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IMPACT OF DROUGHTS AND IRRIGATION TECHNIQUE ON WATER RESOURCES IN THE LOWER VALLEY OF THE TARKA, NIGER

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Niger is one the most arid countries in Africa; Niger currently faces an imbalance between water demand and availability, primarily due to natural water scarcity as well as uneven water distribution. Rapid population and irrigation growth, among other economic and social factors, are likely to worsen the situation. The lower valley of the Tarka (Basse Vallée de la Tarka or BVT), the subject of this study, is an area suitable for irrigated farming with accessibility to groundwater and quality soils. Using WEAP (the Water Evaluation And Planning) model to establish different scenarios, we demonstrated that the BVT has good potential to improve the local population well-being.

INTRODUCTION

Water is essential for all socioeconomic development and for maintaining healthy ecosystems. As population increases and development calls for increased allocations of groundwater and surface water for the domestic, agriculture and industrial sectors, the pressure on water resources intensifies, leading to tensions, conflicts among users, and excessive pressure on the environment. The increasing stress on freshwater resources brought about by ever-rising demand and profligate use, as well as by growing pollution worldwide, is of serious concern (CA, 2007). Africa is endowed with abundant water resources although its distribution and availability for use varies widely, with quite a number of countries facing water shortage and water stress. Regional and national water figures often conceal the dramatic effects of local water scarcity, limited or polluted supplies and inadequate distribution systems. Access to fresh water has been identified repeatedly as a key condition for development. National water policies and conservation efforts often tend to focus on the supply-side for domestic and agricultural use, and less commonly on industrial needs. Under these circumstances the uncontrolled use of a limited resource by water intensive industries takes on a special significance (UN, 2006; Liu, 2009). In general, water scarcity is defined as the point at which the aggregate impact of all users impinges on the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be satisfied fully (UN-Water, 2006). Scarcity has various causes, most capable of being remedied or alleviated. A society facing water scarcity usually has options. However, scarcity often has its roots in water shortage, and it is in the arid and semiarid regions affected by droughts and wide climate variability, combined with high population growth and economic development, that the problems of water scarcity are most acute (UNDP, 2006).

Indeed, inadequate growth in food production and increasingly scarce water pose serious constraints to future agricultural and economic development in Africa, particularly Sub-Saharan Africa (SSA). Global food projections indicate that, although the aggregate global food supply/demand picture is relatively good, with food production in the world growing fast enough for world prices of food to be falling, there will be a worsening of food security in Sub-Saharan Africa (Rosegrant et al., 2005; Amis et al., 2007). In Niger, as in most of developing countries, the Poverty Reduction is strictly related to the development of irrigation. The first of the Millennium Development Goals (MDGs) is to eradicate extreme poverty and hunger, with the target of halving the proportion of people whose income is less than $1 a day between 2000 and 2015. In Sub-Saharan Africa, rural poverty accounts for 83 percent of total extreme poverty, with 85 percent of the poor depending partly on agriculture for their livelihoods (UNICEF, 2012). Considering that agriculture can have the greatest impact on poverty and food security if the benefits of its development are reaped by the poor, priority should be given to the development of small-scale irrigation (Kidane et al., 2006). Agricultural growth is therefore a key to the realization of the first MDG.

Republic of Niger isn’t currently a water scarce country. Water is supplied from three natural sources: groundwater, perennial surface water, and ephemeral (or seasonal) surface water. Water from these sources varies in terms of location, renewability, quality, and reliability. The demand for water is in excess of natural water availability in two river basins. The annual renewable water resources of the Niger are estimated to 32.5 km^3/year. About 29 km^3/year are from the Niger River, making it the principal source of surface water resources. The largely nonrenewable groundwater reserve is about 2,000 billion m^3 (CNEDD 2009; UN, 2012). Groundwater development in SSA is hindered by the relatively high cost of well construction compared to India and China. Costs of more than US$ 5,000-15,000 per well are widely reported. Costs are relatively high because of a shortage of private companies in SSA providing well construction, pump supply, and pump maintenance services. While pump manufacturing facilities and well construction companies rapidly grew in China and India during the 1970s and 1980s, a large private market for groundwater equipment and services has not developed in SSA (Liu et al., 2007).

