborgh, G.J., M. Collins, J. Arblaster, J.H. Christensen, J. Marotzke, S.B. Power, M. Rummukainen and T. Zhou (eds.)], *Climate Change 2013: The Physical Science Basis*, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC (2013). "Annex III: Glossary," [Planton, S. (ed.)], *Climate Change 2013: The Physical Science Basis*, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC (2013). "Summary for Policymakers," *Climate Change 2013: The Physical Science Basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

J. F. Bois, T. Winkel, J.P. Lhomme, J.P. Raffaillac and A. Rocheteau (2006). "Response of some Andean cultivars of quinoa (Chenopodium quinoaWilld.) to temperature: Effects on germination, phenology, growth and freezing," *Europe. J. Agronomy* 25 (2006): 299–308.

J. Rodrigo and M. Herrero (2002). *Effects of pre-blossom temperatures on flower development and fruit set in apricot*, pp. 26.

Jabar, Bayan (2014). *Drought Policy, Governance, and Management Systems in the MENA Region – Summary*, American University of Beirut, October 20.

Jensen, M. E., W. R. Rangeley, and P. J. Dieleman (1990). "Irrigation trends in world agriculture," A. R. Stewart, and D. R. Nielsen (eds.), *Irrig. Agr.Crops*, Vol. 30. Am. Soc. Agron., Crop Sci. Soc. Am., Madison. p. 31–67.

Jensen, M.H. (1997). "Hydroponics," Horticulture 32, 6: 1018–1021.

Jomaa, I., Younes, M., Harfouche, E., Skaf, S., Massaad, R., Hajj Sleimen, R., Mounzer, O. (2013). "Effect of Two Different Irrigation Techniques and the Application of the Partial Root Zone Drying Technique on Potato Crop," 1st CIGR Inter-Regional Conference on Land and Water Challenges-Bari, 10–14 September, Italy.

Jomaa, Ihab (2017). "Early Warning System in Lebanon: climate change and the El Niño effect," Background Paper for *The Cures, Causes, and Consequences of Drought in Agricultural Lebanon*, unpublished.

Jomaa, Ihab and Randa Massad (2017). "Hydroponic system for food production: climate change and the El Niño effect," Background Paper for *The Cures, Causes, and Consequences of Drought in Agricultural Lebanon*, unpublished.

Jones Jr. J.B. (2005). *Hydroponics: A practical Guide for the soilless grower*, 2nd ed. Boca Raton, Fl. CRC press.

Jordan, Rob (2016). "Stanford researchers reveal cost-effective path to drought resiliency," Stanford news, JULY 21, available at: https://news.stanford.edu/2016/07/21/cost-effective-path-drought-resiliency/

Kadiyala, M.D.M., et al., (2016). "Agronomic management options for sustaining chickpea yield under climate change scenario," *Journal of Agrometeorology*, 18 (1): 41–47.

Kenny, L. (1995). "Le câprier (capparis spinosa)," Proceedings of: Journée d'Etude sur le câprier et le figuier de Barbarie, Marrakech, 20 December, p. 15.

Kozai Naoko, Kenji Beppu, Ryosuke Mochioka, Unaroj Boonprakob, Suranant Subhadrabandhu and Ikuo Kataoka (2004). "Adverse effects of high temperature on the development of reproductive organs in 'Hakuho' peach trees," *The Journal of Horticultural Science and Biotechnology*, volume 79.

Kutiel, H, Paz, S. (1998). "Sea level pressure departures in the Mediterranean and the relationship with monthly rainfall conditions in Israel," *Theoretical and Applied Climatology* 60: 93–109.

Kutiel, H., Maheras, P., and Guika, S. (1996). "Circulation indices over the Mediterranean and Europe and their relationship with rainfall conditions across the Mediterranean," *Theoretical and Applied Climatology*, 54, 125–138.

LARI (2010, 2012, 2014, 2016). LARI Annual Reports.

Lawand, T.A., Alward, R., Saulnier, E., Brunet, E. (1975). "The development and testing of an environmentally designed greenhouse for colder regions," *Solar Energy*, V 17, 5: 307–312.

Liang Y., Lin X., Yamada S., Inoue M., Inosako K. (2013). "Soil degradation and prevention in greenhouse production," *Sprongerplus*, s10.

Lichou, J., Edin, M., Tronel, C. and Saunier, R. (1990). *Le Cerisier*, Paris: CTIFL.

