WORKING PAPER 110

Drought Series: Paper 8

A Review of Climate Change Scenarios and Preliminary Rainfall Trend Analysis in the Oum Er Rbia Basin, Morocco

Anne Chaponniere and Vladimir Smakhtin

International Water Management Institute

FUTURE HARVEST
IWMI is a Future Harvest Center
supported by the CGIAR

Working Paper 110
Drought Series: Paper 8

A Review of Climate Change Scenarios and Preliminary Rainfall Trend Analysis in the Oum Er Rbia Basin, Morocco

Anne Chaponniere
and
Vladimir Smakhtin

International Water Management Institute

IWMI receives its principal funding from 58 governments, private foundations and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR). Support is also given by the Governments of Ghana, Pakistan, South Africa, Sri Lanka and Thailand.

The authors: Anne Chaponniere is a Post Doctoral Fellow in Hydrology and Water Resources at IWMI Sub-regional office for West Africa (Accra, Ghana). Vladimir Smakhtin is a Principal Hydrologist at IWMI Headquarters in Colombo, Sri Lanka.

Acknowledgments: The study was supported from IWMI core funds. The paper was reviewed by Dr Hugh Turral (IWMI, Colombo).

Chaponniere, A.; Smakhtin, V. 2006. *A review of climate change scenarios and preliminary rainfall trend analysis in the Oum er Rbia Basin, Morocco*. Working Paper 110 (Drought Series: Paper 8) Colombo, Sri Lanka: International Water Management Institute (IWMI).

/ climate change / river basins / watersheds / groundwater irrigation / water scarcity / precipitation / rainfall-runoff relationships / simulation models / Morocco /

ISBN 92-9090-635-9
ISBN 978-92-9090-635-3

Please direct inquiries and comments to: *iwmi@cgiar.org*

Contents

SUMMARY

The paper reviews the existing tools methods and general literature which deal with the construction of climate change (CC) scenarios and with the assessment of impacts of these scenarios on water resources. It further examines the existing CC predictions specific to Morocco. The paper further describes the publicly available hydrometeorological time series data, which could be used to quantify the future CC scenarios for a river basin in Morocco (Oum er Rbia) and a smaller irrigation scheme within it (Tadla), located in the western part of the country. The data indicates that the impact of future CC on water resources at smaller scales such as smaller river basins, specific water resources and irrigation systems has to date not been properly addressed and, therefore, constitutes a niche for immediate research. This is, especially relevant in areas such as the Mediterranean region, which is predicted to be particularly affected by CC in the future. The preliminary trend analysis of available rainfall data suggests that the possible future CC impacts will decrease the precipitation in parts of the Atlas Mountains, which is the main source of water supply in western Morocco. The more recent data acquisition and the data from national sources in Morocco are necessary to further confirm/reject this hypothesis. The paper also discusses subsequent steps of the study of CC impacts on water resources in Oum er Rbia basin.

INTRODUCTION

Climate is perceived to be changing worldwide and there has been growing concern as to the direction and effects of these changes (e.g., see Labat et al. 2004; Legates 2005; Labat et al. 2005). These concerns are reflected in the UN Framework Convention on Climate Change (UNFCCC) drafted at the Earth Summit in Rio in June 1992. The UNFCCC requires the non-Annex 1 Parties (i.e., developing countries) to conduct vulnerability and adaptation assessments of climate change. These assessments explore and, where possible, quantify the vulnerability of various systems and sectors to climate variability and climate change at the country scale.

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environmental Program (UNEP) to provide an assessment of all aspects of Climate Change (CC) including how human activities can cause such changes and can be impacted by them. The future changes projected by IPCC (Cubasch et al. 2001) include:

- Global increase in the surface air temperature is projected under all scenarios and by all models. Atmosphere-Ocean General Circulation Models (AOGCM) project a global average surface air temperature increase of +3ºC (ranging from 1.3ºC to 4.5ºC) for a "globally high emissions" scenario (referred as the "A2" scenario), and of +2.2ºC (ranging from 0.9º C to 3.4ºC) for a "lower CO_2 emissions" scenario (referred as the "B2" scenario) for the period 2071-2100 relative to 1961-1990. Simpler climate models, that can be calibrated to represent globally averaged AOGCM responses, can be run for a very high number of scenarios since they are not computationally expensive: these estimate an increase of 1.4ºC to 5.8ºC over the period 1990-2100 for the full range of emissions scenarios developed by the IPCC.

- Global increase in average water vapor, evaporation and precipitation as a consequence of the temperature increase which speeds up the hydrological cycle. Both precipitation increase and decrease will be experienced in different regions simultaneously.

- Increase in the frequency of hot days and heat waves over all land areas and, especially in areas where soil moisture decrease occurs. Heat index (a measure of the combined effects of temperature and moisture) is expected to increase due to the changes in surface air temperature and near-surface absolute humidity of the air.

- Global increase of the intensity and frequency of extreme precipitation events.

Extreme events (*floods and droughts*) are perhaps the major issues associated with climate change. Adaptation to them requires changes in both infrastructure and strategies and activities of water management (e.g., Hitz and Smith 2004). Therefore, the impacts of climate change on water resources have to be identified and quantified in order to cope with them in the future.

A number of global-scale studies have been conducted to date to identify and quantify the effects of CC on water resources. Arnell (1999) investigated the effect of CC on global hydrological regimes and water resources. CC scenarios from the Hadley Centre for Climate Prediction and Research were used together with a macro-scale hydrological model (0.5º resolution). Changes in water resources of all countries have been calculated and compared with the national water use estimates developed for the United Nations Comprehensive Assessment of the Freshwater

Resources of the World. The study indicated that the number of people living in water stressed countries[1] will increase significantly by 2025, the figures were relative to the model and scenarios considered, as well to the definition of a water-stressed country. Arnell (1999) also indicated that country-scale studies and indices can mask enormous "within-country" variations. The author consequently stresses the need for CC impact assessment at smaller spatial scales.

Several authors have conducted studies at such scales. Fowler (1999) has identified the likely limits of potential CC impact on water resources in the Auckland region (New Zealand), which served also as guidance to planners when ascertaining possible extremes in impact and the most likely direction of change. His results, however, suggested no immediate reason for concern. Miller et al. (2003) investigated the hydrological response to different CC scenarios for six river basins in California ranging from 891 to 9,989 km^2. An important result that appears for all snowmelt driven runoff basins is that the late winter snow accumulation is likely to decrease by 50 percent towards the end of the century. Similarly, Xu (2000) showed high sensitivity to climate change in central Sweden, major decrease of snow water equivalent (ranging between 13% and 76% depending on the scenario) being observed under 15 reasonable long-term CC scenarios and impacting runoff significantly (ranging between a decrease of 51% to an increase of 35%). Guo et al. (2005) found annual runoff decreases ranging between 2.5 and 5.4 percent for the five main tributaries of the Middle Yellow River basin (362,000km^2) by 2030.

