

Perspectives on water and climate change adaptation

# Vulnerability of arid and semi-arid regions to climate change – Impacts and adaptive strategies



World Water Council  
World Water Forum



co-operative programme  
on water  
and climate



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Arab Water Council

## **This Perspective Document is part of a series of 16 papers on «Water and Climate Change Adaptation»**

‘Climate change and adaptation’ is a central topic on the 5<sup>th</sup> World Water Forum. It is the lead theme for the political and thematic processes, the topic of a High Level Panel session, and a focus in several documents and sessions of the regional processes.

To provide background and depth to the political process, thematic sessions and the regions, and to ensure that viewpoints of a variety of stakeholders are shared, dozens of experts were invited on a voluntary basis to provide their perspective on critical issues relating to climate change and water in the form of a Perspective Document.

Led by a consortium comprising the Co-operative Programme on Water and Climate (CPWC), the International Water Association (IWA), IUCN and the World Water Council, the initiative resulted in this series comprising 16 perspectives on water, climate change and adaptation.

Participants were invited to contribute perspectives from three categories:

- 1 **Hot spots** – These papers are mainly concerned with specific locations where climate change effects are felt or will be felt within the next years and where urgent action is needed within the water sector. The hotspots selected are: Mountains (number 1), Small islands (3), Arid regions (9) and ‘Deltas and coastal cities’ (13).
- 2 **Sub-sectoral perspectives** – Specific papers were prepared from a water-user perspective taking into account the impacts on the sub-sector and describing how the sub-sector can deal with the issues. The sectors selected are: Environment (2), Food (5), ‘Water supply and sanitation: the urban poor’ (7), Business (8), Water industry (10), Energy (12) and ‘Water supply and sanitation’ (14).
- 3 **Enabling mechanisms** – These documents provide an overview of enabling mechanisms that make adaptation possible. The mechanisms selected are: Planning (4), Governance (6), Finance (11), Engineering (15) and ‘Integrated Water Resources Management (IWRM) and Strategic Environmental Assessment (SEA)’ (16).

The consortium has performed an interim analysis of all Perspective Documents and has synthesized the initial results in a working paper – presenting an introduction to and summaries of the Perspective Documents and key messages resembling each of the 16 perspectives – which will be presented and discussed during the 5th World Water Forum in Istanbul. The discussions in Istanbul are expected to provide feedback and come up with suggestions for further development of the working paper as well as the Perspective Documents. It is expected that after the Forum all documents will be revised and peer-reviewed before being published.

# **9 Vulnerability of arid and semi-arid regions to climate change – Impacts and adaptive strategies**

A perspective paper by The Arab Water Council

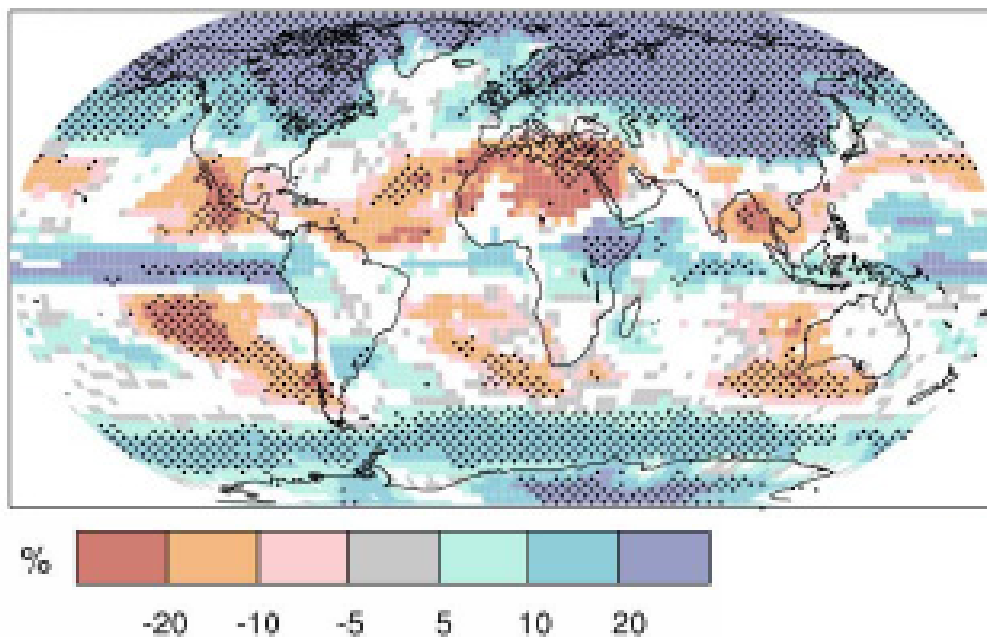
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# Vulnerability of arid and semi-arid regions to climate change – Impacts and adaptive strategies

Climate change is caused by accelerated increase in greenhouse gas (GHG) concentrations in the atmosphere. There is now a strong consensus that climate change presents a fundamental challenge to the well-being of all countries, with potential of being the most harsh on countries already suffering from water scarcity. Water scarcity is a well-established context for development in arid and semi-arid countries. A recent IPCC report (IPCC, 2008) predicts that climate change over the next century will affect rainfall patterns, river flows and sea levels all over the world. For many parts of the arid regions there is an expected precipitation decrease over the next century of 20% or more. Even if efforts to reduce greenhouse gas emissions are successful, it is no longer possible to avoid some degree of global warming and climate change.

