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Developing an Oasis-Based Water Management Tool: Ecohydrologic Approach and Weap Software for a Large Arid Catchment in Morocco

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Abstract: This study is concerned with the management of water resources and development of Water Evaluation and Planning System (WEAP) model and Ecohydrologic approach for the Ziz catchment in South-east of Morocco. The catchment relies heavily on oasis irrigation in three different geographical units. These include firstly, the High Atlas Mountains, secondly, the basin of Errachidia above the Hassan Dakhil Dam (HDD) reservoir and thirdly the ancient date palmeries of Tafilalet below the reservoir. In 1970 the dam was put in to operation for flood protection. The WEAP model and its application to the Ziz basin are presented in this paper. This model allows the simulation and analysis of various water allocation scenarios and, above all, scenarios of users' behavior. There are many evidences concerning degradation, pollution and overexploitation of water resources, resulting from inappropriate groundwater management systems based on the administrative division. But it is possible to achieve sustainability in groundwater use by integration of hydrological and ecological approaches. The Ecohydrological method grounded on profound understanding of the complexity of ecosystem processes on various scale, provide new chances for protection of groundwater resources against traditional, exclusively technological oriented methods.

Key words: Climate change · Oases · Ecohydrology · Tafilalet · WEAP

INTRODUCTION

Water resources management is one of the most important challenges the world faces. It is difficult to think of a resource more essential to the health of human communities or their economies than water. Since 1970s, Morocco has experienced a general rainfall decline. The Ziz-Gheris catchment is typical of a gradient from humid/sub-humid subtropical mountains to their arid foothills and finishing in the sandy desert (Sahara). In this paper we present outlines the rationale for a new approach to integrated water resource management from the local field scale to the watershed and basin scale, which incorporates the balancing of green and blue water flows in agriculture with freshwater to sustain ecosystems and downstream human use of water. It 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 Ziz-Rheris basin. Climate Change (CC) is important to water planners and managers because it may change underlying water management conditions [1,2] and increase the need for new water management programs and capital investments. This study is an example for application of water management model by WEAP (water evaluation and planning system), for Tafilalet region (south-east of Morocco) as an Integrated Water Resources Management (IWRM).

Why a Local Study?

Studies have shown that it is important to include the effect s of climate change in local water planning [3-4], seeking to link present-day planning decisions to uncertain future climate projections, for example, performed a qualitative sensitivity analysis that showed that water-planning decisions were sensitive to uncertainty in the range of global climate model simulations for t he Sacramento basin in California. More recently, researchers have used integrated water resource planning models to evaluate the impact of climate perturbations on the performance of current water management systems [5-7].

The Environment of the Ziz Valley

Regional Setting: The Tafilalet Oasis is located in the Sahara SE Morocco (Figure 1), with an area of about 1370 km^2, is part of UNESCO Biosphere Reserve. It comprises a series of oases and the reservoir of one of