In the case of Morocco, the current total renewable water resources (surface water and groundwater) are evaluated at 29 Billion Cubic Meters (BCM) per annum (Bennani et al. 2001). The utilizable component (that can be utilized given actual technical and economical conditions) is 20 BCM. Out of this, 16 BCM are from surface water and 4 BCM are from groundwater. About 70 percent of this potential is already exploited at present (11 BCM of surface water and 2.7 BCM of groundwater). Morocco has currently 110 large dams with a total capacity of 15.8 BCM. Arnell (1999) predicts the following "water future" for Morocco:

- a decrease of 0 to 25 mm/year in the average annual runoff by 2050
- a change in magnitude of -50 to -25 percent of both the 10-year return period maximum monthly runoff and the 10-year return period minimum annual runoff
- most of the country will experience a decrease in low flows (more than 10% reduction in the 10-year minimum annual runoff)
- a shift from a medium to a highly[2] water stressed country by 2025

Another quantitative estimate of the possible CC impacts on water resources in Morocco, made by Bennani et al. (2001), suggests a decrease of 10 to 15 percent of the surface water and groundwater. Besides, a number of authors point out that the Mediterranean region as a whole will be one of the most affected by future CC in terms of decrease in precipitation and increase in temperature leading to a decreasing availability of water resources (Hulme et al. 2000; Ragab

---

[1] A country is considered water stressed when withdrawals represent more than 20 percent of the renewable water resources (Falkenmark and Lindh 1976).

[2] Medium water stress is defined by the ratio of withdrawals to renewable water resources ranging from 20 to 40 percent. High water stress is when this ratio is over 40 percent (Arnell 1999).

and Prudhomme 2002; Agoumi 2003; El Ghissassi 2005). Morocco is, therefore, facing a real threat from CC and it is important to better understand the implications of CC scenarios on the water future of the country. The Moroccan Committee on Large Dams recently declared that, given the variability of natural water resources in the country and their high sensitivity to CC, the water storage capacity in the country should be maximized (El Ghissassi 2005). The implications of CC for existing infrastructure should also be explored. This requires specific studies at the scale of individual drainage regions, river basins and irrigated schemes. However, so far, the CC-related studies for Morocco have been conducted at a national scale only (Ministere de l'Environnement du Maroc 1994; Goodess et al. 2000). Therefore, the implications of CC on the management of water resources of particular basins, systems and schemes are effectively unknown.

This constitutes the major niche for research and, in 2005, IWMI initiated a project which was intended to look at CC impacts and potential solutions at the abovementioned smaller scales. It focused on Oum er Rbia located in central Morocco and incorporated one of the major irrigation schemes of the country – the Tadla area. The objectives of the project were to examine:

- if any trends can be identified from observed rainfall and runoff data in the region and to what extent they can, if identified, be related to CC.
- what are the impacts of the projected changes in temperature and precipitation on water resources, more specifically, what impacts will these changes have on the hydrology of the headwater areas, which supply most of the surface water to downstream irrigation schemes?
- what is the current proportion of groundwater to surface water irrigation in the irrigated area and how the future CC will impact both types of water sources.
- what are the management interventions needed to ensure the sustainability of the future agricultural production during the extended droughts associated with CC.

This paper reviews the literature sources, tools and methods for developing climate scenarios, and examines the first question from the above in more detail in the context of the Oum er Rbia basin.

THE STUDY AREA

Oum er Rbia, located in western Morocco, is the longest stream in Morocco with a catchment area of 48,070 km^2 (fig. 1). Elevations in the catchment range from 171 m to 4,071 m. A quarter of the area lies below 500 m elevation, and while half the catchment is mountainous the other half consists of plane and plateau. The long-term present-day mean annual discharge at the outlet is 35 m^3s^{-1} ranging from minimum of 8 m^3s^{-1} to a maximum of 1,700 m^3s^{-1} in different years. Oum er Rbia's main tributary is Oued El Abid, with a mean annual discharge of 32 m^3s^{-1} (Hammani et al., 2004; Bellouti et al. 2002).

The mean annual precipitation is around 350 mm. The precipitation decreases from east to west and from the Atlas chain towards the plane. The mean annual temperature in the region is 19ºC. The annual evapotranspiration is around 1,800 mm.

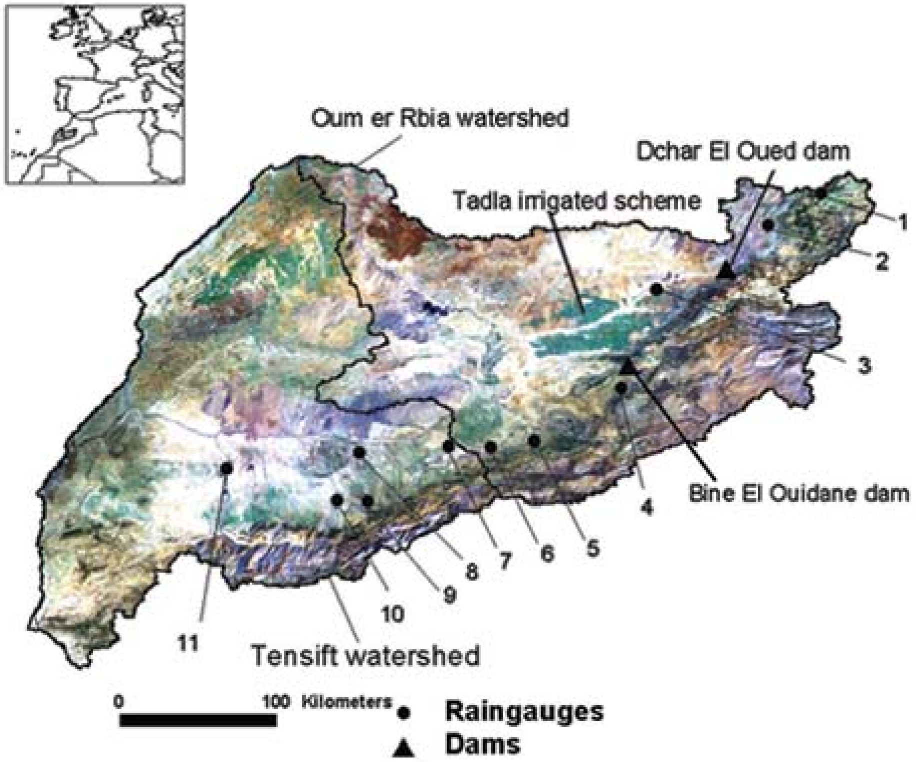
In the middle of the Oum er Rbia watershed lies the Tadla irrigated area (fig. 1) at an altitude of 400 m with a mean annual precipitation of 300 mm. The cropped area in Tadla is approximately 10,000 km^2. Over 12 percent of Morocco's national production of both citrus and olives is produced in the Tadla irrigated area, together with some 23 percent of the national sugar beet production. Eighty-two percent of the fields have an area less than 5 ha and occupy 34 percent of the total area, while 3 percent of the fields have an area more than 20 ha and occupy 34 percent of the total area. The majority of the area is irrigated by two dams (fig. 1) with a total capacity of almost 2 BCM, namely:

1. Dchar El Oued dam (also called Martyr Alhansali), built in 2001 on the Oum er Rbia river with a total capacity of 740 Million Cubic Meters (MCM). The reservoir feeds the northern scheme, Beni Amir, with an area of 27,500 ha.