The 5<sup>th</sup> World Water Forum will pay particular attention to ‘Adapting to climate change’ in its thematic, regional and political processes. This Perspective Document focuses on the arid and semi-arid regions of the world and is one of 15 other documents which are intended to provide input to address adaptation to the consequences of climate variability and change in the short and long term in these regions. The rationale is to provide an overview of the specific issues in the geographical settings of these regions,

share areas with shared key features, provide insight into subsector or specific interest, and identify enabling mechanisms that make adaptation possible within the arid and semi-arid regions. At the invitation of the Topic Coordinator of the 5<sup>th</sup> World Water Forum, the Arab Water Council (AWC) accepted to lead the preparation process of this Perspective Document in consultation with regional stakeholders.



**Figure 1:** Arid regions will suffer the maximum precipitation decreases worldwide. Colours: Change in precipitation. Source: IDA, 2007.

## 1 Impact of climate change on the water sector

Climate change impacts add to already difficult water management challenges in the arid and semi-arid regions. In the Middle East and North Africa (MENA), South and Central Asian countries, and several areas in North and South America, 'traditional' approaches to managing water scarcity - based on lifestyle adaptations that minimized consumption and maximized beneficial local use - were dominant up to the 1970s and are still used today in many of these regions. Terraces were constructed to capture rainfall for crop production; spate flows in rivers were diverted to provide supplemental irrigation; shallow aquifers were exploited by open wells; and *qanats* were constructed to intercept hillside aquifers. These widely varying technical approaches to water management shared two important characteristics. First, because annual rainfall was the direct source of water, consumption did not exceed supply (except, in the short term, excess withdrawal from shallow aquifers). Second, with the exception of very large scale, flood-based irrigation in Egypt and Central Asian countries, coordinated actions were usually concentrated around small groups of farmers who owned and managed the water resources, and developed procedures for sharing available water.

More recently, technological innovations - especially deep tubewells and high-powered pumps - significantly altered water management behaviors. Deep tubewells allowed continual, unsustainable drawdown of aquifers as well as access to fossil water, wherever available. Pumps allowed faster abstraction from canals and rivers than previously possible, disrupting historical patterns of consumption. Both these innovations disturbed the equilibrium - in terms of resource allocation and organizational arrangements. In parallel to these technical developments, population has been growing and incomes steadily rising, adding to the demand on water. Thus, stable and sustainable supplies have been disrupted in recent decades and the current usage is, in many areas, no longer at sustainable levels. As a consequence, the possibility that water resources will limit the socio-economic development of many arid and semi-arid regions has gained credence.

Climate change will impact several sectors of the economy and have worldwide ramifications. The

changes in other parts of the world will impact the economy of arid and semi-arid regions too. Many countries in these regions depend on river flows originating in tropical or temperate regions. The overall water stress will increase. Climate change is expected to lead to declining precipitation in most parts of the world. But projected temperature increase will imply higher evaporation and drier conditions. Rain is also expected to reduce in frequency but increase in intensity. All these will result in frequent droughts and floods. Climate models project decreasing precipitation in already dry areas, such as northern Africa. In South Asia, earlier snow melt and the loss of glacial buffering in the Hindu Kush-Himalayas will affect the seasonal water supply for significant proportion of the population of the sub-continent.

The consumption of groundwater is likely to become unsustainable. Already in many parts of the world - certainly beyond the arid regions where the problem is most common - aquifer drawdown is such that future reliance cannot be placed on this resource. In much of the Arabian Peninsula, for example, the high value of water in all uses, often accentuated by subsidized power, has resulted in significantly larger withdrawals of water than the rate of natural aquifer recharge. According to the IPCC the unsustainable depletion of groundwater will likely be worsened by reduced surface water infiltration in the MNA region. In addition, the increase in the intrusion of salt water to coastal aquifers from sea level rise will further reduce the availability of usable ground water (IPCC, 2007; IDA, 2007).

Agriculture and food security are threatened. Recent research indicates that even if basic adaptive measures are taken (such as changing crop types) global agricultural production will decline 3 per cent by 2080. The demand for water generally increases with temperature - particularly crop water demand. Thus, while climate change is expected to f the supply of water, *demand* will be moving in the opposite direction. One study (Döll, 2002) has estimated that crop water demand will increase by 5-8% by 2070, with regional variations up to 15%. In addition, potential crop yields tend to fall at high temperatures, so the productivity of water in agriculture will fall (Kunzewicz et al, 2007; Cline, 2007). A research on Africa found that dryland farms are specifically sensitive to climate change, the elasticity of net revenue with respect to temperature being -1.6 for dry-

land farms as against 0.5 irrigated farms. A 2.5 °C rise in temperature in Africa will result in decline of net revenues from agriculture by US\$ 23 billion (Kurukulasuriya et al, 2007b)

Urban areas face multiple challenges from climate change. While coastal cities are vulnerable to sea level rise and storm damage, flooding from more intense rains and higher peak river flows presents significant threats to cities inland. Failures of sewerage and storm water systems could lead to major disease outbreaks. With growing dependence on air conditioning, frequent heat waves could result in major losses to productivity and even cause loss of life if power supplies fail. Rural-to-urban migration is likely to increase under climate change conditions, as many rural livelihoods become less viable. To cope with the threats, urban design, building codes, and energy efficiency will need to be reassessed.