Lloyd Hughes, B. and Saunders, M. A. (2002). "Seasonal prediction of European spring precipitation from ENSO and local sea surface temperatures," *International Journal of Climatology*, 22(1), 1–14.

Lockwood, M. (2010). "Solar change and climate: and update in the light of the current exceptional solar minimum," *Proc. R. Soc. A*, 466, 303–329. doi:10.1098/rspa.2009.0519.

Lopez-Bustins, J. A., Martin-Vide, J., Sigro, J., and Sanchez-Lorenzo, A. (2008). "Iberia winter rainfall trends based upon changes in teleconnection and circulation patterns," *Global and Planetary Change*, 63, 171–176, doi:10.1016/j.gloplacha.2007.09.002.

Lopez-Bustins, J.A.; Sanchez-Lorenzo, A. (2006). "The Western Mediterranean Oscillation (WeMO) effect on the sunshine duration variability in Iberian Peninsula," 6th Annual Meeting of the European Meteorological Society (EMS), Ljubljana, SVN.

Lopez-Bustins, JA, and Azorin Molina, C. (2004). "Aplicacion del indice diario de la Oscilacion del Mediterraneo Occidental al estudio de la tipologia pluviometrica en Alicante," *El Clima*, entre el Mar y la Montana. AEC: Santander; 333–345.

Lopez-Bustins, JA., Martin-Vide, J., Moreno MaC, Raso, JM. (2006). "Urban heat island intensity in Barcelona and the Western Mediterranean Oscillation," In: Preprints Sixth International Conference on Urban Climate, G®oteborg University, G®oteborg (Sweden); 830 – 833.

Loussert, R and Brousse, G. (1978). *L'olivier*, Maisonneuce and Larose, Paris, pp. 447

Lykas, C.N., Katsoullas, P., Giaglaras, P., and Kittas, C. (2006). "Electrical conductivity and pH prediction in Recirculated nutrient solution of greenhouse soilless rose crop," *Journal of plant nutrition* 29: 1585–1599.

Maas E.V., (1993). "Salinity and citriculture," *Physiol*: 195–216.

Mahasneh, A.M. (2002). "Screening of Some Indigenous Qatari Medicinal Plants for Antimicrobial Activity," *Phytotherapy research*, 16: 751–753.

Maheras, P., Xoplaki, E., and Kutiel, H. (1999). "Wet and dry monthly anomalies across the Mediterranean basin and their relationship with circulation, 1860–1990," *Theoretical and Applied Climatology*, 64, 189–199.

Mariotti, A., Zeng, N., and Lau, K.-M. (2002). "Euro-Mediterranean rainfall and ENSO - a seasonally varying relationship," *Geophysical Research Letters*, 29(12), doi:10.1029/2001GL014248.

Marsh, T.J., Monkhouse, R.A., Arnell, N.W., Lees, M.L., Reynard, N.S., (1994). *The 1988–92 Drought*, Institute of Hydrology, Wallingford, UK.

Martin-Vide and Lopez-Bustins (2006). "The Western Mediterranean Oscillation and rainfall in the Iberian Peninsula," *International Journal of Climatology*, 26, 1455–1475.

Martin-Vide, J., Sanchez-Lorenzo, A., Lopez-Bustins, J. A., Cordobilla, M. J., Garcia-Manuel, A., and Raso, J. M. (2008). "Torrential Rainfall in Northeast of the Iberian Peninsula: Synoptic patterns and WeMO influence," *Advances in Science and Research*, 2, 99–105.

Mathbout, S., and Skaf, M. (2010). "Drought changes over last five decades in Syria," *Economics of Drought and Drought Preparedness in a Climate Change Context*, A. Lopez-Francos, Ed., Mediterranean Seminars, 95, CIHEAM, 107–112.

Mavi, H. S. and Tupper, G.J. (2004). "AgroMeteorology Principles and Applications of Climate Studies in Agriculture," Library of Congress Cataloging in publication data, pp. 381.

McDonnell, Rachael (2017). "Drought, atmospheric systems, impacts and management in Lebanon," Background Paper for *The Cures, Causes, and Consequences of Drought in Agricultural Lebanon*, unpublished.

Meikle, R. D. (1977). "Flora of Cyprus," vol 1. *Royal Botanic Garden*, Kew.832 p.

