Water Resources and Climate Change

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I. INTRODUCTION

The Arab region stretches across a latitudinal landmass belt known for its acute water scarcity and aridity, which presents Arab countries with a serious water balance predicament that threatens its socio-economic development. These arid conditions are the result of complex global atmospheric circulations that predominantly divert moisture to bordering latitudinal regions. Projected climatic changes are expected to intensify these processes leading to even drier and warmer conditions (Assaf, 2008). The climatic wind system that brings precipitation to North Africa and the Eastern Mediterranean is expected to drift northward removing a large portion of already meager precipitation levels. This grim perspective makes it necessary that Arab countries take active and long-term measures to bridge the widening gap between rising water demands and exhausted and deteriorating water resources.

This paper addresses how climate change may affect water resources in the Arab region and proposes a range of adaptation strategies and measures for consideration by policy-makers. The paper describes a vulnerability-based approach in order to comprehend the role of climate change, among other main stresses such as population growth and land use change, in shaping the status and management of water resources in the region. Specific determinants of vulnerability are emphasized to help decision makers design effective holistic policies that not only address climate change but also consider other pertinent strains on water resources.

II. PROJECTED CLIMATIC CHANGES IN THE ARAB REGION

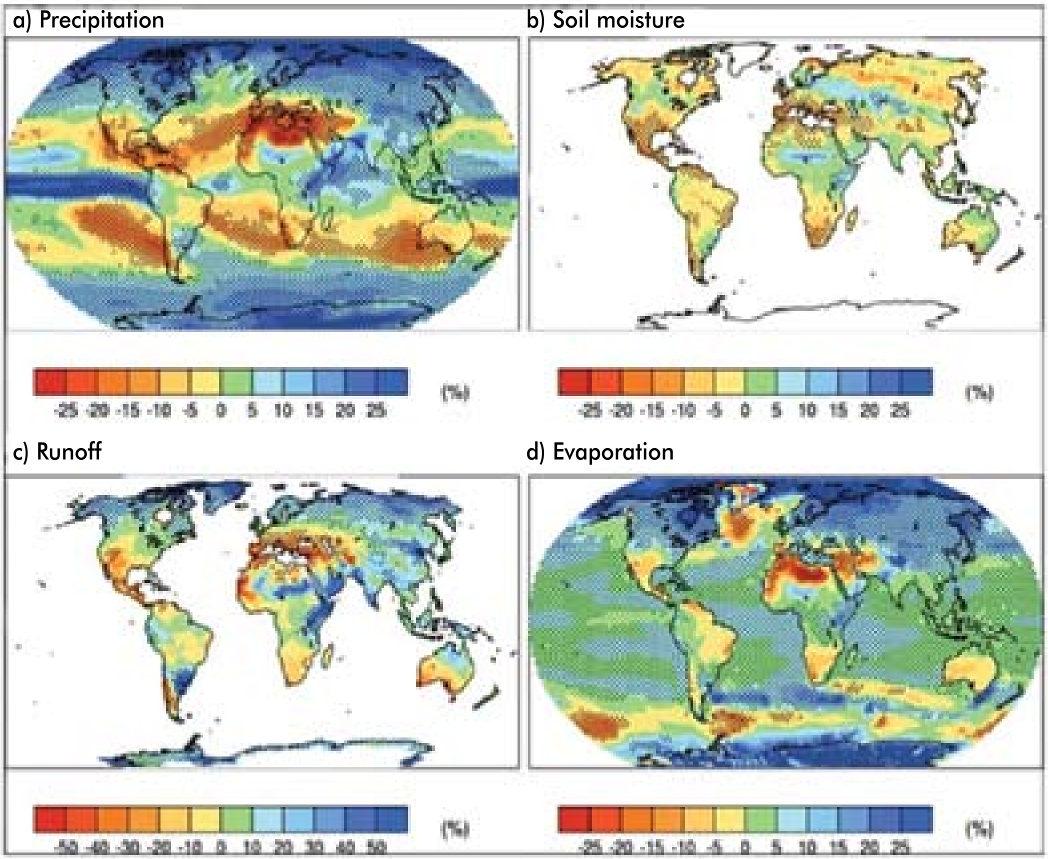
The International Panel on Climate Change (IPCC) Report (IPCC, 2007) and its special paper on the impact of climate change on water (Bates et al., 2008) give a general overview of projected climatic changes across the globe. These changes are usually presented in the context of the IPCC Special Report on Emissions Scenarios (SRES) greenhouse gas (GHG) emissions storylines that represent a wide range of global economic and social developments.