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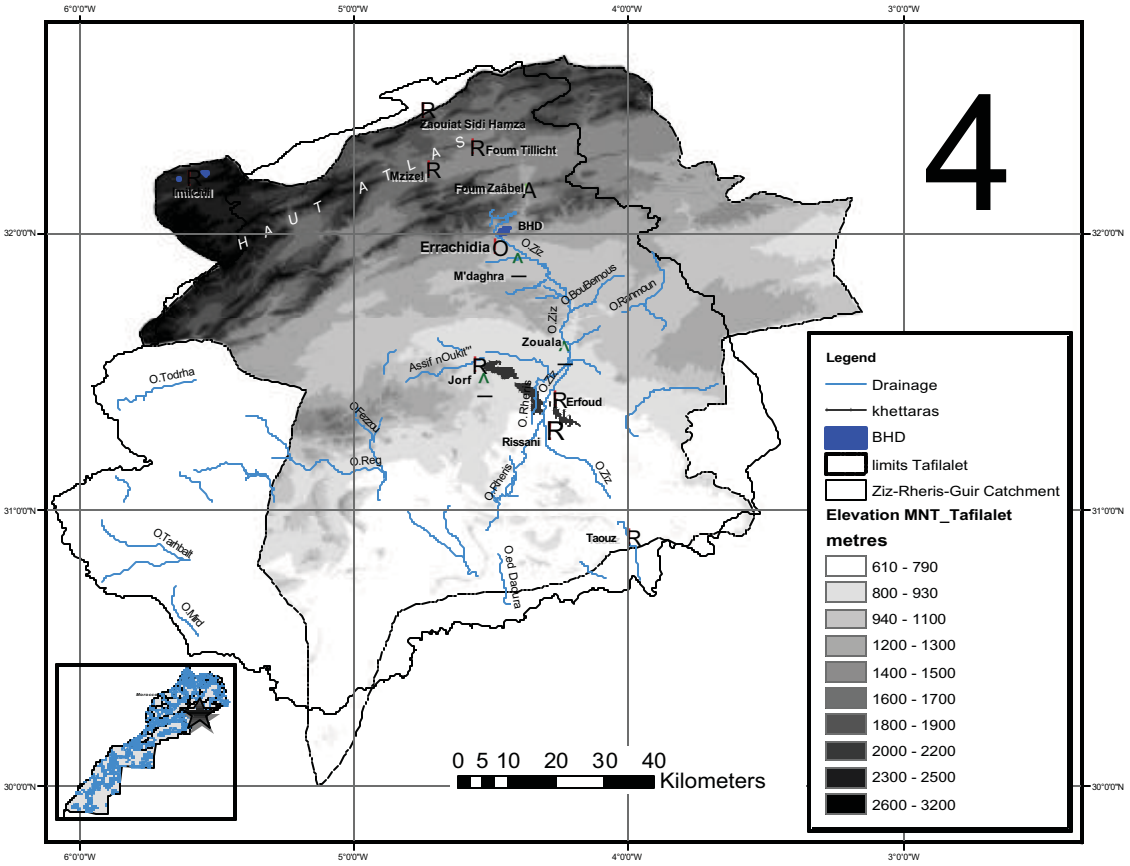

Fig. 1: Tafilalet region (in Morocco, east of the High Atlas Mountains)

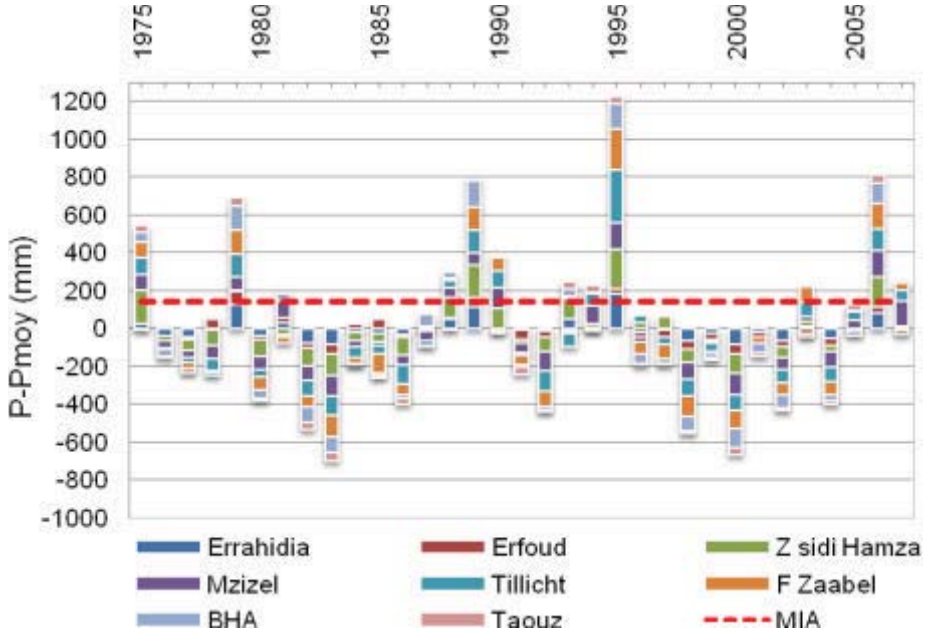

Fig. 2: Annual rainfall residuals and average for weather stations [9]

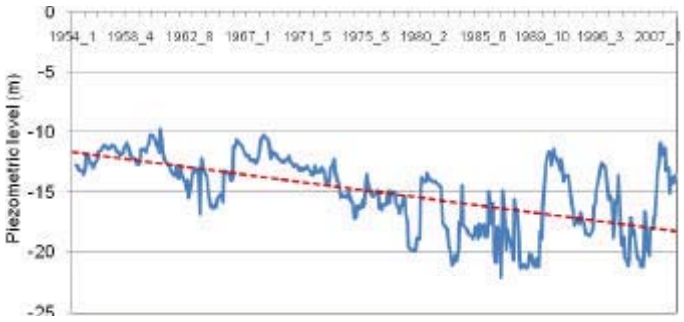

Fig. 3: Piezometric level variation of aquifers (Fezna-Jorf) in the Tafilalet area. [9].