The effects of variable rainfall patterns and different climatic regimes are compounded by high evaporation rates across the country. The greatest threat to water resources in Niger is the impact of cyclical droughts whose consequences are unpredictable for a country that is among the poorest on the planet (UN, 2012). This paper presents an assessment of the impacts of climate change induced water availability variations on the irrigation districts in the lower valley of the Tarka (Basse Vallée de la Tarka or BVT), taking into account the effects that climate change can have on water availability in the municipal and agricultural sectors. In addition to the scenario of climate change, we will introduce the scenario of high rate of population growth and the modernization of irrigation to see the consequences on water resources of the BVT. We use the WEAP program to calculate groundwater balances and current and future demands (irrigation and others) in the BVT. For the soil water balance and irrigation demand calculations we use FAO rainfall runoff method.

PRESENTATION OF THE BVT

The lower Tarka valley is part of the watershed of the Tarka, starting from the northern region of Tanout, Niger. The Tarka is one of the tributaries of the Sokoto River, Nigeria which itself is a tributary of the Niger River. The area of the Great Valley Tarka in Niger was estimated at 47,998 km². According to Adamou (2010), with respect to amendments, pedo-morphological, ecological and climatic conditions occurring along the years, only the downstream portion of the watershed or lower valley of the Tarka (BVT) has currently a hydro-agricultural potential. The watershed of the lower valley of the Tarka is located in West South Central Niger and trends in a north-south direction. Its northern boundary begins just north of the town of Bouza, from 14° 28' north latitude, and its southern boundary stops at the village of Kara Guidan the Niger-Nigeria border. The lower valley of the Tarka is limited to the east by Goulbi N'Kaba, to the west by the Maggia Lamido, the north by the middle and upper valleys of the Tarka, the south by the Federal Republic of Nigeria. In the far north, the Lower Tarka Valley shares a ridge with the valley of Keita. In Nigeria, the lower valley joins Goulbi (Maradi and N'Kaba) in Sokoto State to flow into the river Sokoto. The area of the Lower Tarka Valley is estimated at 4014.21 km². Its watershed has a drainage density that is poorly distributed. The morphology of the watershed has three major parts that have distinct hydrological regimes:

• The right bank: the most hydrologically active, has a branched river system and an area of 2402.06 km² with a slope of 8%;

• The riverbed: is the central part of the valley, which receives water from tributaries. This is an application area of water with huge hydro-agricultural potentials. It covers an area of 419.12 km² with a low slope (2%);

• The left bank has an area of 1235.06 km². It has low hydrological characteristics due to the low slope of the basin (5%) and the presence of increasingly higher sand dunes in the areas of flow.

The watershed of the Lower Tarka Valley consists of 27 watersheds in which sixteen (16) are on the right bank, eight (8) on the left bank, and the riverbed has been divided into three parts. Joel (1994) has partitioned the lower valley in twenty two (22) sub-basins which eleven (11) on the right bank, eight (8) on the left bank and three (3) in the riverbed. Figure 1 presents the watershed of the BVT and Table 1 shows the characteristics of sub-basins of the BVT.

Table 1 describes the characteristics of sub-basins of the BVT. Agriculture and pastoralism are the main activities of the population of the valley. The cultivable area is estimated to be 1351.5 km² and three types of cultures are practiced:

- Rainfed crops (mainly millet, cowpeas and groundnuts) are grown on the plateaus, slopes and sandy soils outside areas of flooding;

- The recession crops (mainly sorghum and cotton) on sandy loam soils located in areas of application of koris and along floodplains where flooding does not last more than two days;

- Irrigated crops (vegetables dominated by onion and arboriculture) in floodplains (water channel) and around the ponds and spray thresholds where water is not very deep. Irrigation is growing in the valley because of the uncertainty in rainfall production. Indeed, this activity provides the public with a sizeable cash income. Market gardening is not practiced in the northern part of the valley and there is a low extra finance.

WATER EVALUATION AND PLANNING (WEAP) MODEL

An easy-to-use tool is needed to match water supplies and competing demands, and to assess the upstream-downstream links for different management options in terms of their resulting water sufficiency or unmet demands, costs, and benefits. The Water Evaluation And Planning tool (WEAP) has been developed to meet this need. It uses the basic principle of water balance accounting: total inflows equal total outflows net of any change in storage (in reservoirs, aquifers and soil). WEAP represents a particular water system, with its main supply and demand nodes and the links between them, both numerically and graphically. Delphi Studio programming language and map Objects software are employed to spatially reference catchment treatment plants,