Figure 1 presents projected changes in yearly averages of hydro-meteorological variables (precipitation, runoff, soil moisture, and evaporation) in the last 30 years of the current 21st century vs. those in the last 30 years of the 20th century based on the SRES A1B GHG emissions storyline which represents midpoint conditions. The projections are calculated as the average of output from 15 leading General Circulation Models (GCMs). Stapled areas are those where 80% of the GCMs agree on the direction of change.

As Figure 1 shows, the majority of GCMs project a grim outlook for the northern part of the Arab region in terms of major reduction in precipitation, increase in evaporation, and subsequent reduction in both runoff and soil moisture. Precipitation is projected to decrease by over 25% which in combination with a 25% increase in evaporation would translate to a drastic 50% drop in runoff by the end of the century. The net effect will be a major reduction in available water resources exacerbating current water scarcity conditions. Some of the reduction in water resources will originate from outside the Arab region in neighboring countries, Turkey and Iran principally, as both countries are expected to suffer similar consequences. However, adaption measures by these two countries could spill an even greater risk to water resources in the Arab region. Turkey has already developed several complex water storage and transfer projects, enabling the country to transfer vast amounts of water out of the Euphrates and Tigris basins to drier parts of the country. Iran has already constructed a dam on the Khabour River cutting off vital supplies to the wetlands and marshes of Southern Iraq. Both countries are expected to divert even greater amounts of water during extended drought periods, further accentuating the water scarcity problems as well as the risk of more severe drought conditions in Syria and Iraq.

North African nations will be particularly hit hard by a projected shift in the Westerlies exposing Morocco, Algeria, Libya, and Tunis to the risk of extended droughts and crop failures. The situation will be similar in the Eastern Mediterranean with Lebanon, Jordan, and Palestine reeling from much lower rainfall quantities. The GCC countries will undergo less precipitation levels, however this is not expected to significantly change or have a measurable impact on the water balance since water is mostly obtained by desalination. In contrast, the climatic projections

FIGURE 1 **YEARLY HYDRO-METEOROLOGICAL CHANGES (2080-2099) VS. (1980-1999) AVERAGED FROM OUTPUTS OF FIFTEEN GENERAL CIRCULATION MODELS RUN FOR THE SRES EMISSIONS STORYLINE A1B**



Legend: (a) precipitation (%); (b) soil moisture (%); (c) run-off (%); (d) evapotranspiration (%)
Source: Bates et al., 2008

for the Nile's headwaters in Eastern Africa and to a lesser degree the southern part of the Arabian Peninsula indicate a net increase in precipitation and runoff. Consequently water balance in Egypt and Sudan are generally expected to gain from projected increase in the Nile's runoff. This will be tempered by the projected reduction in precipitation in Egypt and northern Sudan as well as by the overall increase in evaporation as a result of warming.

III. VULNERABILITY-BASED APPROACH FOR ADAPTATION TO CLIMATE CHANGE

Traditionally, most climate change adaptation studies focus on analyzing the impact of potential climatic changes on a particular sector or sectors to support development of adaptation policies and measures. Although this is a necessary step to obtain a better understanding of the physical basis of the problem, it is often criticized for relying on evolving climate models that are still in their infancy and compounded with high uncertainties (Adger and Kelly, 1999). These reservations may weaken the argument and the political will to support mitigation and adaptation efforts, as stakeholders may not be convinced in supporting funding efforts to alleviate "potential" rather than certain problems.

Alternatively, Adger and Kelly (1999) call for focusing efforts on identifying vulnerabilities and adaptive capacities of human, physical, and ecological systems. Vulnerability can be readily determined based on existing conditions without necessarily projecting future climatic changes.

Such an approach would yield valuable insights, lending support to adaption measures that not only address current conditions and stresses, but also take into account future climatic impacts. For example, the Arab region is faced with a very serious water scarcity that undermines its socio-economic development and may threaten the survival of some of its communities. Addressing the determinants of vulnerability to water scarcity will induce the formulation of policies and measures to manage such susceptibilities under current conditions as well as attend to any anticipated exacerbation by climate change.