Merkel, U. and Latif, M. (2002). "A high resolution AGCM study of the El Nino impact on the North Atlantic/European sector," *Geophysical Research Letters*, 29, doi:10.1029/2001GL013726.

Meyer, V.G. (1966). "Flower abnormalities," *Bot. Rev.* 32, 165–218.

Middle East Eye (2014). *Lebanon Faces Water Crisis after Record Winter Drought,* May 9, 2014, updated October 20, pp. 1–2, available at: <Middleeasteye.net/news>.

Mishra, A. K. and Singh, V. P. (2010). "A Review of Drought Concepts," *Journal of Hydrology* 391, 202–216.

Mishra, A. K. and Singh, V. P. (2011). "Drought modeling – A review," *Journal of Hydrology*, doi:10.1016/j.hydrol.2011.03.049.

Mishra, A.K., Singh, V.P., (2009). "Analysis of drought severity area frequency curves using a general circulation model and scenario uncertainty," *J. Geophys. Res.* 114, D06120. doi:10.1029/2008JD010986.

Mo, K. C. and Livezey, R. E. (1986). "Tropical-extratropical geopotential height teleconnections during the Northern Hemisphere winter," Monthly Weather Review, 114, 2488–2515.

MoA (2006). *Agriculture Homogeneous zones (Summary studies) Agriculture Strategy and Policy*, Project Support to the Agriculture Census, FAO.

MOA (2010). *The Development Plan of Cereals and Legumes in Lebanon*, Ministry of Agriculture (MOA), Lebanon.

MOA and FAO (2007). *Global Agricultural Census in Lebanon. Ministry of Agriculture,* Food and Agriculture Organization.

MOA and FAO (2010). *Global Agricultural Census in Lebanon. Ministry of Agriculture,* Food and Agriculture Organization.

MOA and LARI (2008). *A technical package of booklets for the following selected crops: apple, cherry, grapevine, tomato, potato*, EU Agriculture Development project MED/2003/5715/ADP, Beirut.

MOA, UNEP, and GEF (1996). *Biological Diversity of Lebanon – Country Study Report*, Ministry of Agriculture-UNEP, Project GF/6105-92-72, Publication No. 9.

MOE (2010). *State of the Environment Report*, Ministry of Environment, Beirut, Lebanon.

Morgan, L. (2003). Hydroponic substrates. *The Growing Edge* 15(2):64-66.

Mouterde, P. (1968). "Nouvelle Flore du Liban et de la Syrie," Imprimerie Catholique, Beyrouth.

Nederhoff, E. and Stanghellini, C. (2010). "Water use efficiency of tomatoes in greenhouses and hydroponic," *Practical Hydroponics and Greenhouse*, no. 115: 52–59.

Nelkin, J. and Caplow, T. (2007). "Sustainable controlled environment agriculture for Urban areas," *Acta Horticulture*, 801:449–456.

Oliva, M., López-Bustins, J.A., Barriendos, M., Muedra, C., Martín-Vide, J., (2006). "Reconstrucción histórica de la Oscilación del Mediterráneo Occidental (WeMO) e inundaciones en el levante peninsular (1500–2000)," Congreso de la Asociación Española de Climatología (AEC), Zaragoza.

Pabot H. (1959). Rapport au gouvernement du Liban sur la végétation sylvopastorale et son écologique. F.A.O., Rapport #1126 Rome.

Padbury, G., S. Waltman, J. Caprio, G. Coen, S. McGinn, D. Mortensen, G. Nielsen, R. Sinclair. Agro-ecosystems and land resources of the northern Great Plains Agron. J., 94 (2002), pp. 251–26

Palmer, W.C. (1965). *Meteorologic drought*, US Department of Commerce. Weather Bureau, Research Paper No. 45, 58 pp.

Palmieri, S, Siani, AM, Casale, GR, Meloni, D. (2001). "Climate fluctuations in the Mediterranean," 22th ISODARCO Summer Course on: Global Climate Changes and Impact on Natural Resources, Candriai, Trento; (contributed paper).

Palutikof, J. P., Conte, M., Casimiro Mendes, J., Goodess, C. M., and Espirito Santo, F. (1996). "Mediterranean desertification and land use," *Climate and climate change*, John Wiley and Sons, London.

Parry, M.L., Carter, T.R., Konijn, N.T. (1988). "The effect of climatic variations on agriculture," *The impact of climatic variations on agriculture*, Springer Netherlands, Volume 2: Assessment in Semi-Arid, Part II, pp 175–190.