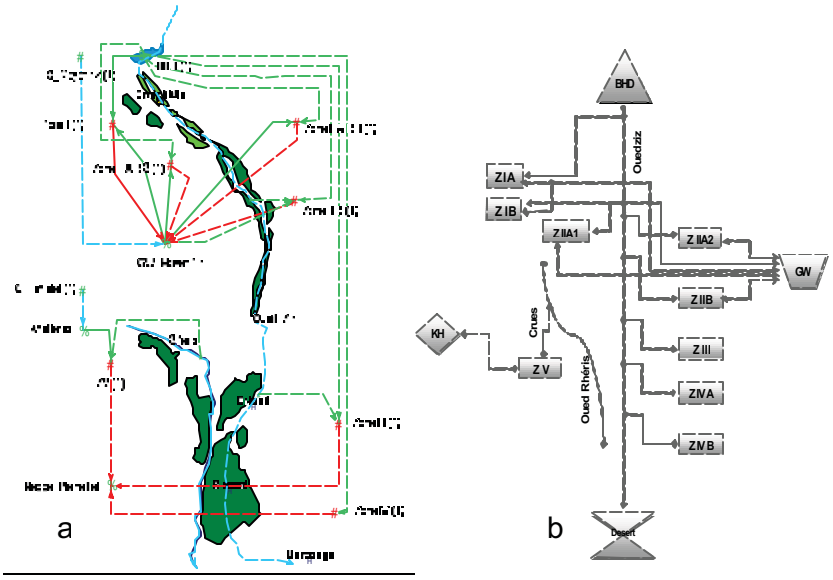

Fig. 4: a) WEAP conceptual Model for water management and irrigated area in Tafilalet, b) Water distribution in main parts of the Z iz oasis
BHD: Barrage Hassan Addakhil; KH: Khettaras; Z: Zone, GW: Groundwater

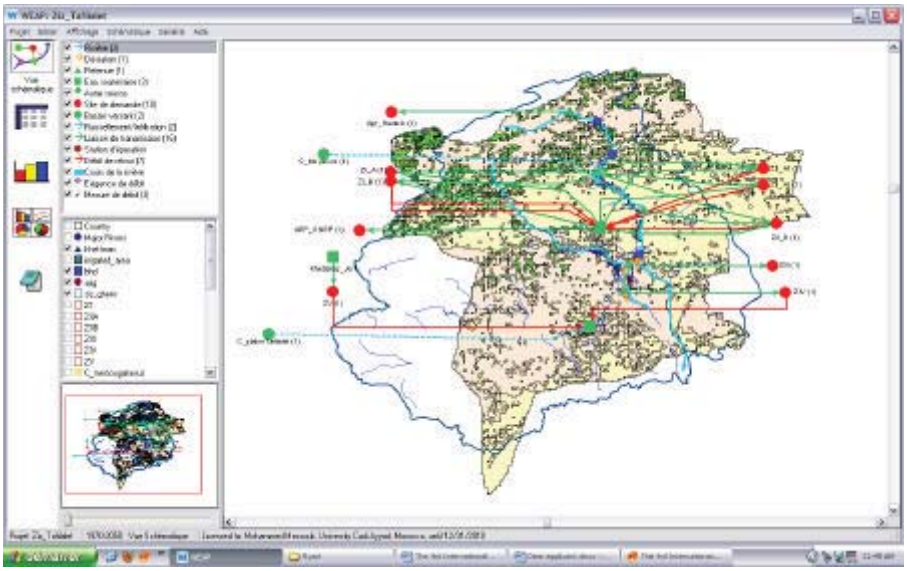

Fig. 5: Schematic view of the WEAP model for Tafilalet region and Ziz-Gheris basin

the oldest dams in Morocco (Hassan Dakhil). The climate is continental and arid. The annual rainfall varies from 70 mm in the extreme south, at Erfoud, to 290 mm in the extreme north, at Imilchil, temperatures vary from -5°C to 40°C, with an annual average daytime high of 20°C. Quantifying interannual to multi-decadal precipitation variability has a multitude of application in water related research and planning.

The subtropical climates of northwest Africa including Tafilalet region are characterized by a considerable year-to-year and decadal precipitation variability (Figure 2). It is crucial to have a physical understanding of the processes governing climate variations and recent historical climate change in order to assess regional climate projections.