Vulnerability assumes several meanings and interpretations in the literature particularly those related to food security, natural hazards, famines, and more recently climate change. Even the IPCC Third Assessment Report (TAR) contains different and contradictory definitions of vulnerability (Adger et al., 2004). Part of this confusion relates to the two distinct but interrelated vulnerability concepts: bio-physical and social/inherent vulnerabilities (Adger et al., 2004). The latter is a characteristic of a system, whether it is human or ecological/political/natural, that determines its ability to withstand, cope, and recover from a hazard. The former is a function of the latter and the hazard the system is being exposed to. It is similar to the concept of risk used in the disaster literature, where risk is a function of the impact of hazard on the system and the probability of its occurrence (Adger et al., 2004). In this report, we address the "social/inherent" vulnerability.

IV. IDENTIFICATION OF WATER RELATED VULNERABILITIES TO CLIMATE CHANGE IN THE ARAB REGION

Vulnerability to climate change is multifaceted and multi-sectoral and relates to a diverse group of players at a wide range of temporal and spatial scales. In semi-arid regions water is the single most important and limiting factor of socio-economic development. As indicated earlier, the Arab countries are situated in climate change hotspots where major reductions in precipitation accompanied with increases in evapotranspiration are projected to result in an even more precarious water balance. The Arab region's historic and extensive experience in dealing with water scarcity at different scales provides an opportunity to gain

insight on how different stressors interact and affect this region, to identify resiliency factors, and learn from the success (or failure) of past adaptation measures. The knowledge gained can help pinpoint strengths and weaknesses in addressing water problems particularly scarcity. This learning can then help articulate a vulnerability-based framework to identify vulnerability determinants, setting up the stage for upgrading existing policies and strategies or developing new ones. This is a holistic approach for reducing vulnerability to climate change as well as other stressors, and improving adaptive capacity.

The vulnerability-based approach is not meant to be a comprehensive and prescriptive framework, rather it provides general guidelines to identify areas of concern in a water sector vulnerable to several strains, such as population growth and land use changes, which are expected to be exacerbated by climatic changes and variability. For example, current shortages in the Amman municipal water supply network driven mainly by natural water scarcity, urbanization, and rapid population growth makes the city population highly vulnerable to further declines in precipitation levels as projected by climate models. A more refined and detailed analysis of this vulnerability can reveal more pertinent problems, such as specific deficiencies in the water network, ineffective pricing policies, and/or inadequate customer service. Knowledge gleaned from this vulnerability analysis can then be used to develop specific or integrated solutions.
In assessing vulnerability to climate change, two broad categories of vulnerability determinants

TABLE 1 **WATER SECTOR VULNERABILITIES, CONSEQUENCES, AND ADAPTATION OPTIONS IN THE ARAB REGION**

Vulnerability Determinants	Potential Consequences	Adaptation options	Examples
Inadequate municipal water service as a result of natural water scarcity, leakages, poor customer service, and inappropriate water pricing.	Water shortages and interruptions leading to public health problems and lower standard of living. In some cases residents may resort to supplement their water supplies with poor quality water.	Analyze causes to identify and implement solutions including enhancing accountability, setting a proper price structure, rehabilitating network to reduce leakage, and improve customer service and awareness.	Beirut suffers from intermittent water municipal services. The problem is related to excessive leakage in the network, inadequate water supplies to meet demand, lack of proper water metering, and poor customer services. A World Bank report has advised the government to rehabilitate water services with particular emphasis on setting up an effective pricing scheduling based on adequate metering of services (World Bank, 2009).
Deficiencies in wastewater and rainfall drainage systems as a result of underdesign and poor maintenance and/or customer service.	Increase the risk of flooding and overflowing of sewage during intense rainfall events. Generally these conditions have detrimental impact on public health and may lead to extensive loss of life in extreme cases.	Examine hydrometeorological records to redesign and enhance existing infrastructure. Examine urban planning policies to limit development in high risk areas.	The recent flooding event in Jeddah – see case study - throws into the spotlight the negligence and possible corruption in the development of the city's flood drainage and sewage treatment and disposal infrastructure. As indicated in the case study box, the impact of flooding would have been negligible had the drainage network been properly designed and constructed and the development of the flooded area properly regulated. Also, the consequences would have been much greater had the dam retaining ewage upstream failed during the event.
Lack of agreements on international watercourses and aquifers.	This presents a great risk of conflict and is currently leading to overexploitation of groundwater resources.	Work towards establishing agreements between countries. While this option is generally elusive in many cases, judging by the scarcity of such agreements, countries should establish working relationships to achieve sustainable development of the resources.	The conflict over the Jordan River basin is difficult to resolve due to the hegemonic position of Israel. The weak political position of the Palestinians places them at a disadvantage in securing their rightful share of water resources (Zeitoun and Allan, 2008). In comparison, despite the existence of a single agreement between Egypt and Sudan on sharing the water resources of the Nile, the Nile Basin Initiative has been successful in maintaining a peaceful, yet uneasy relationship among the riparian countries. Internal conflict in Darfour is largely driven by competition over scarce water resources and vegetated areas (UNDP, 2009). The situation is exacerbated by extended droughts.
Large rural populations in poor semi-arid countries, who are highly dependent on agriculture and pasturing.	Such populations are highly vulnerable to climatic variability as extended drought may lead to crop failure and livestock losses.	Crop planning and support of rural populations through agricultural advisory services. Diversification of economy and human resources development.	Large segments of populations in highly agrarian countries such as Yemen and Sudan are particularly exposed to climatic variability and droughts. This has led not only to malnutrition and famine, but also to internal conflicts that have escalated in Sudan to the level of a protracted civil war.