2. Bine El Ouidane dam, built in 1953 on the El Abid stream with a total capacity of 1,384 MCM. The reservoir feeds the southern scheme, Beni Moussa, with an area of 69,500 ha.

Groundwater irrigation is also growing, but the scale of it has not been assessed. Groundwater is withdrawn from the unconfined Tadla aquifer complex and the confined aquifers (Eocene and Turonien), located approximately 100 m and 200 m below ground level. From the 1980s, the amount of water delivered by both dams no longer met irrigation requirements because of increased industrial water needs and changes in the use of land. There is also a local perception that the duration of

Figure 1: Oum er Rbia and Tenisft watersheds in central Morocco.



Note: The Tadla irrigated scheme located in the middle of the Oum er Rbia watershed is fed by Dchar El Oued and Bine El Ouidane dams. The details of numbered stations are given in table 2.

periods with limited or no rain (i.e., usually simply referred to as ‘droughts’) has increased during the last few decades, although no quantitative assessment of this has been carried out to date. In 1996, the liberalization of agricultural production led to a diversification of the cropping pattern (Petitguyot and Rieu, 2004) and resulted in higher water requirements. As a consequence, groundwater pumping accelerated and the exploitation of unconfined aquifers began. Subsequently, wells were equipped with more powerful pumps, which allowed much deeper resources like the Eocene aquifer to be exploited. As a result, groundwater tables dropped significantly after 1996 (Hammani et al. 2004).

THE RATIONAL

A number of problems associated with increasing water scarcity and recurring and extended droughts have been noticed in the Oum er Rbia basin and Tadla area – particularly in the past few decades (Debbarh and Badraoui, 2002; Hammani et al. 2004; Knippertz et al. 2003; Petitguyot and Rieu 2004). The extended drought periods are often thought to be related to increasing climate variability arising from CC, although studies supporting these perceptions in the area are yet to be carried out. Manifestations of water scarcity include, among others, an alarming reduction of both surface and groundwater resources, which resulted in the introduction of strict water quotas for mandated areas of sugar beet/sugarcane. An increasing number of private wells were developed to circumvent these restrictions, but which resulted in a further adverse impact on the groundwater table. Increased water shortages during the last 20 years, often perceived to be caused by recurring droughts led to the cancellation of the earlier plans to extend the area irrigated by the two main dams. There are concerns that the recurring droughts will deplete the available water resources further. However, the quantification of climate variability and assessment of its impact on water resources are yet to be carried out. The hydrology of the upstream river basin feeding the main dams in the system has not been assessed either for present-day conditions or under scenarios of future CC. The implications of future water availability scenarios for irrigation system management (diversifying cropping pattern, expanding sprinkler irrigation, improving institutional aspects, conjunctive use of surface and groundwater etc.,) are also yet to be examined.

DEVELOPING CLIMATE SCENARIOS

The design of CC scenarios entails several difficulties. First, the estimation of the possible rate and level at which the world community will continue to emit greenhouse gases is quite uncertain and unpredictable. Second, the atmosphere-ocean-biosphere-society system is far from being fully understood and easily modeled. Such uncertainty of climate prediction has prompted the UNFCCC to require all CC impact studies to consider a range of possible scenarios with equal probability of occurrence. The following three methods are used to identify the CC scenarios (Cubasch et al. 2001):

- incremental;
- analog; and,
- model-based climate analysis.

The incremental method consists of adjustments to baseline climate according to anticipated changes to future emissions. This method is used to test system sensitivity to climate, but it involves arbitrary adjustments of temperature and precipitation and may not be meteorologically realistic. The analog method consists of identifying analogs of a changed climate using past records or records from other regions. Identifying such analogs is difficult, and, as such, this method is seldom applied. The most commonly used method to identify CC scenarios is to build the scenarios from the outputs of Global Circulation Models (GCM): the complexity of the processes in the climate system should prevent the use of extrapolation of past trends or statistical and other purely empirical techniques for projections.

Climate change scenarios are thus mainly done using GCM for higher reliability but although GCMs capture the big picture, their coarse resolution (typically around 2-3 degrees) smoothens the local variations and, therefore, are not adapted to identifying local climate scenarios, which occur at much smaller scales (a resolution of under 1 km would normally be required). There are two possibilities for downscaling the GCM outputs (Goodess et al. 2000):

1. model-based (dynamical downscaling): nesting a finer-scale Regional Climate Model (RCM) within the GCM. This is a rather resource intensive approach

2. empirical (statistical downscaling): identifying relationships using observations of large-scale and regional climatic systems (multiple regression, canonical correlation etc.,). This approach, which is easier than the former, assumes that the deduced relationships remain valid under actual CC

Bennani et al. (2001) developed the climatic scenarios for Morocco following the IPCC methodology with “mid-range” emissions scenario (scenario “IS92a”) and the MAGICC-SCENGEN software (Hulme et al. 2000). MAGICC (Model for the Assessment of Greenhouse gas Induced Climate Change) is a set of simple models (gas-cycle, climate and ice-melt models) that are linked. It calculates the annual mean air temperature at the surface and the world-mean sea level under changing conditions of greenhouse gas emissions and sulfur dioxide contents. SCENGEN (global and regional climate SCENario GENerator) is a database containing results from a high number of GCMs experiments and observed climatic data. Mean temperature, precipitation and cloud cover, are estimated at the spatial resolution of 5º degrees. For four regions – Europe, USA, Southern Asia and Southern Africa - the spatial resolution is 0.5º degrees (more surface climatic variables are to be estimated). Both models are linked: the inputs are emissions scenario and model parameters and the outputs are the distributed mean air temperature, precipitation and cloud cover.
The scenarios developed by Bennani et al. (2001) suggest that for Morocco as a whole:

- Mean annual temperature will increase by 0.6ºC to 1.1ºC between 2000 and 2020

- Annual precipitation volume will decrease by 4 percent between 2000 and 2020

Each MAGIC-SCENGEN pixel covering Morocco corresponds to a different climatic zone. The software outputs for each pixel are presented in table 1 (Bennani et al. 2001). No RCM exists in Morocco, and developing one is beyond the task of this project, consequently the scenarios computed by Bennani et al. 2001 will be used in this study. They are the best available, although their coarse resolution is a significant limitation, especially in the arid and mountainous environment where spatial variability is the main climatic characteristic.