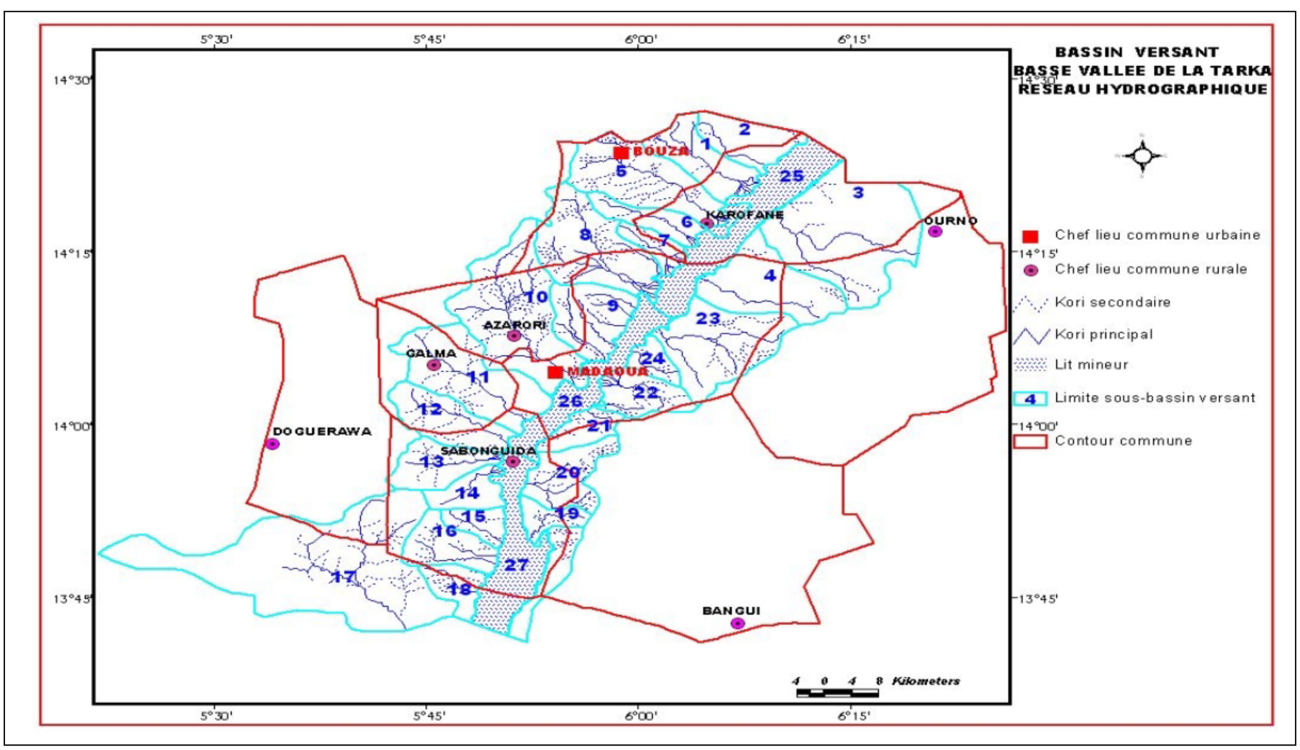

Figure 1. Watersheds of the Lower Valley of the Tarka: Basse Vallée de la Tarka (BVT).

Table 1. The characteristics of sub-basins of Lower Valley of the Tarka (BVT).

N° Sub-basin	Name of the sub-basin	Size (km²)	Overall slope	Position in the basin
1	Badaou	110,35	7%	Right bank
2	Tchimbarka	93,99	6%	
3	Gandou	353,20	5%	Left Bank
4	Tanfaye	184,98	5%	
5	Bouza	193,39	7%	Right Bank
6	Sabon Gari (Toro)	62,82	8%	
7	Tassoliat	41,79	6%	
8	Madetta	207,95	7%	
9	Tikiré	125,14	7%	
10	Illégawane	300,32	8%	
11	Arewa	213,78	8%	
12	Magaria	116,77	9%	
13	Kournoni (Roumbouki)	90,69	10%	
14	Zoukout	58,65	8%	
15	Tallemont	43,27	7%	
16	Dogon Daji	90,86	8%	
17	Bilandao	593,76	8%	
18	Badjinkay	117,04	5%	Right Bank and Left Bank
19	Samon Koura	41,02	5%	Left Bank
20	Amidiré	103,79	5%	
21	Tabirné	53,85	5%	
22	Adjibaou	82,24	5%	
23	Mouléla	204,20	5%	
24	Lakeité	36,22	5%	
25	Iskan Kaba	205,79	3%	Riverbed
26	Kollé	126,10	2%	
27	Sabon Guida	162,23	2%	
TOTAL		4014,21		

catchment and administrative political boundaries (Yates et al., 2005a,b; Sieber et al., 2005). The WEAP (refer to www.weap21.org for more details) has been developed by the Stockholm Environmental Institute (SEI) as a planning tool for water resources management and is distributed free-of-charge for government and nonprofit organizations in developing countries. The program calculates groundwater and surface water balances and current and future demands (irrigation and others) at a catchment, sub-catchment or land use class scale level. For the soil water balance and irrigation demand calculations the user can choose from three different built-in algorithms or enter own expressions:

-FAO crop requirements only (input parameters: reference crop evapotranspiration, crop coefficient, irrigation efficiency, effective precipitation),

-FAO rainfall runoff method (input parameters: like above plus the runoff fractions to ground and surface water),

-Soil moisture method (input parameters: detailed crop, climate, soil, slope and irrigation parameters). Its graphical user interface (GUI) is easy to use and setting up model constraints is straightforward. Physical dependencies between modeling units can be defined, reordered or removed by drag and drop operations on a drawing surface. Modeling data can easily be changed or updated either directly within the GUI, by importing spreadsheet-data or by linking WEAP to an external database management system using WEAP's Application Programming Interface (API). Based on a reference year multiple development scenarios can be designed (incorporating prediction data or functions) and the respective water balance results can be visualized, compared and evaluated as graphs or tables by the user and then support respective decisions for the best or most likely planning scenario.

METHODOLOGY

Demand sites were aggregated for water consumption in the study area. Water use information was applied to construct alternative scenarios that examine how consumption of water evolves over time for domestic uses, irrigation and livestock from year 2010 to year 2030.

Study Area

Because we don't have enough information on the use of surface water (The Tarka), only groundwater in the BVT in the Republic of Niger was selected for the water consumption. The average rainfall of the study area is approximately 500 mm/year. The rainy season usually starts in May-June and ends in October. Rainfall is generally spread over 30 to 40 days. The maximum rainfall is recorded during the months of July and August, peaking in August. It was during this period that the rain water after wetting the soil seeps into the ground to reach the groundwater. The Evapotranspiration (ET) is marked by a great consistency and is between 170 mm/month from October to January and 150 mm/month from February to September.

In this study, we are interested in the consumption of water for people, livestock and irrigation. The study area is represented in Figure 2.

Current Accounts and Reference Scenario

The region of Lower Tarka Valley is very favorable for irrigation and pastoralism. In this work, we considered the consumption for human, the livestock and for irrigation. For the Current accounts (2010), the population is estimated at 200,000 inhabitants with an annual growth rate of 2.42%. The annual need for water is estimated at 9125 m^3/person. The livestock are estimated at 144,500 heads in the Tropical Livestock Unit (TLU) with an annual growth rate of 6% and an annual consumption of 12,775 m^3 head of TLU. The irrigated area is estimated at 10,000 hectares. Its surfaces have increased 10% annually. The need is 8000 m^3/ha. Water demand varies from 87.3 million m^3 in 2010 to 547.1 million m^3 in 2030 at the end of our scenario as shown in the Figure 3.

First Scenario: High Population Growth

Population pressure on the total amount of available water (demographic water scarcity) expressed as people per flow unit of one million cubic meters of water per year. This parameter expresses on the one hand the level of dispute proneness in a country or region, since the finite water availability has to be put to a set of parallel uses, generating disputes between sectors and users, urban and rural water uses, upstream and downstream water uses, and between water-dependent and water-impacting activities. On the other hand, it also expresses the number of