DAMS TO PRESERVE WATER IN LEBANON

Fadi G. Comair

The typically Mediterranean climate in Lebanon is characterized by strong precipitations during winter followed by a dry period with high humidity for the remaining seven months of the year. However, the influence of the sea, the particularities of the topography and the presence of the Syrian Desert in the North create a variation of microclimate inside the country with sharp variations in the distribution of both temperature and precipitation.

The annual precipitation average is estimated at 800 mm, varying between 600 and 900 mm along the coast and 1400 mm over the mountains. It decreases to 400 mm in eastern regions and less than 200 mm in the northeastern regions of the country.

At altitudes of over 2000 m, the essential precipitations are snow and can help in generating good output for 2000 water sources during the dry periods. Precipitations are produced in 80 to 90 days of the year, mainly between October and April. Approximately 75% of the total volume of the surface flow occurs during five months between January and May, 16% in June and July and only 9% for the remaining five months from August till December. In 2000, water resources used in Lebanon were about 1.5 billion m^3 per year, with an increasing annual demand that will lead to enormous water deficit as early as 2015.

The annual total volume of ground water in Lebanon is estimated at 567 million m^3, whereas the flow in dry period (July-October) in various basins is estimated at around 141 million m^3. While the country enjoys a favorable situation in cumulative flows, availability is limited during five dry months, coupled with complicated karstic geological conditions. Total annual water demand exceeds 2 billion m^3 in 2010, reaching 3.4 billion m^3 in 2040.

A decennial strategic plan prepared by the General Directorate of Hydraulic and Electric Resource (GDHER) in Lebanon has been designed to ensure that enough water will be available to meet the necessary demand in all sectors. It constitutes an Integrated Water Resource Plan (IWRP) for Lebanon and covers major technical hydraulic infrastructure projects which are essential for the economic development of the country. The decennial strategic plan is based on developing:

- Additional water resources (dams, lakes, recharge of aquifers, sea fresh water springs, desalinations, etc.)
- Drinking water projects (distribution network and efficiency, public-private partnership involvement, etc.)
- Appropriate irrigation projects (ensuring food security, network efficiency, etc.)
- Wastewater collecting and treatment plants (water reuse for irrigation, municipal use and artificial recharge of aquifers, etc)
- Infrastructure for flood mitigation, rectification and alignment of river beds.

The increase in water demand-led to increased deficit in urban areas located mainly along the Lebanese coast and in Mount Lebanon, as well as in the rural regions in the south, the Bekaa Valley and the north of the country. The utilization of available and renewable water from springs is not enough to meet the needs during the drought season. Moreover, the intensive use of ground water by the public and private sectors caused many problems, mainly decrease in the flow, reduction of ground water in the aquifers in the Bekaa plain and intrusion of seawater into the coastal aquifers.

Although the strategic plan takes into account the increase of the efficiency of water supply and irrigation networks from 60% to 85% in a period of 10 years, the water balance will still experience a huge water shortage (>600 Mcm in 2020). This explains the inevitability to build dams and mountain lakes to store the surface water generated from the precipitation of the winter season that will then be used during the dry season. The execution of these reservoirs for storing surface water should be preceded by: preparation of detailed geological and hydro-geological maps, controlling of the ground water level, and protecting the aquifers and the water sources.