Pelling, M. (2010). Hazards, risks and global patterns of urbanization,in Wisner, B., Kelman, I., and Gaillard, J. C. (eds.) *Routledge Handbook of Natural Hazards and Disaster Risk Reduction and Management*, London: Routledge.

Pereira, L.S., Oweis, T., Zairi, A. (2002). "Irrigation management under water scarcity," *Agricultural Water Management*, 57, 175–206.

Pervez, M.A., Ayub, C.M., Khan, H.A., Shahid, M.A. and Ashraf, I. (2009). "Effect of Drought Stress on Growth, Yield and Seed Quality of Tomato," *Pak. J. Agri. Sci.*, 46(3).

Peters, E., van Lanen, H.A.J., Bradford, R.B., Cruces de Abia, J., Martinez Cortina, L., (2001). "Droughts derived from groundwater heads and groundwater discharge," Assessment of the Regional Impact of Droughts in Europe, Final Report to the European Union, Institute of Hydrology, University of Freiburg, pp. 35–39.

Pettit, Harry (2017). Doomsday seed bank in Lebanon gets bigger as humanity's 'last resort' is bulked up with 70,000 new samples. Daily Mail UK Online. November 22. Available at: http://www.dailymail.co.uk/sciencetech/article-5107765/Humanity-s-resort-Lebanon-doomsday-seed-bank-grows.html.

Piechota, T.C., Dracup, J.A., (1996). "Drought and regional hydrologic variation in the US: associations with the El Niño-southern oscillation," *Water Resour. Res.* 32 (5), 1359–1373.

Piervitali, E, Colacino, M, Conte, M. (1997). "Signals of climatic change in the central-western Mediterranean basin," *Theoretical and Applied Climatology* 58: 211–219.

Pilloni, Adriano (2014). "Economics of Commercial Hydroponic Food Production," Hydroponic Benefits, Systems, Technology, October 9, available at http://www.powerhousehydroponics.com/economics-of-commercial-hydroponic-food-production/.

Place, Frank, Dennis Garrity, Sid Mohan, and Paola Agostini (2016). *Tree-Based Production Systems for Africa's Drylands,* World Bank, Washington D.C.

Post, G. E. (1932). *Flora of Syria, Palestine and Sinai*, American University of Beirut, pp. 134–135.

Quirk, L. (2007). "Grape production and Climate Variation," Climate Change Workshop, Cowra. September 20.

Raffaello Cervigni and Michael Morris (editors) (2016). *Confronting Drought in Africa's Drylands: Opportunities for Enhancing Resilience,* Africa Development Forum Series, World Bank, Washington D.C.

Reckinger, K.H. (1964). *Flora of Lowland Iraq*, ed. Weinhein Verlag von J. Cramer, New York, p. 746.

Redwood III, John (2017). "Drought policy and management for the agricultural sector: international experience and in the Middle East and North Africa region," Background Paper for *The Cures, Causes, and Consequences of Drought in Agricultural Lebanon*, unpublished.

Reidsma, P., and F. Ewert. (2008). "Regional farm diversity can reduce vulnerability of food production to climate change," *Ecology and Society* 13(1): 38, available at: http://www.ecologyandsociety.org/vol13/iss1/art38/

Rivera, D., Friis, I., Inocencio, C., Obon, C., Alcaraz, F., Reales, A. (2003). "Proposal to conserve the name Capparis cartilaginea against C. inermis (Capparaceae)," *Taxon*, 52: 357–357.

Rodrigo, J. (2000). "Spring frost in deciduous fruit trees Morphological damage and flower hardiness," *Scientia Hort.*, 85: 155–173.

Romanou, A., G. Tselioudis, C. S. Zerefos, C.-A. Clayson, J. A. Curry, and A. Andersson (2010). "Evaporation–precipitation variability over the Mediterranean and the Black Seas from satellite and reanalysis estimates," *J. Climate*, 23, 5268–5287, doi:10.1175/2010JCLI3525.1.

Schneider, S.H. (Ed.) (1996). *Encyclopaedia of Climate and Weather*, Oxford University Press, New York.

Seemann, J., Chirkov, Y.I., Lomas, J., Primault, B. (1979). *Agrometeorology with 89 figures*, Springer-Verlag, Berlin Heidelberg, New York, pp 332.

Shaban, A. (2014). "Physical and anthropogenic challenges of water resources in Lebanon," *Journal of Scientific Research and Reports*, 3, 479–500.