Population: According to the 2004 census, the population of Errachidia province is 554350, 42 percent urban and 58 percent rural. Population density is 10,8-22,4 per cultivated hectare, 5,1 per uncultivated hectare and 2 per square kilometer for the rest of the province. Sixty percent of the province's population is engaged in full and part-time farming; the rest is involved in construction, government, commerce, national and international migration and services [8].

These climatic conditions preclude the practice of rainfed agriculture and necessitate the use of irrigation. Oasis soils are loamy to silt-clay, regenerating from alluvial deposits caused by river floods used for irrigation during the past centuries. The date palm is the basis of life and agricultural activity in the district. Cultivated land is generally located along river banks, in narrow strips in the mountains area and in larger tracts in the oases. The main cultivated crop species are: date palm, olive and apple trees (mountainous), cereals, alfalfa, vegetables and henna. Three agro-ecological zones can be distinguished each one is characterized by a particular production system:

- Mountain zone: irrigation derives from perennial waters mobilized using diversion dams. Livestock grazing area, alfalfa, cereals, potato are the main crops cultivated in a two-level crop system in association with olive and rosaceous fruit species.
- Intermediate zone: In the hills and valleys at the foot of mountains, it is characterized by an intensive three-level cropping system with date palms as the upper level, olive trees as intermediate one and cereals, forages, legumes and vegetables as the lower level. River floods and springs are used in irrigation.
- Plain zone: Water for irrigation comes from river floods, pumping, khettaras, perennial streams and springs and Hassan dakhil dam. A two-level cropping system is dominant with date palm trees and underneath cereals, alfalfa and vegetable crops. Animal husbandry is dominated by D'man sheep raised for both milk and meat production.

Land tenure is characterized by small holders (micro-farms). Average farm size is almost 1 ha divided in 3 plots. 90% of the farmers own less than 5 ha. Private ownership represents 95% of land tenure. The remaining 5% belongs to the religious holdings, Habous [10].

Agriculture: Agricultural resources are concentrated mainly in cereal cultivation, arboriculture and livestock. The area available for the practice of farming is 43069 hectares and the potential area covers 48,069 hectares making up 45000 farming household units. On the provincial level, the farming system is partitioned as follows: cereals occupying 70 percent of the farming area (1984-1994) and 54 % (1990-2001), alfalfa 17 percent, vegetable gardens 4 percent and henna and cumin 1 percent. Arboriculture, mainly dates and olives, plays a crucial role in the economic development and ecological survival of the area accounting for 60 percent of household income. Livestock is the third important economic aspect of the valley's agriculture, with an average of 5 to 6 head of sheep per household [11]. In summary, the potential productivity of the region is restricted by climatic conditions affecting the resilience of the valley's irrigated farming. Water scarcity and its erratic variability over time and space, recurrent droughts and frequent locust invasions have contributed to the impoverishment of the valley's environment. The bayoud *Fusarium oxyisporum* disease ravaging the date palm trees and the annual alternating olive production combine to reduce household welfare. All these factors have, in one way or another impeded the optimization of the agricultural resources.

Irrigation and Water Management: Until the early seventies, irrigation was practiced in Tafilalet oasis along the Ziz River (Figure 4 and 5) using traditional systems such as seguias and khettaras. The water scarcity caused by the climate change has constrained farmers to adopt new means to mobilize water for irrigation. Wells were then sinked and equipped with pumping stations for both individual and collective use. In the prefecture of Tafilalet there are more than 600 private wells, 60 common pumping

stations among which 40 are managed by cooperatives and 570 khettaras. The technology of pumping stations is relatively new for farmers in this region.

Groundwater in Tafilalet: In the Tafilalet, groundwater is estimated at 200 Mm3 including 120 Mm3 mobilized annually from moderately deep water. They are exploited by means of pumping stations, wells and Khettaras. From a hydrological viewpoint, there are four levels of surface aquifers to medium deep: The system of groundwater basins Quaternary which is closely related sub-flows and ground limestone of Turonian, constituting the main aquifer, the intermediate layers composed of Cenomanian horizons of continental waters and red sandstone and deep layers of the Infra-Cenomanian of Ain El Atti.Groundwater is the only perennial water resources for the people of the region Tafilalet especially during low water. Thus, in response to climate change that knows the area; wet periods are increasingly rare in the region. Thus, the volumes of water extracts of water are on permanent increase that translates into a lower level of the ground (Figure.3), which may influence the water quality of the water by the concentration of chemical elements following the increase the rate of evaporation.