The Chabrouh dam was the first project of the decennial strategy to be executed. The construction of this hydraulic infrastructure started in August 2002 and was completed in October 2007. This was the only one implemented among 17 major dam projects included in the 10-year strategic plan. In 2005 the construction of the Assi River (Orontes) derivation dam in the district of Hermel commenced, but the work was halted in July 2006 due to an Israeli airstrike on the

construction site. Once the planned dams have been built, Lebanon could have the capacity to store an additional 850 million m^3 of fresh water, helping to alleviate water shortages until 2040.

The study of the water resources in Lebanon shows clearly that the country is blessed with an annual precipitation volume of about 8 billion m^3/ year, but several disadvantages render the utilization of this water quantity a very complicated task to be accomplished. Those include:

- 90% of the rainfall quantity occurs within a period of three months.

- Evapotranspiration rate is estimated at 50% and this volume is likely to increase with the climate change phenomenon.

- Geological karstic nature of the Lebanese soil induces a high infiltration ratio.

- Relying on groundwater utilization as a major source of water supply for the Lebanese population constitutes a bad design for the water planning and management in Lebanon. This concept leads to an over- pumping of the aquifers, which generates various environmental problems.

- Absence of wastewater treatment plants makes the utilization of non-conventional resources difficult for agriculture and municipal sectors. Also this resource could be used for the artificial recharge of aquifers in addition to the high pressure induced on the ecosystems of the watercourses.

- Absence of surface water storage since the 1960 led to a continuous discharge of fresh water in the Mediterranean, amounting to about 1.2 billion m^3/ year. This irresponsible behavior from the water administration and the political decision makers constitute a waste of financial input to the national budget estimated at 100 billion US dollars.

- Until 2002, only the Qaraoun dam has been built, and the construction of Chabrouh dam which was completed in October 2007 was the only project executed of the 10-year strategic master plan.

- The drinking and irrigation water networks efficiencies should be improved in order to meet IWRM requirements with respect to water losses and for a better service coverage.

- Other non-conventional resources for the future utilization such as: sea fresh water spring, desalination and reuse of wastewater require a new complementary formulation within the 10 year master plan bearing in mind that the resources utilizations by gravity should be used at first priority.

The effects of climate change on Lebanon tend to make the Lebanese territory progressively drier. The first obvious measure to be taken by the Lebanese government is to reduce the amounts of water discharging into the sea. Unfortunately, the execution of this solution has proved to be difficult, mainly due to two major factors: the first is that while project priorities were set according to actual and future water demand management at the national level, politicians have been trying to tailor them to suit short-term interests; the second is that financing has been constantly blocked by political interests.

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are identified: generic and hazard-specific. The former refers to determinants related to general issues such as poverty, governance, infrastructure, education, and social status which can be used to develop country-wide indicators to categorize highly vulnerable countries. Hazard-specific determinants may include prices of stables, number of storm shelters in a community, and building standards (Brooks et al., 2005). Water related determinants may include services provision coverage, redundancy and condition of water supply infrastructure and networks, access to alternative water supplies such as desalination or water transfer from other regions or countries, strategic storage of food stables, and stable access to friendly food markets that help the country wither through periods of crop failures.

In surveying general water resources and service conditions in the Arab world, several water related vulnerabilities have been indentified that need to be addressed to increase adaptive capacity in the Arab region in the face of impending climate change. The determinants of these vulnerabilities along with their potential consequences, adaption options, and examples from the Arab region are presented in

Table 1. As the table indicates, water related vulnerabilities are tied to all aspects of socio-economic development and environmental well-being. Natural water scarcity is a common driver of vulnerability as it restrains urban and industrial development and poses risk to agriculture and food production. Inadequate water services provision is another important determinant driven by several factors including water scarcity, lack of capital, weak accountability, and lack of pricing incentives. Absence of international agreements or cooperation over transboundary water resources poses special risk to regional stability, which could induce armed conflict under extended drought conditions. All these factors can interact in a vicious cycle that could exacerbate adverse conditions leading to political instability, mass migration, malnutrition, and/or community disintegration.