Shafieizargar Alireza, Yahya Awang, Freydun Ajamgard, Abdul Shukor Juraimi, Radziah Othman and Ahmad Kalantar Ahmadi (2015). "Assessing Five Citrus Rootstocks for NaCl Salinity," *Asian Journal of Plant Sciences*, 14: 20–26.

Shaman (2014). "The Seasonal Effects of ENSO on European Precipitation: Observational Analysis," *Journal of Climate*, 27, 6423–6438, doi:http://dx.doi.org/10.1175/JCLI-D-14-00008.1.

Shyam S. Yadav, Bob Redden, David L. McNeil, Yantai Gan, Aqeel Rizvi, A.K. Vrema and P.N. Bah, (2010). *Strategies to combat the impact of climatic changes: Climate Change and Management of cool season grain, legume crops*, Springer Science, Business Media: 433–445.

Sozzi, G.O. (2001). "Caperbush: botany and horticulture," *Horticultural reviews*, 27:125–188.

Spensley, K.G.W., Winsor, and Cooper, A.J. (1978). "Nutrient film technique-crop culture in flowing nutrient solution," *Outlook on Agriculture*, 9, 6, no:299–305.

Stäubli, B., Wenger R., Wymann S. and Dach V. (2008). "Potatoes and climate change," *InfoResources Focus*, 1(08).

Steffens, G. L .and Stutte G .W. (1989). "Thidiazuron substitution for chilling requirement in three apple cultivars," *Journal of Plant Growth Regulation*, 8(4), 301–307.

Stigter, K. (Ed) (2010). *Applied Agrometeorology*, Springer, ISBN 978-3-540-74698-0.

Sun, Y., Solomon, S., Dai, A., and Portmann, R. (2006). "How often does it rain?" *Journal of Climate*, 19, 916–934.

Takuji W. Tsusaka (Philippines), Keijiro Otsuka (Japan) (2013). "The changes in the effects of temperature and rainfall on cereal cropyields in Sub-Saharan Africa: a country level panel data study,1989 to 2004," *Environmental Economics*, Volume 4, Issue 2.

Taylor, K. E., R. J. Stouffer, and G. A. Meehl (2012). "An Overview of CMIP5 and the Experiment Design." *Bulletin of the American Meteorological Society* (BAMS) 93: 485–98.

The Daily Star (2017). "Startups pioneering hydroponics in region," Pressreader Online, by Federica Marsi, January 17, Lebanon, available at: https://www.pressreader.com/lebanon/the-daily-star-lebanon/20170117/281582355328453.

Time Magazine (2015). "Lebanon's Hash Farmers Join the Fight Against ISIS," by Rebecca Collard, Bekaa Valley, Lebanon, February 12, available at: http://time.com/3706677/lebanon-hash-farmers-isis/.

Tohme G. and Tohme H. (2007). *Illustrated Flora of Lebanon: 2600 Wild Flowers*, CNRS Publication.

Trillot M., Masseron A., Mathieu V., Bergounoux F., Hutin C. and Lespinasse Y. (2002). *Le Pommier*, CTIFL, Paris.

UNFCC (2015). Republic of Lebanon Lebanon's Intended Nationally Determined Contribution under the United Nations Framework Convention on Climate Change (UNFCC), September, available at: http://www4.unfccc.int/submissions/INDC/Published%20Documents/Lebanon/1/Republic%20of%20Lebanon%20-%20INDC%20-%20September%202015.pdf.

UNODC (2011). World Drug Report 2011. United Nations Office on Drugs and Crime (UNODC). Available at: https://www.unodc.org/documents/data-and-analysis/WDR2011/World_Drug_Report_2011_ebook.pdf

UN Secretariat General (1994). *United Nations Convention to Combat Drought and Desertification in Countries Experiencing Serious Droughts and/or Desertification, Particularly in Africa*, Paris.

United Nations Food and Agricultural Organization (FAO), Regional Office for the Near East, and National Drought Mitigation Center (NDMC), University of Nebraska (2008). *The Near East Drought Planning Manual: Guidelines for Drought Mitigation and Preparedness Planning*, Rome, pg. 1.

USAID, et. al. (N.D.) *Development of the MENA Regional Drought Management System*, Washington D.C., pg. 3.

USDAFAS (2016). "Lebanon Market Overview," Gain Report, June 26.