The effects of climate change on water resources could significantly affect hydropower in many developing countries, placing stress on the energy infrastructure. Larger facilities for water storage will be needed in many parts of the world. More erratic river flows will affect water quality and consequently human and animal health. Extreme weather events already threaten vulnerable infrastructure, such as roads.

Ecosystems, particularly forests and wetlands are at risk. Changes in water flows through river systems and from coastal storm surges threaten to destroy many wetlands, with loss of filtering and buffering services they currently provide. Hot, dry conditions will increase the risk of wildfires in all types of forest, while warmer and longer growing seasons in mountain forests could lead to an explosion of pest population.

Coastal areas are vulnerable from the increase in sea levels, flooding, storm surges, and stronger winds. More than 150 million people in developing countries live less than five metres above sea level. During this century, flooding from the rising sea level and storm surges will threaten the viability of some islands as well as some major deltas, such as the Nile and Mekong. The IPCC (2007) projects that sea levels will rise by 20 to 50 cm during this century. There is, however, large uncertainty about the rate at which the ice sheets of Greenland and Antarctica are melting, so the sea level rise estimate could significantly exceed. The Nile Delta region in Egypt is highly vulnerable to any expected rise in sea water

levels due to climate change. A sea level rise of one metre would flood a quarter of the Nile Delta, forcing about 10.5% of Egypt's population from their homes. It also would hit Egypt's food supply as nearly half of Egypt's crops, including wheat, corn, and rice, are grown in the Delta. The impact would be all the more staggering if Egypt's population, as expected, doubles to about 160 million by the middle of the century. The situation is serious and requires immediate attention.

Disease patterns are likely to change, making control more difficult. Climate change will affect human health through increase in heat stroke mortality, tropical vector-borne diseases such as malaria, and urban air pollution (ground-level ozone levels are sensitive to ambient temperatures). Africa, for example, is already vulnerable to several climate-sensitive diseases such as Rift Valley Fever, which afflicts both people and livestock; cholera, associated with both floods and droughts; and malaria. Climate change has already resulted in the spread of malaria to the highlands of Kenya, Rwanda, and Tanzania (IDA, 2007). Dengue epidemics have been more frequently observed in Delhi in the past several years.

The impacts of climate change are likely to affect women and girls more severely. They will need to spend more time collecting water and fuel/wood and more time caring for sick family members. In addition, because most agricultural work in many developing countries is undertaken by women, any increased work load is likely to fall on them (IDA, 2007). In Kenya, the frequency of drought has resulted in women walking as much as 10 to 15 km per day to collect water, facing personal risks in the long treks. Girls are unable to attend school. The physical burden of carrying water long distances is debilitating to their health. Small-scale water harvesting is becoming common.

Climate change has the potential to escalate existing regional tensions. Although it is complex to link, there is evidence that scarcity of renewable resources can intensify latent conflicts. For example, it has been observed that frequent drought cycles in Darfur resulted in differing interpretations of rights to access water and land among nomadic and sedentary groups. These differences contributed to the escalation of ethnic tensions.

Conflicts will also occur because of uncertainty in cooperation between nations sharing international watercourses. The Arab countries, for example,

depend on international watercourses for 65% of their water requirements. If upstream riparians maintain constant use while river flows decline, the downstream users will be severely impacted. Similarly, investments in hydraulic infrastructure by upstream riparian can change the water availability of downstream users. The Greater Anatolia Project of Turkey, for example, affects water availability in Syria and Iraq (IDA, 2007).

Quality of water will decline. IPCC reports state that higher water temperatures, and an increase in droughts with lower stream flows, will adversely affect water quality due to pesticides, pathogens, sediments, dissolved organic carbon, and thermal pollution. In the congested rural settlements along the Nile River delta, for example, residents and farmers have become an important lobby group demanding the cleaning up of canals and rivers from municipal and agricultural pollution. Among farmers, exporters of high value farm products have been concerned that the marketability of their products is affected by water pollution. Overall, tour operators and resort owners are powerful interest groups that have joined environmentalists and farm exporters to lobby for enhanced water quality management.

## **2 Policy challenges**

There are several key policy challenges that have to be confronted for successfully adapting to climate change in respect to water. The first challenge concerns information and data collection and sharing. The current knowledge on the impact of climate change to water resource management requires systematic and well-planned improvement. With accurate scientific data, planning for adaptation, as well as advocacy among stakeholders, will be easier to achieve. The collection of information can be a complex process, as coordination among sectors, countries as well as among knowledge sectors that do not ordinarily interact, will be essential.

The adaptation strategy is another challenge, varying from one country to another based on the projected impact of climate change. There are multiple stakeholders in a region, and the interest of each will have to be prioritized. Moreover, the community should be aware of the adaptation strategy, which implies that the development of the strategy should be preceded by community discussions and debates.

Some of the strategies may require changing behavioral patterns, which could be controversial and take time.