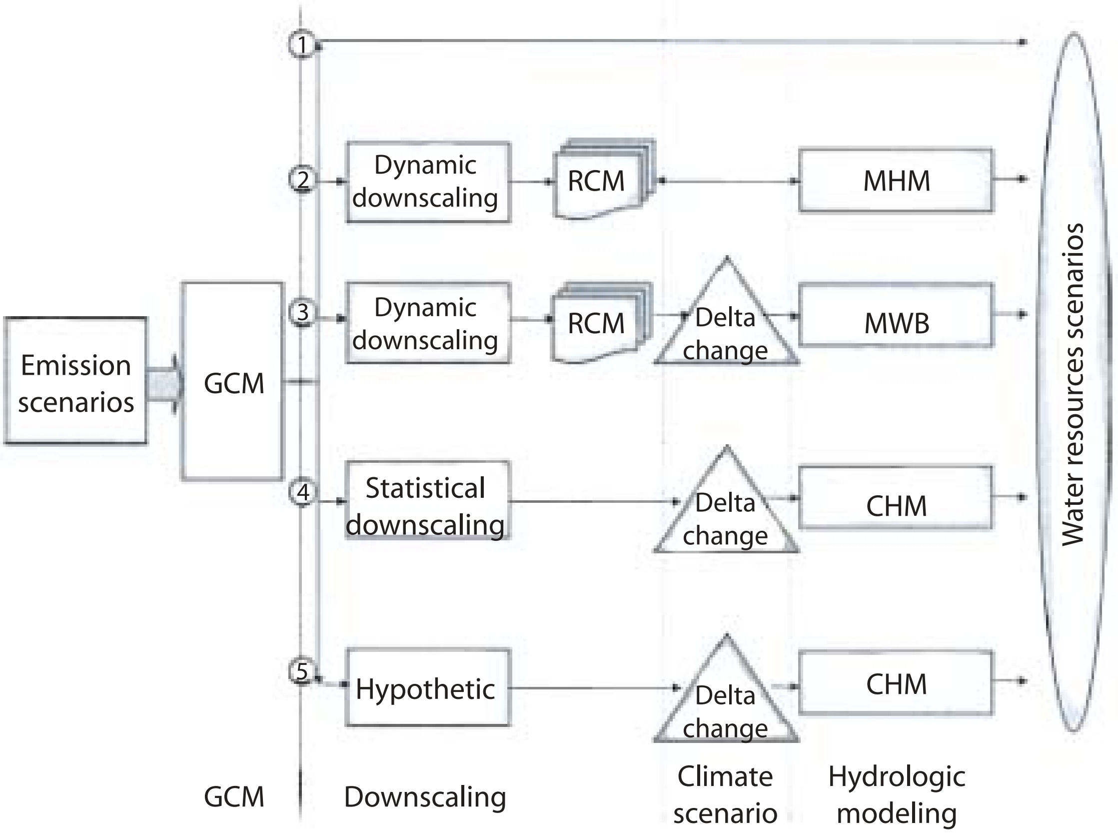
A recent literature review shows that five different methods can be used to simulate hydrological impacts of CC (Xu and Singh 2004 - fig. 2):

Table 1: Distributed changes on temperature and precipitation in Morocco.

Climatic zones	Representative stations	ΔT		$\Delta p/p$	
		range	mean	range	mean
		ºC	ºC	%	%
North-West	Tanger, Tetouan	0.6 – 0.8	0.7	-2.8 – -5.4	-3.3
Oriental	Oujda, Bouarfa	0.6 – 0.9 0.8 – 1.1	0.7 0.9	-1.8 – -5.5 -7 – 0	-2.3- -4.2
West	Kenitra	0.6 – 1	0.8	-7 – 0.1	-3.8
Oum er RbiaTensift	Marrakech	0.8 – 1	0.9	-7 – 0.1	-4.3
Middle and High Atlas	Ifrane, Beni Mellal	0.8 – 1.1	0.9	-7 – 0	-4.3
Tensift Draa	Agadir	0.8 – 1.1	0.9	-7 – 0.1 -11.7 – +2.8	-4.3 -10
South-East	Ouarzazate, Errachidia	0.8 – 1.1	1	-7.5 – 0 -11.7 – +2.8	-4.3 -11
South	Laayoune, Dakhla	0.8 – 1	0.9	North: -8 – -1 South: +1 – +4	

Source: Bennani et al. 2001

Figure 2: The different methods used to assess impacts of CC on water resources.



Source: Xu and Singh, 2004

1. Runoff is extracted from the GCM-derived hydrological output (GCMs have very simplistic land surface and ocean components that simulate runoff). This, however, usually provides poor estimation.

2. and 3. GCM outputs are dynamically downscaled via an RCM. In (2) the RCM is coupled with macro-scale hydrologic models (MHM) via the energy balance. In (3) the RCM outputs are used as input on a Macro-scale Water Balance model (MWB) which is run “off-line” (no coupling).

4. GCM scenarios are downscaled through a statistical tool and then used in a catchment-scale hydrologic model (CHM).

5. Historical time series of climatic data are modified according to some CC scenarios (typically $\Delta T=+1, +2^{o}C$, $\Delta p=0$, +/- 10%, +/-20% …) and used as an input to a CHM already calibrated for the catchment that is under study.

A simpler alternative to the abovementioned methods is to undertake sensitivity analysis of the rainfall-runoff relationship, stochastically generate rainfall time series and consider the range of runoff responses obtained.

However, caution has to be taken when simulating the hydrological impacts of CC or when analyzing runoff trends. Land-use change may have pronounced impacts on hydrological processes; so far they have been more significant than any perceived or predicted CC impacts. It is necessary to take them explicitly into account by, for example, using an appropriate hydrological model. In any case, CC impacts have to be separated from land-use impacts.

DATA

The study will be conducted with limited data – a typical situation in many developing (and sometimes even developed) countries. In addition to acquiring data from various local sources and partners, an attempt has also been made to extract suitable information from global datasets. Some of these data sources are briefly reviewed below.

GPCC Spatial Rainfall Data

The Global Precipitation Climatology Center (GPCC) is a German contribution to the World Climate Research Program (WCRP) and to the Global Climate Observing System (GCOS). It provides what is referred to here as “products” – which are spatially distributed monthly precipitation volumes at resolutions of 0.5^{o} to 2.5^{o} .Two GPCC products have been examined in the context of this study. The first product (called “monitoring product”) provides monthly precipitation volumes at 1^{o} spatial resolution from 1986 to date, and is based on quality-controlled data from 7,000 stations worldwide. The second product (called “re-analysis product”) provides monthly precipitation volumes at 0.5^{o} resolution from 1951 to 2004, and is based on quality-controlled data from a much larger number of stations (up to 43,000), although all station records do not cover the entirety of the time period considered.