Climate Change in the Southern Atlas Mountains: The development of climate scenarios for Morocco according to IPCC methodology reveals a trend towards an increase in average annual temperature (between 0.6°C and 1.1°C) as well as a trend towards a decrease in average annual rainfall volume by about 4% in 2020 compared to 2000 levels [12].

In the Maghreb, recent developments show that climate warming is more important than average. Indeed, if global temperature rise to 20 century was 0.74°C, that the Maghreb was between 1.5 and 2°C depending on the region, more than double the global average rise. As for the decline in rainfall, it varies between 10 and 20%. [13].

MATERIALS AND METHODS

Data Availability: This work is based on an extensive source of data base of ecological, meteorological, hydrological, hydrogeological, sedimentological, water management, GIS and remote sensing, vegetation, social, cultural and economic (Table 1) [14-16].

Approach: WEAP's approach is to build a straightforward and flexible tool to assist, but not substitute for, the user of the model. WEAP represents a new generation of water planning software that utilizes the powerful capability of today's personal computers to give water professionals everywhere access to appropriate tools.

Water Evaluation and Planning System (Weap): Because of evapotranspiration not all water in the catchments will runoff to the rivers. WEAP uses the rainfall runoff method (FAO) to calculate the ratio between demand of the crops and the runoff to the river. The Rainfall Runoff Method uses crop coefficients to calculate the potential evapotranspiration in the catchment, then determines any irrigation demand that may be required to fulfill that portion of the evapotranspiration requirement that rainfall cannot meet. The remainder of rainfall not consumed by evapotranspiration is simulated as runoff to a river, or can be proportioned among runoff to a river and flow to groundwater via catchment links [17].

Weap Ziz Basin Model (Tafilalet): The Upper Ziz hydrology was represented by the model WEAP (Water Evaluation and Planning System) (Figure 4). The model has been adapted, calibrated and validated for the Ziz Basin in the framework of the MIOS (Modèle Intégré des Oasis du Sud) and permits the analysis of different hydrological parameters in different climate and policy scenarios. With WEAP, first Current Account of the water system under study is created. Then, based on a variety

Table 1: Details of climatic stations. (Data availability; [9]

Station	Lat	Long	Alt(m)	Mean annual rainfall,(mm)	Record period	Number of years
Z. sidi -Hamza	32.43	-4.72	1738	258,13	1970 - 2008	38
M'zizel	32.23	-4.72	1600	176,74	1970 - 2008	38
Tillicht	32.31	-4.55	1627	191,50	1975 - 2008	33
F. Zaâbel	32.16	-4.36	1253	179,0	1970 - 2008	38
BHA	32.00	-4.45	1158	119,8	1973 - 2008	36
Errachidia	31.95	-4.4	1036	119,0	1957 - 2008	51
Radier- Erfoud	31.43	-4.23	800	61,91	1957 - 2008	51
Taouz	30.91	-3.98	676	44,73	1970 - 2008	38