The institutional capacity should be strong enough to undertake adaptive measures. The challenge here is to develop policies that are specially directed to climate change, incorporating climate change perspective in other policies, establishing organizations that will ensure focus on adaptations, embed adaptive processes in existing institutional structures and re-train water managers to the changing realities.

One of the greatest policy challenges would be the financing of climate change adaptive measures. With imperfect information about the magnitude of climate change impact, the allocation of financial resource to construct expensive infrastructures will be a great challenge for developing countries. Over time, as the information base improves, this decision is likely to get easier. However, there is an urgent need to allocate money for collecting information itself. The conceptual difficulty is in determining the appropriate financial allocation for collecting information today, which will help in accurately predicting, sometime in the coming decade, climate change-related calamities further into the future. If this investment is not made, on the other hand, there would be no accurate information about future calamities, and financial planning will risk being over- or under-estimated.

## **3 Current adaptive experiences**

Many countries and regions in the world are already taking actions that will help them manage the challenges of climate change. The MNA region is one of them. Others include countries in the Andean region, Central and South Asia and Africa. The approach that each has followed is specific to the context of the region or the country. The main emphasis is on improving information, strengthening institutions and devising strategies for reducing the negative impact on vulnerable population groups. These are discussed below.

The Nile River basin extends over 10 nations, eight upstream riparian (Ethiopia, Eritrea, Uganda, Rwanda, Burundi, Congo, Tanzania and Kenya) and two downstream (Sudan and Egypt). The basin is home to 190 million people, half of whom live below

the poverty line. Six of the riparian nations figure among the top 10 poorest in the world. The Nile is, therefore, one of the toughest transboundary water issues in the world. Climate change has the potential to create conflict in the region with serious ramifications for the poorest. NASA is closely associating with the AWC and existing institutions in the Nile basin to develop satellite-based water management and forecasting techniques, improving hydrological data for cooperative water management.

Currently, the Nile Basin Decision Support System (NBDSS) engages all 10 riparian nations in water management and planning. The Egyptian Ministry of Water Resources and Irrigation (MWRI) has developed a Nile Forecast System for the Aswan Dam. Although both these systems are operated by skilled technical staff, there is a deficit of data which renders the models incomplete. NASA is developing a Land Data Assimilation System (LDAS) to merge high quality satellite data with data obtained on the ground to develop a dynamic model which reflects real-time hydrological changes. This will improve NBDSS reliability in applications that include flood warning, reservoir management and irrigation planning (Zaitchik, 2008).

The anticipated benefits from the NASA supported project include understanding the impacts of various climate change scenarios, choosing future development strategies with due appreciation of social costs and benefits, early opportunity to take actions against impending floods or droughts, mapping crop and irrigation intensity for superior accounting of water use and identification of water resources hot-spots along the basin through trend analysis.

NASA is planning a similar LDAS for the Arab region as a whole to drive a suite of advanced land surface models with the goal of providing optimal estimates of hydrological states and fluxes relevant to water resource management (NASA, 2008).

The impact of climate change is expected to be severe in high altitude mountain ranges. A project is currently underway in the Andean region of South America to understand how climate change will impact countries of this region. Increase in temperature is resulting in accelerated retreat of glaciers in the mountain tops, increasing variability of water flows to downstream regions and threatening sustainable water use planning for the future. Tropical glaciers in the Andes covered an area of over 2,940

km<sup>2</sup> in 1970 but declined to 2,493 km<sup>2</sup> by 2000. The largest of these glaciers in the Cordillera Blanca have lost 15 per cent of their glacier surface area over the past 30 years. Several glaciers in the region, such as Cotacachi in Ecuador, have already disappeared and the region has experienced a decline in agriculture and tourism as well as loss of biodiversity. Waterless streams and decreased water levels have led to water conflicts which are expected to worsen with time.

Glacier retreat will affect regional water supply. For large urban centers such as Quito in Ecuador (pop. 2 million) where glacier basins (Antisana and Cotopaxi in particular) supply two thirds of Quito's drinking water, or La Paz and El Alto in Bolivia (pop. 2.3 million) where the glaciers of the Cordillera Real have until recently supplied 30–40 per cent of potable water, the changing circumstances can affect costs of supply and ultimately the ability of urban centres to maintain vibrant economies. Glacier retreat and other climate changes will also impact local agriculture. Arid and semi-arid mountainous ecosystems in the region are highly vulnerable to disruption of local hydrological patterns, placing subsistence agriculture and consequently rural livelihoods at risk. Moreover, the region relies on hydropower to cover most of its power requirements (80% in Peru and 50% in Ecuador). While glaciated basins only contribute to a small fraction of those tapped for hydropower, changes in water regulation induced by warming of these basins will reduce the potential for power generation (World Bank, 2007a).

The project in the Andean region is expected to result in a better understanding of climate change impacts through: (i) an analysis of current glacier hydrology, including an update of previous glacier inventories, glacier variations, and records of glacier melt hazards and disasters; (ii) estimation of the availability of water resources due to glacier melt at the national level up to 2050; and (iii) an evaluation of adaptation strategies in the management of hydro resources in basins with a glacier under climate change conditions. These outputs will guide the selection process of priority adaptation measures for the Andean region in the future and will strengthen their design (World Bank, 2007a).