The study catchment of Oum er Rbia fits within 8 cells of 1^{o} X 1^{o} resolution GCM, and the coverage of the network to gauge precipitation is poor. Three of the 1^{o} X 1^{o} cells contain no precipitation stations, three contain one precipitation station and the two remaining cells contain 2 precipitation stations each. The precipitation time series for each cell are therefore calculated with a very high level of uncertainty.

Station Data

Data on monthly rainfall time series are available for three stations in the basin from the Global Historical Climatology Network (Vose et al. 1992), and for six stations in the nearby Tensift basin (situated on the south-west border of the Oum er Rbia, fig. 1) from the local Watershed Agency "Agence de Bassin Hydraulique du Tensift". In addition, annual precipitation data are available in Oum er Rbia at Khenifra and Ouiouane for the period 1961-1990 from El Jihad (2003).These two stations are located in the upper part of the Oum er Rbia catchment (fig. 1). The length of the record period ranges from 30 to 64 years (table 2).

The runoff data were downloaded from the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC). This Center is a NASA-sponsored source of biogeochemical and ecological data. This type data are useful in environmental research (http://www-eosdis.ornl.gov). Oum er Rbia monthly flow data time series at Dchar el Oued, in the upper part of the watershed, are available from 1954 to 1988.

More data (rainfall and runoff) for the Oum er Rbia watershed are expected to be available, especially those using recent records. The acquisition of these additional data is in progress.

ANALYSING DATA TRENDS

An attempt has been made to examine whether the climate is actually changing throughout the study area and in the nearby Tensift watershed. This has been done by trend analysis of the available time series and the stations, as grouped in table 2.

Table 2. Details of precipitation stations.

Nº on Figure 1	Group	Station	Mean annual rainfall, mm	Record period	Number of years
1	1	Ouiouane	1,051.2	1961-1995	30
2	1	Khenifra	637.3	1961-1995	30
3	2	Kasba Tadla	431	1917-1984	40
4	2	Azilal	540.7	1918-1981	64
5	2	Demnate	570.5	1927-1981	49
6	2	My Youssef (dam)	433.8	1969-2001	32
7	3	Sidi Rahal	344.4	1970-2001	31
8	3	Marrakech	222.4	1970-2000	30
9	3	Tahanaoute	361.9	1970-2001	31
10	3	Lalla Takerkoust (dam)	261.3	1962-2001	39
11	3	Chichaoua	175.3	1965-2001	34

Stations and corresponding figures are categorized into three groups (table 2). Figures 3, 4 and 5 display the residuals (annual rainfall minus the long-term mean annual rainfall) together with the 5-year moving average for stations in the respective areas. The first group contains the stations located in the high altitude part of Oum er Rbia watershed (stations Ouiouane and Khenifra) with significantly higher annual rainfall than the others. The second group contains other stations located in the Oum er Rbia watershed (stations Kasba Tadla, Azilal, Demnate and Moulay Yousseff). They are characterized by higher rainfall than those located in the Tensift watershed and by a longer time series. The third group includes Sidi Rahal, Marrakech, Tahanaoute, Lalla Takerkoust and Chichaoua stations, which have the lowest annual rainfall and shortest time series. The annual precipitation in the three groups follows a decreasing gradient in a south-west direction.

Figure 3 displays the upper-Oum er Rbia precipitation stations, Ouiouane and Khenifra (Group 1). The mean annual rainfall volumes are high: 1,051mm for Ouiouane and 637 mm for Khenifra. Both records clearly reflect an extended drought period between 1980 and 1990. The rainfall seems to become closer to long-term mean at the end of this drought period. The most recent records, which are in the process of being acquired (after 1995), would shed more light on the stability of this trend. These stations depict the climatic variability in the mountainous part of the basin. They are effectively the main indicators of the change since the region relies on water resources generated in the Atlas Mountains. Climatic changes and extended meteorological droughts in this part of the watershed impact strongly on the water availability, generally, in Oum er Rbia, and, specifically, in the Tadla area as the dams are located here.

Figure 3: Annual rainfall residuals and moving average for stations in Group 1.

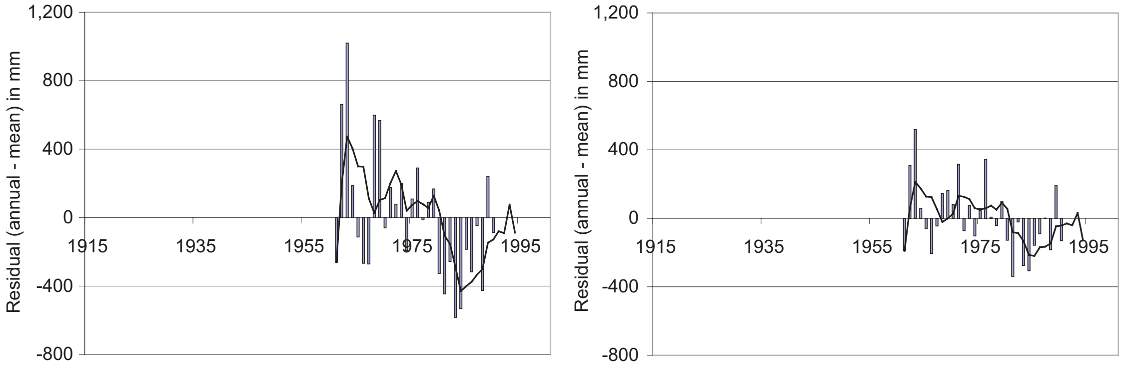


Figure 4 displays the rainfall records of the Oum er Rbia stations (Group 2). As regards the Kasba Tadla station, no obvious trends can be identified for want of records since 1984. The rainfall at Azilal and Demnate stations shows an alarming decreasing trend since 1973, although no records were available after 1981. For Moulay Yousseff station, the records are more recent but show no clear climatic trend, except for relatively consistent and frequent droughts (at least three pronounced multi-year droughts over 1975-2000, with the most recent one being after 1997).

Figure 4: Annual rainfall residuals and moving average for stations in Group 2.