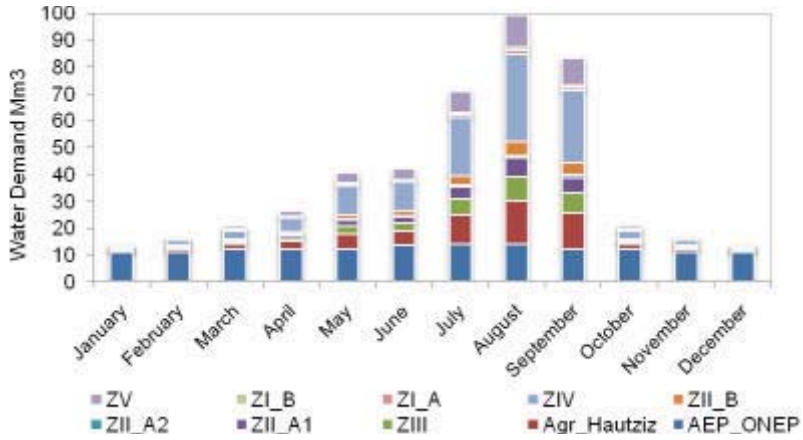

Fig. 6: Average monthly water demand of irrigated area in million m^3

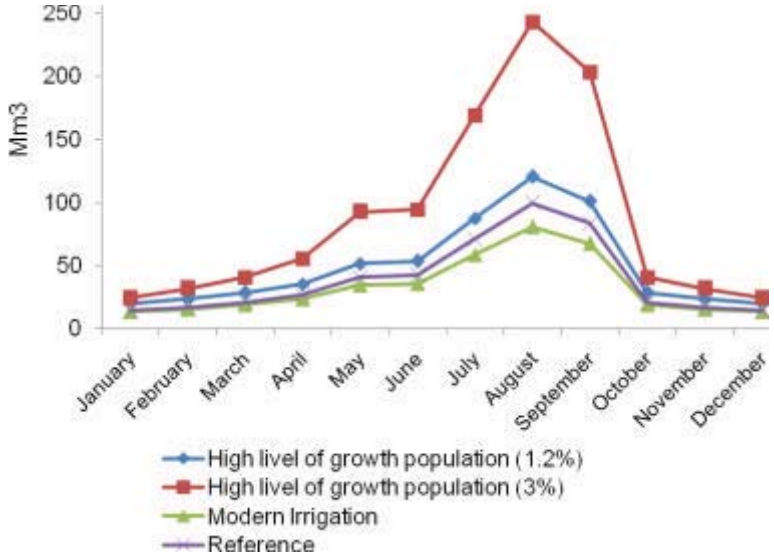

Fig. 7: Water demand scenarios of irrigated area in Tafilalet (1970-2050)

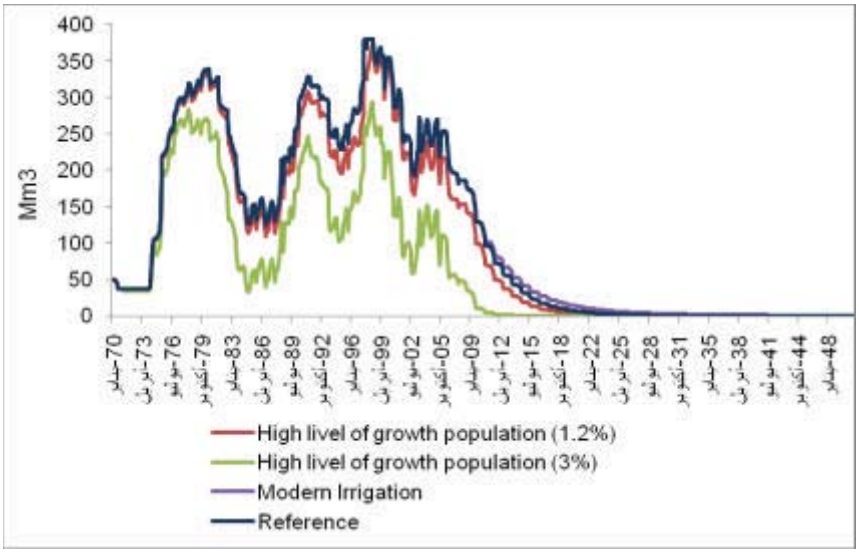

Fig. 8: Reservoir Storage Volume scenario 1970-2050

of demographic, hydrological and technological trends a "reference" scenario projection is established, referred to as a Reference Scenario. Then one or more policy scenarios are developed with alternative assumptions about future developments. Only the major water users were described for each major user, the activity level, the annual water demand (net values after accounting for losses), the monthly variation as well as a return flow.

Creating Reference Scenarios for a Period from 1970-2050: Water sustainability assessment requires a scenario approach for taking a long wide view that considers futures with fundamentally different development and environmental assumptions and policies. Using integrated water management scenarios, diverse stakeholders can engage in informed dialogues around balancing trade-offs and devising appropriate actions.

Reference Scenario (1970-2008): The reference scenario is the base scenario that uses the actual data, to help in understanding the best estimates about the studied period. The objective of a reference scenario is to help planner and water resource manager to understand what likely could occur if current trend continue and to understand the real situation. Reference scenarios can also be useful for identifying where knowledge is weak in analyzing likely trends and where more information needs to be collected.

High Level of Growth Population Scenario (1970-2050): Analyzing the living conditions of the population in relation to the use of water and land in the catchment area of the Ziz river the population dynamics is an important indicator for social change. In order to meet the complexity of demographic processes, quantitative-statistical data and qualitative social-scientific data were collected and evaluated on different spatial levels from regional to local. For scenario analysis and the projected inclusion into information or decision support systems, the findings are integrated and analyzed with the aid of WEAP model.