V. FOOD SECURITY AND VIRTUAL WATER

Over the past several decades many Arab countries have placed great emphasis on achieving food security through local production even at the cost of depleting nonrenewable fossil water. Faced with the reality of physical water scarcity, sharp increases in pumping costs driven by high energy prices, and declining water levels in strategic aquifers, many Arab countries have started to reorient their food policies by relying on imports and restricting irrigation to high value crops. These strategic changes have created a positive virtual water balance as water became imbedded in imported agricultural produce (Allan, 1997), which would have consumed an equal if not a much larger amount of local water resources, due to the arid conditions. The concept of virtual water trade has been advocated as a method for mediating the asymmetric global distribution of water resources and supporting efforts to manage

DROUGHT IN SYRIA: ONE MILLION PEOPLE AFFECTED

Drought in eastern and northeastern Syria has driven some 300,000 families to urban settlements such as Aleppo, Damascus and Deir ez Zour in search of work, in one of the "largest internal displacements in the Middle East in recent years," according to a 2009 report by the United Nations Office for the Coordination of Humanitarian Affairs. The lack of water has caused more than 800,000 people in eastern Syria to lose "almost all of their livelihoods and face extreme hardship," stated the report. About 80 percent of the hardest hit "live on a diet consisting of bread and sugared tea."

Syria's water shortages have been worsening year by year. In 2006, northeastern regions such as Hasakeh and Qamishli were the first to feel the effects of a lack of rain. Shortly after, farmers and crop-growers in southern and eastern areas started to suffer from a major drop in rainfall.

The United Nations described the situation as "the most severe drought in Sryria over 40 years," and appealed for assistance to help those affected. A report estimated that 59,000 small Syrian farmers lost almost all of their cattle, while 47,000 farmers lost between 50-60 percent.

"Our wells are dry and the rains don't come," said Ahmed Abu Hamed Mohieddin, a wheat farmer from the town of Qamishlimm, in an interview. "We cannot depend on God's will for our crops. We come to the city, where the money is." He and three sons work as porters in the capital's vegetable markets.

Mohieddin said that he left Qamishli when his well ran dry and he could not afford a new pump. He sold a flock of sheep because grazing land had withered and he didn't have commercial feed. He came to Damascus in May 2009 and lives among the dusty lanes separating do-it-yourself tents of plastic and cotton sheets. "I'm thinking maybe we can build a little house here," Mohieddin said. "We can't go back to Qamishli. We prayed for rain too long."

"For the first time in two decades, Syria has moved from being a net exporter of wheat to a net importer," stated a February 2010 report by the U.S. State Department, adding that agriculture accounted for about 17 percent of 2008 GDP.

"It's an emergency," Syrian economist Nabil Sukkar warned. "If we have two more years of drought, then we do have a crisis…Unfortunately, we haven't introduced modern technology, and so we are totally dependent on rainfall".

But rainfall, or lack of it, is not the only culprit, he says. Syria and Iraq blame Turkey's huge network of dams on the Tigris and Euphrates rivers for reducing water supplies by 50 percent. Turkey is the site of the headwaters of a river system that Syria and Iraq depend on. An informal agreement determines the flow downstream.

"When we had bad relations with Turkey, they reduced the flow of water despite the agreement. Now, thank God, we have excellent relations with Turkey and, hopefully, we will not see any cutoff of water," Sukkar said.

In southeast Turkey, the Euphrates River is clear, blue and deep. The Ataturk Dam harnesses water for one of the biggest irrigation and electric power schemes in the world, the Southeastern Anatolia Project. When the multibillion-dollar project was inaugurated more than a decade ago, then-President Suleyman Demirel said neither Syria nor Iraq could lay claim to Turkey's water, any more than Turkey could claim Arab oil.

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water scarcity and consequently to decrease vulnerability to climatic changes. Allan (1997) has indicated that the MENA region "ran out of water in the 1970s" and has effectively managed to meet its food requirements and consequently augment its water resources through rapidly increasing imports of food commodities, particularly wheat.

However recent food shortages and subsequent hikes in food prices have exposed the vulnerability of food importing countries to the volatility of the global food supply and markets. This has opted several GCC countries to seek acquirement of titles to land resources and even fishing rights in developing countries in Africa and Asia to secure food for their rapidly growing populations (Woertz et al., 2008). Although these policies are considered reasonable given that they increase the import of virtual water, they have raised concerns over the sovereignty of food producing countries as many of them are struggling to feed their

FIGURE 2 **NILE RIVER BASIN**

Source: World Bank, 2004

own populations. The situation is considered particularly sensitive under conditions of global food scarcity, which would hike up prices and may push the poor in food producing countries to malnutrition and possibly starvation.