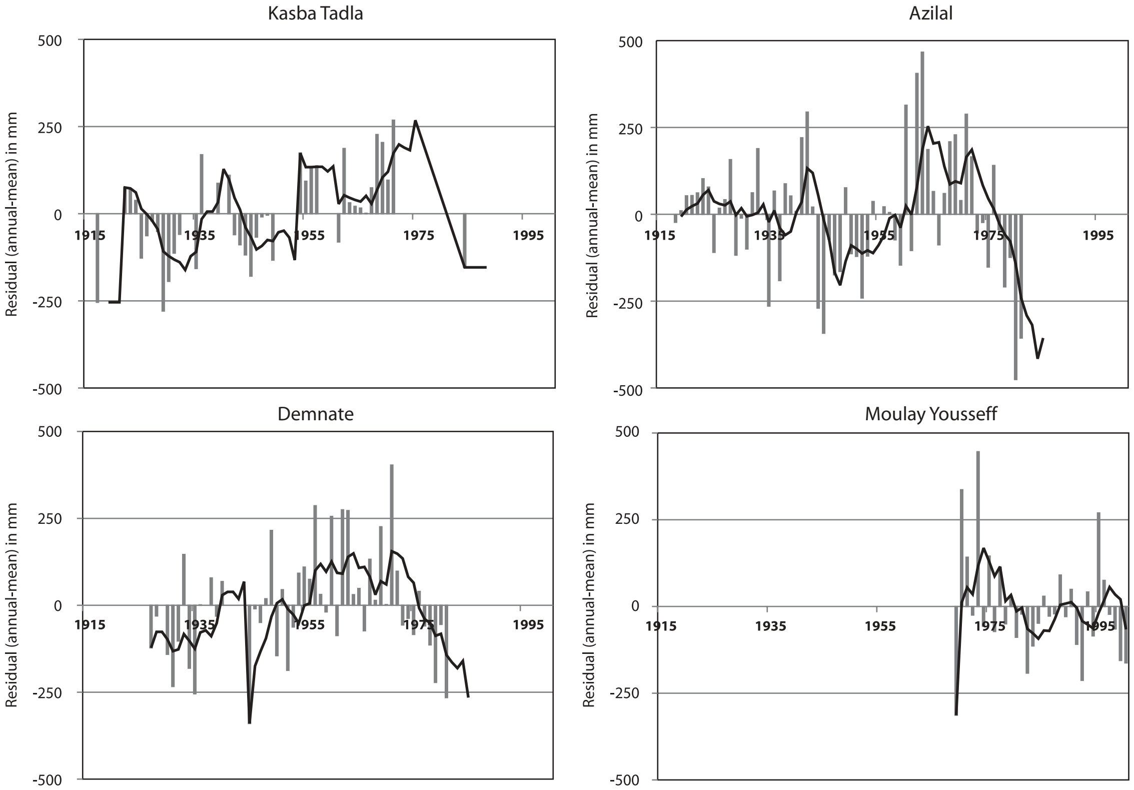


Figure 5 focuses on stations for the neighboring arid Tensift watershed. Rainfall amounts are much smaller than for those of Groups 1 and 2, and the records used are between 1970 and 2000. At all stations, except Tahanaoute, low rainfalls were recorded since 1998 pointing to the same drought period recorded at Moulay Yousseff station. However, no obvious trends in rainfall can be identified from the records available.

Precipitation has high variability, especially in a semi-arid climate. Generally, the records are either not from a long enough time series or do not include the most recent years to identify a clear climatic trend. Despite an alarming decrease in precipitation at some stations, it is premature to draw conclusions about how stable and geographically widespread any perceived trend is, and on that basis — whether it is actually a reflection of climatic change. The acquisition of all relevant data is currently in progress.

The only runoff data available at present are for Dchar El Oued (fig. 1). The record is from 1954 to 1988 with a mean annual discharge of 31.6 m^3/s. Figure 6 presents the residuals between annual runoff and a long-term mean annual runoff. The records from 1978-1988 show a major water deficit. Dchar El Oued is the outlet of the sub-watershed where stations Ouiouane and Khenifra are located The decrease of runoff is obviously related to the decreasing rainfall volumes observed during the same period at these two stations (fig. 3). However, additional factors like the changes in the use of upstream land may also contribute to the observed trends. As in the case of rainfall data, more recent flow data are being acquired to extend the period for trend analysis. The analysis of land-use evolution over the entire period would also facilitate better insight into the nature of flow variability in this basin.

Figure 5: Annual rainfall residuals and moving average for stations in Group 3.

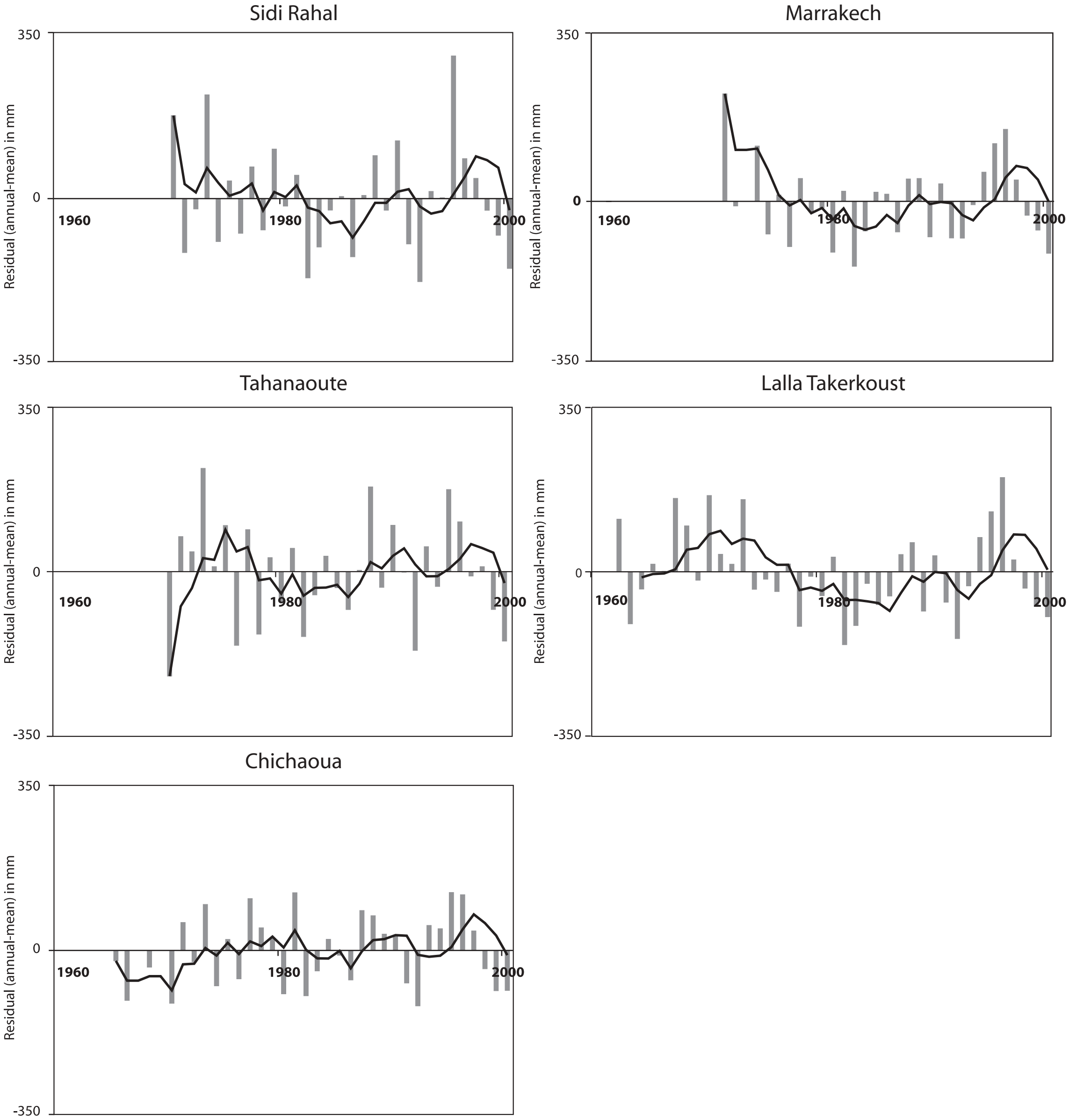
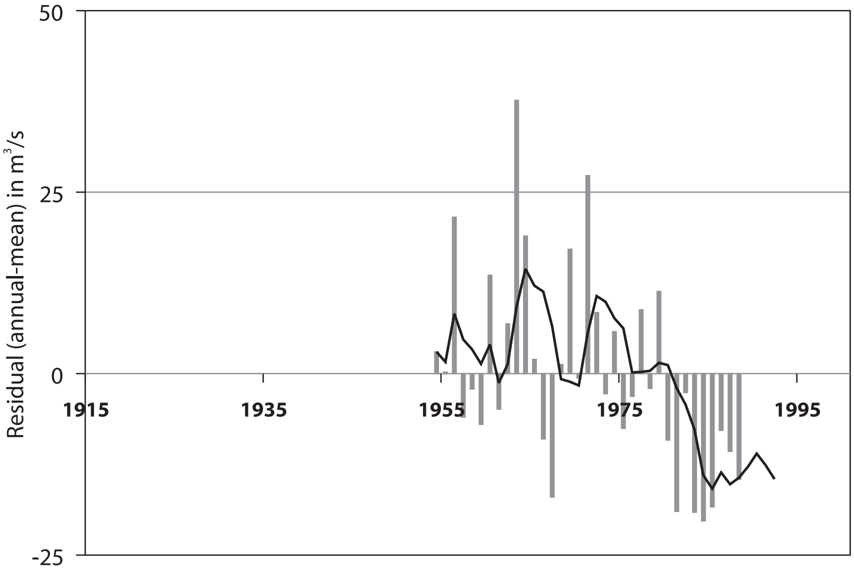