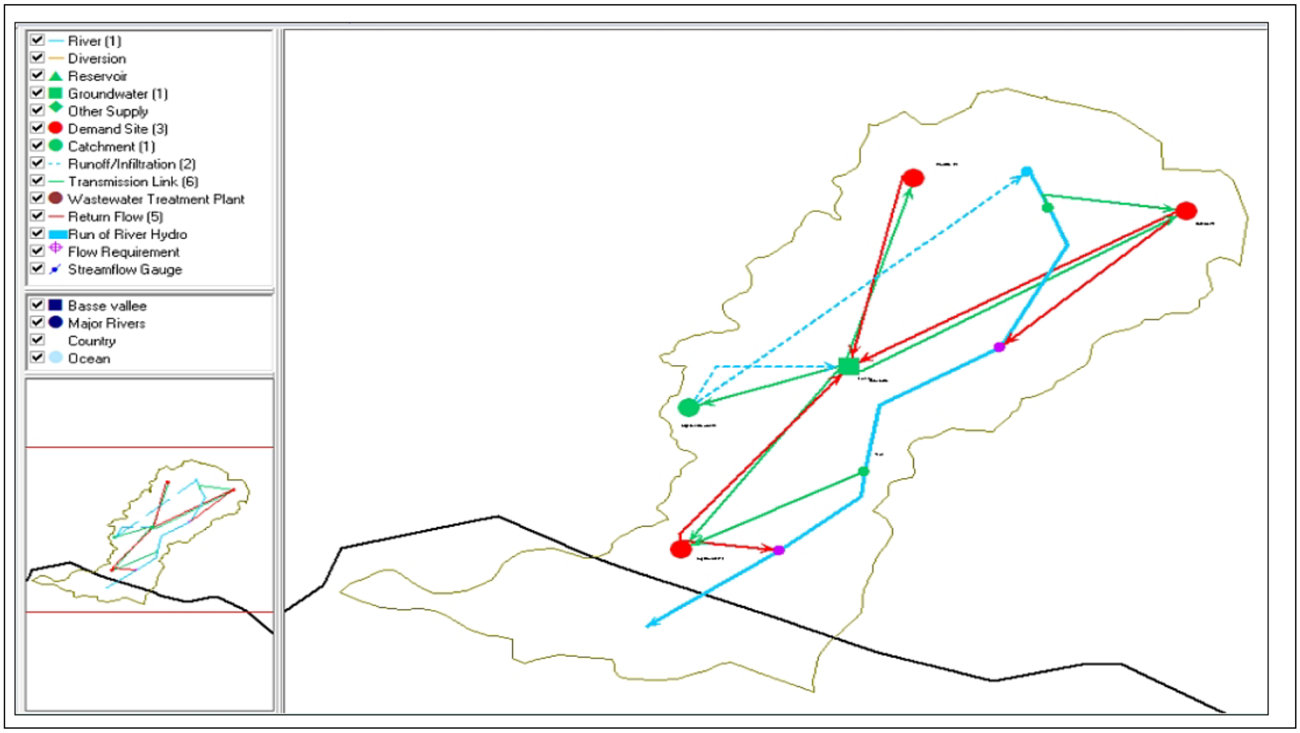

Figure 2. Study area of the Lower Valley of the Tarka: Basse Vallée de la Tarka (BVT).