Empirical research on the behavior of farmers in Africa to sustained changes in weather conditions has found that farmers will likely adapt to climate changes by sowing crops that are suitable to the new conditions. Thus, climate change in the Continent



will result in farmers opting for heat tolerant crops. The research emphasizes the scientific discovery of seed varieties that have higher heat tolerance. The research also cautions against over-estimation of losses resulting from climate change because, as stated, farmers will reduce losses by switching to crop varieties that are heat tolerant (Kurukulasuriya, et al, 2007)

In semi-arid regions of South Asia – Rajasthan in India and Sindh in Pakistan – the World Bank has undertaken projects aimed at strengthening institutional arrangements for water management as well as for developing technical capacity in irrigation. The Rajasthan Water Sector Restructuring Project supported the creation of the State Water Resource Planning Department for the purpose of planning and regulating water allocation across economic sectors, including irrigation. The project improved data collection procedures and encouraged community-based management practices. Similarly, the Sindh On-Farm Water Management Project concentrated on strengthening local level institutions for better water management practices. Farmer's organizations were formed, which provided training for efficient water management and formally assigned responsibilities to manage the irrigation systems. In addition, technical improvements for higher agricultural productivity were also undertaken, such as drip irrigation, modern agronomic practices, etc. (World Bank<sup>1</sup>).

Ebro River Basin Authority in Zaragoza, Spain, has developed sophisticated information management systems which help in predicting and surmounting natural calamities such as flood and drought. The Ebro Basin Agency is the oldest organization of its type in Spain – having been founded in 1926. The agency, manned by 1000 staff, is the apex organization which (a) prepares and implements the basin hydrologic plan, (b) monitors the quality and quantities of water resources, (c) decides on the uses and allocation of water resources in the basin and (d) constructs and manages the operation of the major infrastructure of the basin (dams, canals, monitoring stations, etc.).

The advanced Hydrological Information System in the Ebro basin is supported by 662 remote stations and provides real-time data on the stock of water resources. Decision Support System (DSS) software analyses the data and helps in assessing current water levels and forecasting likely future scenarios. Both the quantity of water as well as its quality is analysed. All major decisions are taken by the management board of the Authority which is constituted of user's representatives (33.3%), communities or territories (33.3%) and ministries, trade unions and civil society (33.3%). The investment is normally financed by the central government and amortized in the tariff.

The MNA countries have undertaken institutional reforms to adapt to changing water resource availability in the region. Morocco is one example. The rivers service the farms and a growing urban and regional economy. Improved agricultural practices have been supported by excellent road communications to the export market for fruits and vegetables. Large urban centres have become magnets for migrants from rural areas, attracted by off-farm jobs, though their untreated wastes pollute the river downstream. Water is everybody's business, and its management is influenced by policy within and outside the water subsectors.

The experience of the Central Asian countries of Kazakhstan, Krygyz Republic, Tajikistan, Turkmenistan and Uzbekistan are relevant to understanding how communities will be impacted if irrigation diminishes in a predominantly agrarian and dry region. Some 20 to 40% of the GDP of these countries comes from agriculture. Until the last two decades, these countries had robust irrigation infrastructure under the erstwhile Soviet rule, but the infrastructures are in advanced stages of decay because they were not maintained after the political changeover of the early 1990s. The yields per hectare have diminished and soil salinity has increased. The farmers have adapted to this situation by switching to drought or salt resistant crop. They are limited, however, by government policies in some of the countries, which prescribe what they must grow where and when. Farmers often lack information on diversifying crop or adopting new water management and soil management techniques. The local elites are very dominant, in the absence of sound institutions, and they divert much of the canal water upstream, often resulting in conflict with downstream users. There

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<sup>1</sup> <http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/SOUTHASIAEXT/EXTSAREGTOPWATRES/0,,contentMDK:20273283ffi pagePK:34004173ffiipiPK:34003707ffitheSitePK:494236,00.html>, accessed on 14 Oct 2008.

are no proper conflict resolution mechanisms. Many villagers have abandoned agriculture, taking to animal husbandry or becoming farm laborers. But very few have migrated, which is probably because of lack of opportunities elsewhere and also strong ties to family and cultural roots.

Studies have found that rehabilitating the infrastructure is economically viable in many parts of the region. Even where it is not economically viable, the repair will have positive short to medium-term socio-economic consequences and is worth undertaking. Halting the deterioration of the infrastructure will benefit the poor significantly.

Kenya, which is highly vulnerable to climate change because it is a predominantly dry country, has acted early to adapt to climate change. Currently implementing the Kenya Arid Lands and Resource Management Project (ALRMP), the government has realized the need to incorporate climate change issues too. Hence, a new project is being undertaken – Kenya Adaptation to Climate Change in Arid Lands (KACCAL). This project is embedded within the highly successful ALRMP. The objectives are to improve national coordination of information and action for management of climate risk, integrate long-term climate risk perspective in local planning and investments, support community driven initiative on livelihoods and provide technical assistance at the local level (World Bank, 2007b)

#### 4 Global/national level planning and actions

Traditionally, water-scarce regions have developed and managed their water resources productively and sustainably. For centuries, water systems operated to benefit the population, providing essential supplies to municipal, domestic and agricultural sector, and protecting against negative impacts through drainage systems and flood control works. These successful water management systems have followed a clear and common pattern that can be summarized as the ABCDEF of water management (Perry, 2008).