Figure 6: Annual runoff residuals and 5-year moving average at Dchar el Oued.



CONCLUSIONS

Several global-scale studies have concluded that the Mediterranean will be one of the most significantly affected regions by the future CC in terms of decrease in precipitation and increase in temperature leading, eventually, to decreasing availability of water resources. It is, therefore, necessary to focus on detailed CC impact studies in this region and other regions, which are predicted to be similarly affected. In Morocco, authorities are already concerned with possible impacts of CC on water resources, and, as such, have cancelled earlier plans to extend irrigated schemes, set water-quotas and scheduled the building of additional dams. At the same time, despite the initiation of such precautionary measures there actually is only a very limited quantitative understanding of CC impacts in the country.

Closely linked with the above is the issue of the scale of CC impact assessment studies. Overall, most of the CC studies to date have focused on global, regional or country-wide analysis of CC impacts. This masks the potential impacts of CC on the individual river basins (like Oum er Rbia) or irrigation schemes (like Tadla). The assessment of CC impacts at these scales constitutes the major niche for future research. Also, it is important to convert the general predictions/scenarios, which are normally expressed in increments or decrements to the means, into actual time series of water resources variables, such as streamflow. The flow time series reflecting the scenarios of possible future climatic change in individual river basins can be used to quantitatively assess the impacts of CC on water availability and, consequently, to formulate strategies to alleviate such impacts. The current study intends to look at CC impacts and potential solutions at such scales and, therefore, will attempt to start filling the present void.

The paper attempted to review the available climate data pertaining to the study area and present a preliminary analysis of rainfall data. Trends in rainfall data for 11 stations were examined. The trend at some stations indicated growing rainfall deficits, possibly related to CC, especially over the Atlas Mountains, which are the main source of water for the entire western region in Morocco. More recent data are necessary in order to make more reliable conclusions on the stability of trends and possibilities of their extrapolation into the near future. The acquisition of additional rainfall data for more meteorological stations from the Oum er Rbia Basin is currently in progress in collaboration with local partners including “Institut National de Recherche Agronomique”, the “Office Regional de Mise en Valeur du Tadla” and the “Agence du Bassin Hydraulique Oum er Rbia”. Also, some information on land-use evolution, particularly upstream of the Tadla area, will be collected in the near future. A combination of trend analysis of all rainfall records in the region with some CC estimates (e.g., Bennani et al. 2001) reviewed in this paper ought to facilitate the quantification of CC scenarios.

As mentioned in the “Introduction,” the goal of the study is to identify how CC will impact the water resources in the basin and, eventually, what management measures can be implemented at the basin/scheme level in order to administer these possible impacts. The scenarios built, may, for example, be used as input to the hydrological catchment-scale model, which will most likely be combined with a daily reservoir model and/or a water allocation model. The first will predict future inflows to two main reservoirs and, the second will examine the best options to develop and operate the water resources infrastructure in the basin under these new CC conditions. The hydrological simulations may be created using the Soil and Water Assessment Tool (SWAT) — a physically based distributed catchment model operating with a daily time step (Arnold and Allen 1996). SWAT uses the topography, land use/cover conditions, soil and meteorological time series as inputs, and simulates the water balance for each Hydrologic Response Unit (HRU). An HRU is a spatial calculation unit that consists of a combination of land use and soil type related to a groundwater system (users can consider up to two aquifers — shallow and deep) and to a single stream or subbasin (one stream per subbasin). A reservoir simulation model could then be used with different scenarios of inflow, to examine what feasible combinations of cropping pattern and water allocation can be satisfied in the future. A combination of these two models should form a good basis to examine how to optimize the future water use in the Tadla area. The development of this assessment methodology will form an integral part of future studies.

LITERATURE CITED

Agoumi, A. 2003. “Vulnerability of North African Countries to Climatic Changes: Adaptation and Implementation Strategies for Climate Change.” *Climate change Knowledge Network, http://www.cckn.net/compendium/north_africa.asp*

Arnell, N.W. 1999. “Climate change and global water resources.” *Global Environmental Change* 9: S31-S49.