VI. INCORPORATING NONSTATIONARITY IN THE DESIGN AND OPERATION OF WATER RESOURCES INFRASTRUCTURE

Climate change is projected to alter the stochastic nature of meteorological variables particularly the spatio-temporal distribution of precipitation. However, water infrastructure components are designed assuming stationarity or static statistical properties of meteorological variables. This is problematic from two main design perspectives: optimal capacity and safety. Components designed based on wetter records can be ineffective and may result in squandering scarce financial resources. For example, an extensive water irrigation infrastructure project designed on past wetter periods in Morocco failed to meet farmer's requirements as dams did not fill to half of their capacities and irrigation canals did not have enough water for most of two decades from mid-1980s to mid-2000s (World Bank, 2007). In contrast, overlooking potential upward changes in the frequency and intensity of rainfall events may lead some authorities to underestimate the risk of flooding and develop inadequate drainage infrastructure. Jeddah's recent disaster – see case study – is a testimony to the failure of developers to assess the intensity and damaging potential of rainfall storms. Shortsighted developers have decided against building an extensive drainage network judging it unnecessary due to the extreme aridity of the area.

Dealing with nonstationarity requires adopting a more adaptive and flexible approach in the planning, design, and operation of water resources infrastructure. This requires improving understanding of changes in meteorological conditions through extensive data monitoring and analysis. Operational flexibility can be achieved by tying operational policies to improved long-term and short-term forecasts of runoffs. For example, following an extended dry period in the mid-1980s, the Ministry of Water Resources and Irrigation in Egypt - see case study - established the Nile Forecast Center (NFC) to provide forecasts of water inflows to Lake Nasser. The NFC applies a remote sensing modeling system developed through technical support from the U.S. National Oceanic and Atmospheric Administration (NOAA) and the Food and Agriculture Organization (FAO) (Conway, 2005).

Hydrologic uncertainty brought about by climate change can be managed through diversifying water supply options and adopting an incremental water supply development strategy. Rather than pursuing costly and ineffective mega infrastructure development, as Morocco's irrigation project attests to, large schemes can be broken into stages starting with the most cost effective components and proceeding progressively as the trajectory of climatic change becomes clearer. For example, the current plan to transfer water from the Litani River to Beirut is structured in two incremental stages: an initial plan that consists of constructing a pipeline to transfer water from an existing water pond, and a complimentary plan that involves constructing a dam to store additional water (Watson, 1998).

Diversification of water supply options provides additional insurance against climatic variability and changes. Groundwater recharge using excess winter rainfall or treated wastewater increases strategic reserves necessary for withering through drier periods. Desalination is increasingly becoming a viable option particularly in the heavily populated coastal areas to augment or replace traditional water supplies (Brekke, 2009).

CASE STUDY – EGYPT'S ADAPTION TO CLIMATE VARIABILITY IN THE NILE

Egypt relies almost exclusively on runoff from the Nile, which travels thousands of kilometers from the Ethiopian highlands and Lake Victoria (Figure 2). Over millennia, Egypt was at the mercy of fluctuations in the Nile that have brought death and destruction from floods and famine in dry years. The construction of the Aswan High Dam (AHD) in the early sixties has effectively shielded the country from annual fluctuations of the river. However, an unprecedented - since 1870 - sequence of especially dry years from

1978 to 1987 reduced the AHD reservoir to alarmingly low levels and brought the country to the brink of extreme water shortages and exposed its vulnerability to the interdecadal variability of the Nile basin (Conway, 2005). In response, the government took several measures to reduce demand including extending a ban on winter irrigation, reducing areas allocated for rice production, and improving hydraulic conveyance and efficiency (Conway, 2005). Although the prolonged drought ended with the abundant yield of 1988, the country has taken concrete steps to develop capacity on hydro-meteorological forecasting by first establishing a "planning and models" department at the Ministry of Water Resources and Irrigation (MWRI) which has developed into the Nile Forecast Center (NFC) through financial support from USAID and technical support from NOAA and FAO (Conway, 2005). The NFC utilizes remote sensing information on the main upper reaches of the Nile to produce river flow forecasts. Moreover, the Nile Basin Management (NBM) decision support system was established based on modeling studies of the hydrologic, infrastructure, and environmental components of the Nile Basin. The NBM is used to formulate and assess different climatic and management scenarios (Conway, 2005) that are necessary for drafting climate change adaptation strategies.