The essential elements are:

- Hydrological information on the availability of surface and groundwater available to society (Assessment)

- The political process through which society decides on the principles for allocating available water resources (Bargaining)
- The legal process that translates policy into rules and regulations defining the water services to various use groups (Codification)
- The empowerment of agencies (government, private, cooperative, etc.) responsible for delivering water services (Delegation)
- The construction of infrastructure necessary to deliver water to users (Engineering).
- The effectiveness of adaptive measures through monitoring and evaluation (Feedback)

These elements – which also point to the contributing disciplines of hydrology, political science, law, institutional economics and engineering – can be observed in the *aflaj* in Oman, Balinese Water Temples in Indonesia and traditional *mesqas* in Egypt. Each has different rules, allocation procedures, operational responsibilities and engineering design – but these elements are clearly defined and mutually supportive.

The water management planning to face the emerging challenges went through three distinct phases:

- Pre-IWRM (pre-1990s) was a phase in which the water management practice was driven by the urgency to invest in all forms of hydraulic infrastructure – the pure supply-driven approach – with assessment being restricted to standard cost-benefit analysis for justifying the investments.
- IWRM phase (post-Dublin and Rio) emphasized sustainable outcomes, with some codification (such as cost recovery for WSS utilities, bringing the various water sub-sectors under one water ministry, etc.). While there was progress, incentives outside the sector (notably energy subsidies, virtual water imports, political reluctance to raise tariffs, etc.) were not fully incorporated in water management practices.
- Post-IWRM phase in which there is a greater understanding of the drivers for reforming water management. This phase emphasizes the need for a new management approach.

The three phases are compared in terms of the ABCDE elements of water management in table 2 below.

**Table 2:** Comparing water management approaches over time.

Phases Elements of water management approaches	The ideal sequence in water manage- ment	Pre-IWRM	IWRM	Post IWRM
Understanding how much water is available – <b>ASSESSMENT</b>	1	No	Partial	Partial
Allocating the water among competing uses – <b>BARGAINING</b>	2	No	No	Partial
Setting the <b>rules</b> and understanding the <b>incentives</b> – <b>CODIFICATION</b>	3	Partial	Partial	Partial
Assigning responsibility for mitigating <b>risks</b> – <b>DELEGATION</b>	4	No	No	Partial
Developing the facilities – <b>ENGINEERING</b>	5	Yes	Yes	Yes

Assessment requires much information. The current knowledge stock on climate change, now more than ever in the past, requires constant and systematic updating. Cooperation between various institutions spread across the world and cross-sectoral knowledge is necessary for this purpose. As, for example, cooperation between NASA and the 10 nations of the Nile Basin is critical for developing information on Nile river flow trends. With real-time data on water flow, and fairly good estimation of future flows, the planning process will be much simplified for all countries in the region.

IPCC and others have recommended that adaptation planning should consider a portfolio approach. Since it is difficult to predict the magnitude of climate change, this approach will provide flexibility, developing coping strategies against an array of climate change scenarios. To simplify information complexity of organising such a huge task, adaptation strategy could begin by undertaking a bottom up vulnerability assessment of the existing system. Thus, instead of analysing complex climate change models, the local water management institution could analyse information it already possesses, and assess the type of quantity and quality changes which will present the greatest threat to its current functioning. Based on this knowledge, the institution could plan several initiatives that will lessen the impact of climate change whenever it occurs.

Bargaining, codification and delegation are institutional issues. The European Environmental Agency has advised that the top priority for adaptation in water sector should be to minimize vulnerabilities of people and communities to changes in

hydro-meteorological trends, increased climate variability and extreme weather events. Human survival should, therefore, be the central focus of any adaptive strategy. The second should be to protect and restore ecosystems, and the third to close the gap between supply and demand. The Agency also advocates embedding adaptation strategies within the existing national policy and institutional framework, enabling integration of climate change with other issues that drive the economic sectors.

Involvement of multiple stakeholders is important in adapting to climate change. As adaptation at one level can strengthen- or weaken- the adaptive capacity, it is essential to have national, sub-national and local level interactions. Civil society and the business sector should also be involved. Policy actions for adaptation can range from capital investments to campaigns for promoting behavior changes.

The learning and capacity-building programme for water management at the national and local levels requires re-definitions to meet the challenges of climate change. Executive education water programmes need to be developed, with the purpose of creating water managers who are able to look beyond their narrow areas of specialization, respecting the contribution that other specialists make. The inspiration comes from successes in the field of business management through executive management programmes that promoted ‘lateral’ thinking by visionaries like Alfred Sloan and Peter Drucker. Through these programmes business management became a more systematic process of directing and controlling people and entities with the objective of accom-

plishing the enterprise goals. The MNA countries, for example, have recognized this challenge and, through the leadership of the Arab Water Council, are establishing an Arab Water Academy to organize learning events that would create a new genre of ‘water managers’ from different disciplines, representing all sections of the society.