Two Scenarios of High Level of Growth Population Were Used in this Study: Scenario A: Growth rates between 1993 and 2030 were as follows: domestic 1.12-1.2 %, livestock 1.2 % and irrigation 1.2% [18].

Scenario B: proposed Scenario of High level of growth population and climate change scenario 2050 were: domestic, livestock and irrigation 3%.

RESULTS AND DISCUSSION

One of the strong components of WEAP is the way results can be presented and combined in graphs, tables or maps. Many options exist to aggregate data in time, space or per hydrological component. Moreover different scenarios can be compared easily. Additionally, data can be exported to Excel for further analysis. The most important features to display output will be presented in this chapter. Focus will be on results for the Reference scenario the comparison with the other scenarios.

Population Growth Scenario for Water Demand: The result show the effect of increased population growth on the water demand, the effect is much more visible on the population, unlike the water demand and unmet demand for Sits demand purpose, evident to say that the city water usage, irrigation, water demand and unmet water demand percentage increase, demand is higher in summer the months (Figure 7).

The downstream reservoir Hassan Dakhil situated near Errachidia, the regional capital, is strongly dependant on water input from the mountain catchments. Over the past few years, there have been large fluctuations in water input into the reservoir and its minimum capacity is often no longer reached. Apart from being negatively affected by several years of water shortage, the Hassan Dakhil dam has been also subject to substantial infill by sediments and consequently rapid capacity loss. (Figure 8)

DISCUSSION

In the geographically, politically and economically peripheral region of the Ziz catchment, water allocation functions according to a complex system of inherited water rights using communally built, managed and defended irrigation channels. Although the exact characteristic of the local irrigation methods and the relationship between water users varies, similar systems exist in the High Atlas Mountains as well as in the Errachidia basin and in the Tafilalet valley south of the Hassan Dakhil dam. In the wetter mountainous areas the water availability is generally better but shows a higher regional variability than in the ziz valley. Here the lack of water from the dam caused an almost complete abandonment of the old system. Local farmers increasingly reacted to periods of water scarcity through the building of wells operated by motor pumps, thus individually exploiting scarce subterranean aquifers.

Research also showed that, even if water from the river Ziz is less easily available and materially important, its "ownership" as laid down in the "traditional" irrigation system, remains an important category of symbolic prestige throughout the villages.

The irrigation system is not only governed by social relationships, but rather subject to intracommunity relationships designed to disguise the extortion of collective labor, especially when the level of technology and resource management techniques are simple, yet demand communal participation.

Following increased water scarcity, the region witnessed massive out-migration of large parts of its population during the past decades, resulting in monetarisation processes and a decrease in importance of agricultural production. Parallel to the observed rural out-migration were processes of urbanization. Beneficiaries were not only the large coastal cities, but also local centers like the provincial capitals of Errachidia and Erfoud and medium-sized towns like Erich.

The valley's growth is placing too many latrine systems too close to too many wells. The septic waste are seeping into drinking-water wells on the nearly every Kasbah, high levels of nitrates are showing up in water wells and most of sampled wells had bacteria contamination from septic wastes.

Although tourism is an expanding industry in southern Morocco, the influence on the local labor marked is rather small. Major beneficiaries are international tourist enterprises who run hotels and travel agencies in the urban centers. Moroccan entrepreneurs only benefit in some tourist hot spots. As water is a highly fragile resource, tourism, especially the big luxurious hotels recently constructed in the south, can increase the ecological problems.

Farming in the Ziz Valley oasis area is based on traditional, intensified, polyculture systems (date palm, fruit trees, olive, alfalfa, cereals and vegetables) developed in response to high population density and limited irrigation. Alfalfa is the main forage used to feed sheep, which are a principal component in the farm economy. Alfalfa is used as green forage in warm months and as dry forage in winter. In winter, alfalfa is generally insufficient for animal feeding, so off-farm feed is often purchased at great expense. Though low forage production is related to environmental factors (drought, salinity and high temperature) and the low diversity of forage crops, alfalfa is the main forage used for several centuries and is adapted to local environmental factors that other forage species can't tolerate. In general, women are in charge of forage production on farms, but they are not usually involved in research and development or even in forage and animal feeding technology transfer. Irrigation, managed mostly by men, is also a key limiting factor, as is groundwater salinity, which limits irrigation frequency.