Arnold, J.G.; Allen, P.M. 1996. “Estimating hydrological budgets for three Illinois watersheds.” *Journal of hydrology* 176: 57-77.

Bellouti, A.; Cherkaoui, F.; Benhida, M.; Debbarh A.; Brahim Soudi, B.; Badraoui, M. 2002. “Mise en place d’un système de suivi et de surveillance de la qualité des eaux souterraines et des sols dans le périmètre irrigué du Tadla, au Maroc.” *Actes de l’atelier “Vers une maitrise des impacts environementaux de l’irrigation*.” 28-29 Mai, Montpellier, France.

Bennani, A.; Buret, J.; Senhaji, F. 2001. “Communication Nationale Initiale a la Convention Cadre des Nations Unies sur les changements climatiques” *Ministere de l’Amenagement du Territoire, de l’Urbanisme de l’Habitat et de l’Environnement.* pp.101.

Cubasch, U.; Dai, X.; Ding, Y.; Griggs, D.J.; Hewitson, B.; Houghton, J.T.; Isaksen, I.; Karl, T.; McFarland, M.; Meleshko, V.P.; Mitchell, J.F.B.; Noguer, M.; Nyenzi, B.S.; Oppenheimer, M.; Penner, J.E.; Pollonais, S.; Stocker, T.; Trenberth, T.E. 2001. “Technical Summary.” *Report by Working Group I of the IPCC.* pp.63.

Debbarh, A.; Badraoui, M. 2002. “Irrigation et environnement au Maroc: situation actuelle et perspectives” *Actes de l’atelier “Vers une maitrise des impacts environementaux de l’irrigation.”* 28-29 Mai, Montpellier, France.

El Ghissassi, A. 2005. “Moroccan National Committee reviews the press: Favorable to dams!” *The Dams Newsletter, No.4.* . Paris, France : ICOLD-CIGB.

El Jihad, M.D. 2003. “Les secheresses saisonnieres dans le haut basin de l’Oum-er-Rbia (Maroc Central): aspects et frequences.” *Secheresse* 14 (3): 157-167.

Fowler, A. 1999. “Potential climate change impacts on water resources in the Auckland region (New Zealand).” *Climate Research* 11: 221-245.

Goodess, C.; Palutikof, J.; Agnew, M. 2000. “Climate Change Scenario for the Mediterranean: A Basis for Regional Impact Assessment.” *International Workshop “Climate Change and Mediterranean Coastal Systems: Regional Scenarios and Vulnerability Assessment” Venice, December 9-10, 1999.*

Guo, S.; Chen, H.; Zhang, H.; Xiong, L.; Liu, P.; Pang, B.; Wang, G.; Wang, Y. 2005. “A Semi-Distributed Monthly Water Balance Model and its Application in a Climate Change Impact Study in the Middle and Lower Yellow River Basin.” *International Water Resources Association* 30 (2): 250-260.

Hammani A.; Kuper, M.; Debbarh, A.; Bouarfa, S.; Badraoui, M.; Bellouti, A. 2004. “Evolution de l’exploitation des eaux souterraines dans le perimetre irrigue du Tadla” *Actes du Seminaire “Modernisation de l’Agriculture Irriguee,” Rabat, Maroc, 19-23 Avril 2004.*

Hitz, S.; Smith, J. 2004. “Estimating global impacts from climate change.” *Global Environmental Change* 14: 201-218.

Hulme, M.; Wigley, T.; Barrow, E.; Raper, S.; Centella, A.; Smith, S.; Chipanshi, A. 2000. “*Using a Climate Scenario Generator for Vulnerability and Adaptation Assessment.*” MAGICC and SCENGEN Version 2.4 Workbook, Norwich, U.K.: Climate Research Unit. pp. 52.

Knippertz, P; Christoph, M.; Speth, P. 2003. "Long-term precipitation variability in Morocco and the link to the large-scale circulation in recent and future climates" *Meteorology and Atmospheric Physics* 83: 67-88.

Labat, D.; Godderis, Y.; Probst, J.P.; Guyot, J.L. 2004. "Evidence for global runoff increase related to climate warming." *Advances in Water Resources* 27 (6): 631-642.

Labat, D.; Godderis, Y.; Probst, J.P.; Guyot, J.L. 2005. "Reply to comments of Legates et al." *Advances in Water Resources* 28 (12): 1316-1319.

Legates, D.R.; Lins, H.F.; McCabe, G.J. 2005. "Comments on "Evidence of global runoff increase related to climate warming" by Labat et al." *Advances in Water Resources* 28 (12): 1310-1315.

Miller, N.L.; Bashford, K.E.; Strem, E. 2003. "Potential Impacts of Climate Change on California Hydrology." *Journal of the American Water Resources Association* 39 (4): 771-784.

Ministere de l'Environnement du Maroc. 1994. "Resume et Conclusions de la Communication Nationale initiale". pp.14.

Petitguyot, T.; Rieu, T. 2004. "Dam's releases as a tool to improve conjunctive use of groundwater and surface supplies: Application to the Tadla irrigated Scheme in Morocco" *Proceedings of the International seminar on Water Resources Management for local development: Governance institutions and Policies.* November 8-10, 2004, Aventura Loskopdam, South Africa.

Priestley, C. H. B.; Taylor, R. J. 1972. "On the Assessment of Surface Heat Flux and Evaporation Using Large Scale Parameters." *Monthly Weather Reviews* 100 (2): 81-92.

Ragab, R.; Prudhomme, C. 2002. "Climate Change and Water Resources Management in Arid and Semi-Arid Regions: Prospective and Challenges for the 21st Century." *Biosystems Engineering* 81 (1): 3-34.

Vose, R. S.; Richard, L.; Schmoyer, P. M.; Steurer, T. C.; Peterson, R. H.; Thomas R. K.;, Eischeid, J. 1992. "*The Global Historical Climatology Network: Long-term monthly temperature, precipitation, sea level pressure, and station pressure data.*" ORNL/CDIAC-53, NDP-041. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Xu, C.Y. 2000. "Modelling the Effects of Climate Change on Water Resources in Central Sweden." *Water Resources Management* 14: 177-189.

Xu, C.Y.; Singh, V.P. 2004. "Review on Regional Water Resources Assessment Models under Stationary and Changing Climate." *Water Resources Management* 18: 591-612.

Postal Address
P O Box 2075
Colombo
Sri Lanka

Location
127, Sunil Mawatha
Pelawatta
Battaramulla
Sri Lanka

Telephone
+94-11 2787404

Fax
+94-11 2786854

E-mail
iwmi@cgiar.org

Website
http://www.iwmi.org

IWMI
International
Water Management
Institute

FUTURE HARVEST
IWMI is a Future Harvest Center
supported by the CGIAR

ISBN: 92-9090-635-9
ISBN: 978-92-9090-635-3