Water management is as– if not more- multi-disciplinary than running a modern business enterprise, and requires a different culture of thinking with stakeholders ranging from farmers, slum dwellers, civil society, media and political leaders to civil servants, planners, economists and engineers. Involving these disciplines and interest groups in the national, regional and local decisions that they face requires a framework for the discussion, such as that provided by ABCDE outlined above. The framework requires appreciating the human, financial, natural and technological aspects of water management through systematic engagement of stakeholders in learning about water management, and recognising that any change (to allocations, technology, laws, etc.) has implications for other aspects of the system.

Demand management is an important tool against climate change. The challenge for water management, therefore, is about using financial, economic and institutional instruments to sustainably and productively manage with less, but more predictable, water supply, while balancing the growing

demands from many competing uses – including domestic, environmental flows, industrial, commercial and agricultural uses. Also, investment options should be flexible to enable alignment with changing priorities. The options could be of different types, such as building new dams against less costly management options and whether to encourage decentralized decision-making, create incentives for partnerships with other riparian communities and focus on wastewater reuse for maintaining status quo.

Another powerful influence is national economic policies (notably trade regimes, taxes and subsidies). International trade allows water scarce countries to import ‘virtual water’ through water-intensive commodities – ideally exporting ‘expensive’ virtual water in fruits and vegetables while importing ‘cheap’ virtual water in cereals. Government policies that support free trade will tend to result in such outcomes without specific ‘virtual water’ policies. Chart 1 below illustrates these trends by taking the example of MNA countries. Green represents renewable sources (both from surface and ground water), and includes desalinated water. Pink represents the proportion of water extracted from non-renewable sources (the proportion is larger in countries with significant energy subsidies), and brown represents virtual water embedded in agricultural commodities that are imported through trade.

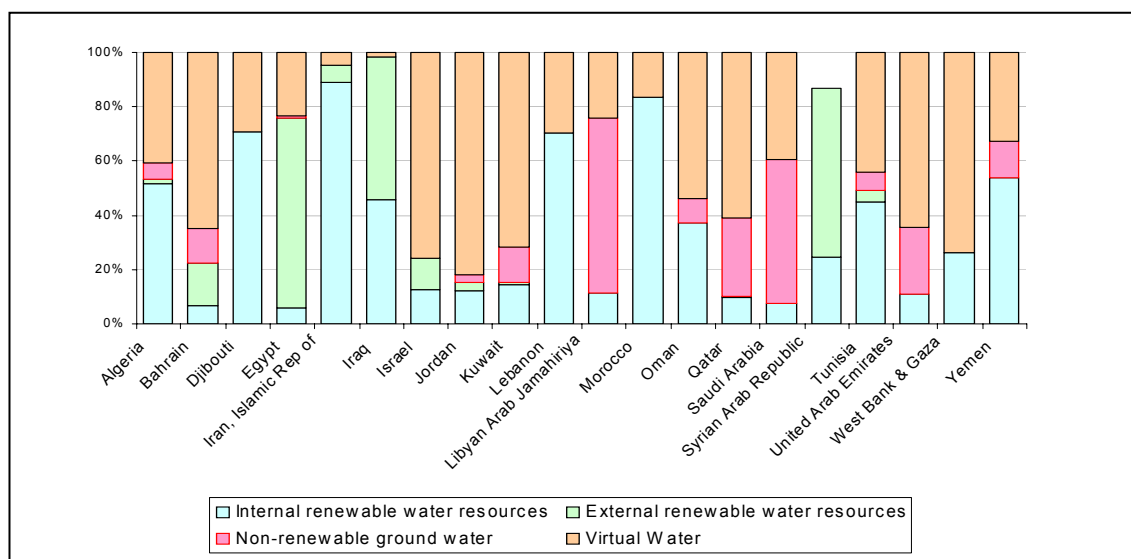


Chart 1: Role of renewable, non-renewable and virtual water in MNA countries.

Increased rice, wheat, dairy and beef imports, for example, result in significant virtual water being available to local consumers, while exports of fruits, vegetables, olives and dates have relatively low water embedded in their production. Countries with more liberal trade policies are able to augment the quantity and value of scarce local water resources by importing virtual water. However, the global changes in food prices and cost of energy call for flexible policies which allow each country make the right choice for optimum usage and management of their water resources.

## 5 Conclusion

Water resources management in countries that are already severely water stressed faces new challenges and new opportunities. In addressing this uncertain future it is critical to draw as much strength as possible from the lessons of the past, particularly to ensure that the approach chosen – which may vary from country to country – is coherent and clearly articulated to reflect the varied responsibilities and disciplines involved in successful water resources management. The optimal water allocation for a growing number of competing water management requirements (e.g. agriculture, public consumption, industry, hydro-energy, ecosystems, etc.) under a changing climate system places a heavy burden on water managers.