Valkoun, J., Giles-Waines, J. and Konopka, J. (1998). "Current Geographical Distribution and Habitat of Wild Wheats and Barley," *The Origins of Agriculture and Crop Domestication. Harlan Symposium*, Damania, A.B.J.

Van Loon, A.F., and Van Lanen, H.A.J. (2013). "Making the distinction between water scarcity and drought using an observation-modeling framework," *Water Resources Research*, 49, 3, 1483–1502.

Van Zeist, W. and Bakker-Heeres J.H. (1982). "Archaeobotanical studies in the Levant 3. Late-Palaeolithic Mureybit," *Palaeohistoria* (26): 171–199.

Venterella D. (2006). *Climate change, vulnerability and adaptation in agriculture: the situation in Italy*, CRA-SCA, Bari, Italy.

Verner, D (2012), *Adaptation to a changing climate in the Arab countries: a case for adaptation governance and leadership in building climate resilience*, World Bank, Washington, DC.

Verner, D., Lee D., and Ashwill, M. (2013). *Increasing resilience to climate change in the agricultural sector of the Middle East: The cases of Jordan and Lebanon*. World Bank, Washington, DC..

Vogel, R.M., Kroll, C.N., (1992). "Regional geohydrologic–geomorphic relationships for the estimation of low-flow statistics," *Water Resour. Res.* 28 (9), 2451–2458.

Wand S.J.E., W.J. Steyn, K.I. Theron (2008). "Vulnerability and Impact of Climate Change on Pear Production in South Africa," *ActaHortic*.

Weber HE, (1995). Gustav Hegi, Illustrierte Flora von Mitteleuropa. Ed.: Conert HJ, Jäger EJ, Kadereit JW, Schultze-Motel W, Wagenitz G, Weber HE. Volume IV, Part 2A, Spermatophyta: Angiospermae: Dicotyledones 2(2), 3rd edition.Blackwell, Berlin, Germany.

Wen J., Wang X., Guo M. (2012). "Impact of Cliamte Change on Reference Crop Evapotranspiration in Chuxiong City, Yunan," *Procedia Earth and Planetary Science*, V 5, 113–119.

Williams, C.L., M. Liebman, J.W. Edwards, D.E. James, J.W. Singer, R. Arritt, D. Herzmann. Patterns of regional yield stability in association with regional environmental characteristics, Crop Sci., 48 (2008), pp. 1545–1559

WMO and GWP (2014). *National Drought Management Policy Guidelines: A Template for Action*, World Meteorological Organization and Global Water Partnership, Geneva.

Wolter, K. and Timlin, M. S. (2011). "El Nino Southern Oscillation behaviour since 1871 as diagnosed in an extended multivariate ENSO index (MEI.ext)," *International Journal of Climatology*, 31, 1074–1087, doi:0.1002/joc.2336.

World Bank (2016). *The Little Green Data Book 16*. Washington, DC: World Bank.

World Bank (2016). *World Development Indicators 2016*. Washington, DC: World Bank. doi:10.1596/978–1-4648–0683–4.

World Meteorological Organization (WMO) (1986). *Report on Drought and Countries Affected by Drought During 1974–1985*, WMO, Geneva, p. 118.

World Meteorological Organization (WMO) (2010). *Guide to Agricultural Meteorological Practices*, WMO No. 134. pp. 799.

World Meteorological Organization (WMO) and Global Water Partnership (GWP) (2014). *National Drought Management Policy Guidelines: A Template for Action*, Geneva, pp 7–9.

Xoplaki, E, Gonzalez-Rouco, JF, Luterbacher, J, and Wanner, H. (2003). "Mediterranean summer air temperature variability and its connection to the large-scale atmospheric circulation and SSTs," *Climate Dynamics* 20: 723–739.

Zhao, Meng, Isabella Velicogna, and John S. Kimball (2017). "Satellite observations of regional drought severity in the continental United States using GRACE-based terrestrial water storage changes," *Journal of Climate* 30.16 (2017): 6297–6308.

Zohary, M. (1960). "The species of Capparis in the Mediterranean and the near east countries," *Bull. Res. Counc. of Israel*, 8D: 49–64.

Zohary, M. (1962). *Plant life of Palestine*, The Ronald Press Company, New York, p. 262.

Zohary M. (1973). Geobotanical foundations of the Middle East. *Geobotanica Selecta*, III, 6, 14, 1–49.

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