To alleviate tension on sharing the water resources of the Nile, Egypt has championed the development of the Nile Basin Initiative (NBI), which grouped all riparian countries of the Nile as members. The NBI conducts high-level meetings and capacity building workshops and seminars. Although no comprehensive agreement has yet materialized among all riparian countries, the NBI has eased tension and created a forum for dialogue and arbitration of potential conflicts. Therefore, the NBI is an important adaption strategy that reduces vulnerability to conflicts that could arise from competition over finite water resources made increasingly scarce by climate change and growth in demand, particularly in the upstream riparian countries.

CASE STUDY – THE JEDDAH FLOODING EVENT

Jeddah is the second largest city in Saudi Arabia. On November 26, 2009, a major storm dropped over 90 millimeters of rain within 4 hours, equivalent to twice the yearly average. By midday the rain accumulated into massive torrents that ripped through the poor southern neighborhoods of the city and swamped thousands of vehicles caught in a heavy traffic jam exacerbated by the earlier light flooding of highways. The flood wave razed hundreds of buildings and swept thousands of cars and buses loaded with passengers. The death toll was over 150 (Usher, 2009), with damages to over 8,000 homes and over 7,000 vehicles (Alsharif, 2009).

Jeddah came also under eminent risk of a major public health disaster as sewage water levels rose high in the upstream "Musk" lake (Abumansour, 2009). Originally planned for flood control and water supply, the lake was later turned into a dumping reservoir for sewage tankers since the city virtually lacks a sewage network. At the peak of the storm the lake was estimated to contain around 50 million m^3 of sewage water.

Although the Jeddah flooding event is not necessarily tied to climate change, it nevertheless highlights vulnerabilities that are relevant to projected climatic change stimuli (increase in precipitation intensity). From a hydrologic perspective, the event is not very significant. However it has manifested into a catastrophe due to several vulnerabilities at the individual, societal, and institutional levels. The most severely hit parts of the town were built on a "wadi" bed with virtually no drainage system. Poor planning and alleged corruption opened the way to haphazard development of poorly constructed buildings and densely populated shanty houses occupied mostly by migrant workers. The devastated area is crossed by several highway junctions kept busy by inadequate traffic planning and control. Many of the commuters were not aware of the danger nor at first alarmed by the floods, which added to the later chaos and death toll. Many survivors reported lack of response from the police and civil defense and could not reach authorities as emergency lines were reported mostly busy during the event. Many people were trapped and could not get help. The situation was further exacerbated by electric outages as the ravaging floods knocked down power lines.

The high mortality is tied to several key generic and hazard-specific vulnerabilities. The generic vulnerabilities include those of poverty, social status, governance (corruption, accountability), and infrastructure. Those linked to hazard-specific vulnerabilities include the lack of adequate public drainage and sewage disposal and treatment, improper building structure, poor traffic management, improper urban planning, and the inexistence of emergency preparedness planning. This event has exposed several vulnerabilities to climatic hazards that could intensify under projected climatic change. It therefore provides an important lesson for decision makers, homeowners, and society at large to work on reducing these vulnerabilities.

VII. CONCLUSION AND RECOMMENDATIONS

This chapter addresses vulnerability of water resources in Arab countries to climate change. Being situated mostly in mid-latitudes, Arab countries are expected to undergo a major reduction in their water balance due to projected decrease in precipitation levels combined with increased evaporation rates.

The predicament is particular critical for Arab countries considering that most of their renewable water resources originate outside their boundaries in regions which are also expected to experience a similar fate.

Climate change is one of several stressors, along with population growth and land use change, that accentuates water-associated vulnerabilities. Given that climate change projections are still plagued with uncertainty, a vulnerability-based approach provides a more logical framework to select and formulate adaptation strategies based on accumulated knowledge of the strengths and weaknesses of different sectors and systems to given vulnerability determinants. By addressing these determinants that include water scarcity, climate variability, demographic factors, land use changes, and deficiencies in water services, it would be possible to enhance the resilience of different systems to projected climatic change. This is a win-win situation for Arab countries as they prepare to address current as well as future water challenges.

Two case studies were presented to illustrate different experiences in dealing with climate variability. Jeddah's recent flood is a testimony of the failure of planners in addressing intrinsic vulnerabilities that relate to the inadequacy of the drainage system, poor urban planning, and lack of emergency preparedness. Egypt's experience in managing the Nile's water flows provides a brighter spot where the country has built adaptive capacity to variable river conditions. In both cases, the experience with climate variability acts as a "preparatory exercise" for future events that may become more common

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