Climate change is a serious threat confronting the world and it is necessary to plan for this challenge. As its impact is likely to be faced most severely by the least-developed countries, there is an urgent need to plan adaptive strategies at the global level and work towards strengthening national capacities. The current water resource management approaches will have to be modified, taking into account the climate change scenarios. Prior to all this, however, the systematic collection of data, sharing of cross-sectoral knowledge and developing global and national institutions focused on climate change are critical issues to immediately address. The following few actions are recommended from an arid region perspective:

- 1 Arid and semi-arid regions are most vulnerable to climate change. Adaptive strategies to manage the climate change risk are necessary to be for-

- 2 Political focus on climate change offers opportunities to invest in reduced uncertainty and improved results in water management. If policy-makers can anticipate changes and use opportunities to promote reforms, climate change may help improve water management.
- 3 Systematic collection of information on water resources and their dissemination is essential for comprehending climate change impacts. This could require multi-disciplinary approach and involve trans-global cooperation. An institutional framework for sharing information at the global and regional levels, and their dissemination to the local level, is necessary.
- 4 There is economic value to the information collected on climate change in relation to water. Hence, governments should be encouraged to commit to investments in this objective. An advocacy plan to promote this objective needs to be formulated.
- 5 Robust irrigation infrastructure, even if economically not viable, may be necessary to cope with climate change risks in the short to medium-term, until farmers are trained in alternative livelihoods. Maintenance of existing infrastructure in vulnerable countries deserves early attention.
- 6 The institutions for water management should be improved to manage the risk of climate change. The capacity of water managers in developing countries should be expanded through training and exposure to adaptive measures in developed countries.

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## Annex 1

### Financial modeling for climate change

Investment in events that are inherently uncertain in their likelihood of occurrence or magnitude is a serious challenge for policy-makers. The impact of climate change in a country, as already discussed, can be of several types. The exact series of events that will occur and for which investments should be made is hard to predict. The magnitude of these events is harder to quantify. Investments are needed for collecting information over time and the new information, it is expected, will decrease uncertainty about likely future scenarios. The question is how much should one invest currently for acquiring information that might prove useful in the future.

When analysing complicated risk problems, it is useful to model them as games against nature which assume that nature will randomly, and non-strategically, select a particular state of nature. In its normal form, games against nature have the following elements: (i) states of nature and their probabilities of occurrence; (ii) actions available to decision-makers facing the nature and; (iii) payoffs available to decision-makers against each combination of state of nature and action.

As an example, the following three scenarios are possible in the case of climate change in next 50 years: severe, moderate, none. The three possible actions are high investments, moderate investments and low investments. The corresponding probabilities and payoffs are given in table 3 below.

**Table 3:** Games against nature: Expected value of climate adaptation alternatives.

State of nature	Severe impact of climate change	Moderate impact of climate change	Low or no impact of climate change	
Probabilities	0.001	0.004	0.995	
Actions (alternatives)	Payoffs (net cost in billions of dollars)			Expected value (billions of dollars)
High investments	5,060	1,060	60	69
Moderate investments	10,020	2,020	20	38
Low investments	30,000	6,000	0	54

Adapted from Boardman et al, (2001).

**Table 4:** Reformulated games against nature: Value of information on climate change.

	Game 1 P = 0.001		Game 2 P = 0.999		
State of nature	Severe impact of climate change		Moderate impact of climate change	Low or no impact of climate change	
Probabilities of states of nature (over next century)	1		0.004004	0.995996	
Actions (alternatives)	Payoffs (net costs in billions of dollars)	Expected value	Payoffs (net costs in billions of dollars)	Expected value	
High investments	5,060	5,060	1,060	60	64
Moderate investments	10,020	10,020	2,020	20	28
Low investments	30,000	30,000	6,000	0	24

The lowest expected value is US\$ 38 billion, which is the most preferred action given the probabilities.

A greater fundamental problem is that state of nature is likely to be known only if investments are made in collecting information. How much should the world (or a country) invest in collecting information? Assuming that collection of information will result in certainty of knowledge whether or not severe climate change impact will occur in the case of a country. In such a case, the game against nature can be characterized as in table 4.

In the case of Game 1, the ideal course of action is investing US\$ 5,060 billion and in Game 2, US\$ 24 billion. Prior to collecting the information, we do not

know which of the two Games is likely to be played. Hence, the expected value of the two games is  $0.001 \times 5060 + 0.999 \times 24 = \text{US\$ } 29$  billion.

The optimal choice of action without information was US\$ 38 billion from the previous computation. Hence, the value of information is  $\text{US\$ } 38 - 29 = \text{US\$ } 9$  billion. Consequently, as long as it costs less than US\$ 9 billion to gain information about the future, it is efficient to have it. This cost modeling is a simple example and will have to be developed further for actual applications. Some of the challenges are determining the probabilities of events and, of course, computing payoffs.

## Acronyms

ABCDE	Assessment-Bargaining-Codification-Delegation-Engineering
ALRMP	Arid Lands and Resource Management Project
AWC	Arab Water Council
BCM	Billion Cubic Meters
CO <sub>2</sub>	Carbon Dioxide
DSS	Decision Support System
GHG	Green House Gas
IPCC	Intergovernmental Panel for Climate Change
IWRM	Integrated Water Resource Management
KACCAL	Kenya Adaptation to Climate Change in Arid Lands
LDAS	Land Data Assimilation System
MNA	Middle East and North Africa
MWRI	Ministry of Water Resources and Irrigation
NASA	National Aeronautics and Space Administration
NBDDS	Nile Basin Decision Support System
NPV	Net Present Value