To improve forage production in the oasis area of the Ziz Valley, the participation of man and women in development must be institutionalized according to task and responsibility by gender. Women's participation is especially needed to conserve alfalfa landraces in the oasis agroecosystem using their traditional knowledge and in the sharing of improved methods. Better use of water resources is more a concern of men, who are responsible for irrigation. To increase forage production, some farmers are adopting improved varieties that are not adapted to local environments, requiring more water and exposing local landraces to genetic erosion. On-farm conservation of landraces is essential to prevent unsustainable water use and loss of biodiversity.

Soil and Land Management: Climate change adaptation for agricultural cropping systems requires a higher resilience against both excess of water (due to high intensity rainfall) and lack of water (due to extended drought periods). A key element to respond to both problems is soil organic matter, which improves and stabilizes the soil structure so that the soils can absorb higher amounts of water without causing surface run off, which could result in soil erosion and, further downstream, in flooding. Soil organic matter also improves the water absorption capacity of the soil for during extended drought.

Soil erosion by water is a severe problem in the Ziz Basin region. This is indicated by the analysis of the sedimentation of the reservoir Hassan Dakhil, located in the centre of the catchment. If the rapid infill of dam due to high sediment transport rates in rivers continues at the present rate the dam will no longer be fully functional for irrigation as soon as the year 2030. Even now, the dam capacity is insufficient to meet the needs of the downstream consumers during drought and water-shortage conditions. Once the dam reaches a critical silted level (at about half its capacity), it will lose its regulatory flow. Irrigation will be increasingly subject to irregular, flood-dominated flows and will rely more heavily on groundwater resources. As a result the evaporation will show a decrease for the climate scenarios. In future, the extensive spread of oasis areas at the outlet of the mountain areas has to be controlled, since extensive withdrawal of water in these higher regions can strongly influence the water remaining for irrigation from the dam.

Applying Ecohydrology: Ecohydrology is more than just hydrology and ecology combined. It is functional to its best only, if science, engineering and construction, public administration and political decision assist each other in an integrated scheme and on a common scale. The Biosphere Reserve "Tafilalet Oasis", in south of Morocco, is dependent on all four aspects for its sustained existence.

The results of the first phase of the work implementation show the potential for the application of ecohydrology and phytotechnology measures in the Ziz basin, which has attracted the interest of local and regional authorities. The integrated approach to Ziz catchment and river-reservoir management has to address several aspects. Spatial planning and land-use regulations. Improving the quality of water requires several parallel actions, including wastewater technology for sewage treatment and ecohydrological methods. Hydraulic modeling will enhance sedimentation in controlled areas in the river mouth. The removal of sediments, which can be used for fertilizer by local farmers, will reduce internal nutrient loading. Particular attention will be given to increasing environmental awareness of local communities. This will result in the revision of traditional aquaculture technologies, reduction of environmental degradation (e.g., ecotone vegetation zone degradation,) and provision of economic opportunities (e.g., new farming opportunities). On the basis of ecohydrology, a simplified model of sustainable groundwater management can be established.

CONCLUSIONS

Population Growth: Clearly, population growth is important factor influencing domestic water demand in the Ziz valley. It is also the most difficult to predict and control. Migration to the region is influenced by a host of factors including economic conditions, housing prices, transportation corridors, quality of life, etc., some of which can be controlled by governments and some of which cannot. This implies that sufficient flexibility must be built in to the water management system in order to accommodate unexpected changes in service populations.

Climate Change: As with population growth, climate change had a relatively important influence on scenarios01 of future residential water demand. The significance of climate change is in the water management planning horizon. Depending on the population growth scenario, annual water demands predicted without climate change may occur in excess of a decade earlier when climate change scenarios are factored in.

In the biosphere reserve in southern Morocco, water is at the top of the local population's preoccupations. However, we are in a context minimal involvement of these people that face the challenges of climate change and water management.

The knowledge related to water and the impact of the CC should be conveyed to the widest possible audience in order to a have a change in behaviors leading to a reduction of waste or abuse of water in order to reduce the impacts of climate change on this resource.

Faced with this situation, it seemed essential to implement the efforts undertaken by local projects through a communication action. This will give the general public (women, homes, schools ...) and local decision makers (elected officials and managers) to understand some key issues and trigger their willingness to participate in this effort to mitigate the effects of climate change in the biosphere reserve.

The establishment of pilot adaptation projects in collaboration with the people. These pilot projects will focus on sectors greatly affected by climate change (water resources, water erosion, pastoralism, agricultural production and soil fertility) and will "identify the level of past and current relations between communities and the environment in order to assess and possibly adjust the speed at which a strategy for adapting to climate can be established in these communities, "

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