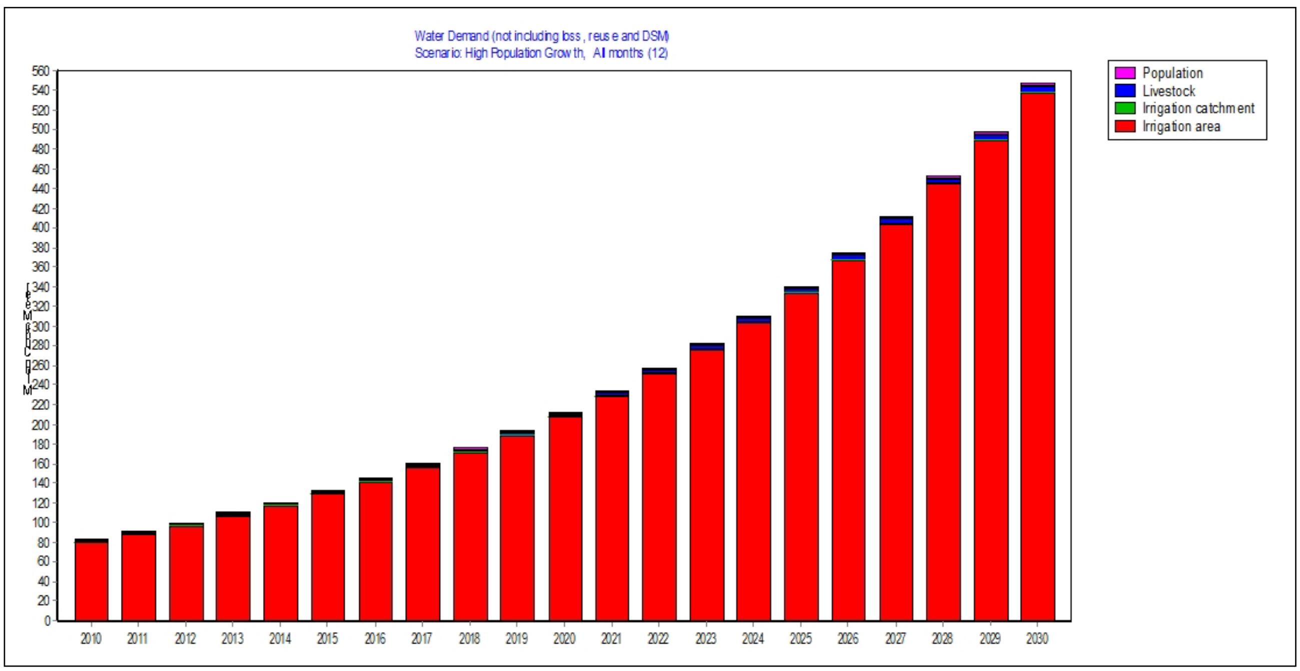

Figure 3. Water demand for reference scenario.

people polluting each flow unit of water, thereby providing an indication also of the pollution load (Falkenmark et al., 1993; UN, 2010). Lower Tarka Valley is a region rich in water; the population in this region is expected to grow up to the national rate (3.3%) with WEAP scenario whereas, its actual rate is 2.42% (reference). WEAP revealed a slight increase in water demand that will be 547.3 million m^3 in 2030.

Second Scenario: Impact of climate change

Climate change raises serious problems in terms of social and economic development in all countries. Developing countries are particularly vulnerable because they rely heavily on natural resources and ability to cope with the impacts of the phenomenon is limited. Niger has regular droughts, causing severe recurrent famines like those of years 1974, 1985, 1994, and 2005. Food insecurity is more structural. Once every three years there is a high deficit of between 200,000 and 300,000 tons of cereals. This requires substantial food imports and the implementation of aid international food (Republic of Niger, 2007). Potential climate change impacts on Niger can be drawn from global assessments as well as local case studies. For example, a composite climate change index (based on the strength of monthly temperature and precipitation changes relative to present natural variability) places Mali, Niger and Burkina Faso in the same low-intermediate category as the UK according to Baettig et al. (2007). This implies that projected regional changes in monthly statistics will be hard to detect against a background of significant climate variability. In the case of Niger, the index is most heavily influenced by expected changes in temperature. Projected increases in surface and groundwater water withdrawals driven by income and population growth (as well as by demands for electricity generation) are also expected to reduce per capita water availability in the region (Kundzewicz et al., 2007). One of the most remarkable aspects of the climate of the Sahel is the widely documented reduction in rainfall between the late 1960s and mid 1980s (Hulme, 1992; Niel et al., 2005). Depending on the zone, annual rainfall declined by between 15 to 30%, and isohyets shifted ~200 km southwards (Measham et al., 2011).

Unlike the reference scenario that assumes that all years are normal, in this scenario, we took into consideration the variations in rainfall (dry, very dry, wet, very wet or normal). Relative to normal year we have: very dry year = 0.2; dry year = 0.6; normal year = 1; wet year = 1.2 and very wet = 1.6. For example if in normal year the rainfall is 500 mm/yr, in very dry year the rainfall will be estimate at 100 mm/yr and 800mm/yr in very wet year. We were inspired by the different variations of rainfall in Niger during the period 1970 to 2000 to build our scenario as shown in Figure 4.

Third Scenario: New Technology

For the Reference Scenario, according to estimates by the Regional Agricultural Development Tahaou, Niger (Adamou, 2010), the amount of water needed for the irrigation of the onion crop reaches 8000 m^3/ha. The crop water requirement of a certain crops under particular climatic circumstances was estimated with the CROPWAT model (Allen et al., 1998; FAO, 2003) using climate data at a regional level. In arid or semiarid areas like the Sahel region, the optimal maximum volume is estimated at 6000 m^3/ha (Geerts et al., 2010). For example Irrigation water use efficiency of onion at Mekelle in Ethiopia was 6349 m^3/ha (Mulubrehan et al., 2008; Toe et al., 2012). In Targus basin the estimate is between 4500 and 5800 m^3/ha (Garcia-Ruiz et al., 2010). By comparing the water used in irrigation in the lower valley of the Tarka (BVT) and in other regions of Niger, we see there is an over-exploitation of water resources in irrigation. With a view to reduce the wastage, we have fixed a target to reduce consumption of irrigation by 1000 m^3/ha in the year 2030 (Figure 5).

REMARKS

This study confirmed the results of some work that was carried out on the water resources in Niger Republic. (World Bank, 2000; Adamou, 2010):

1 - Despite the aridity of its climate, Niger has important water resources, as is the case of the lower valley of the Tarka (BVT). For all scenarios, we didn't observe any unmet demands as is shown in Figure 6.

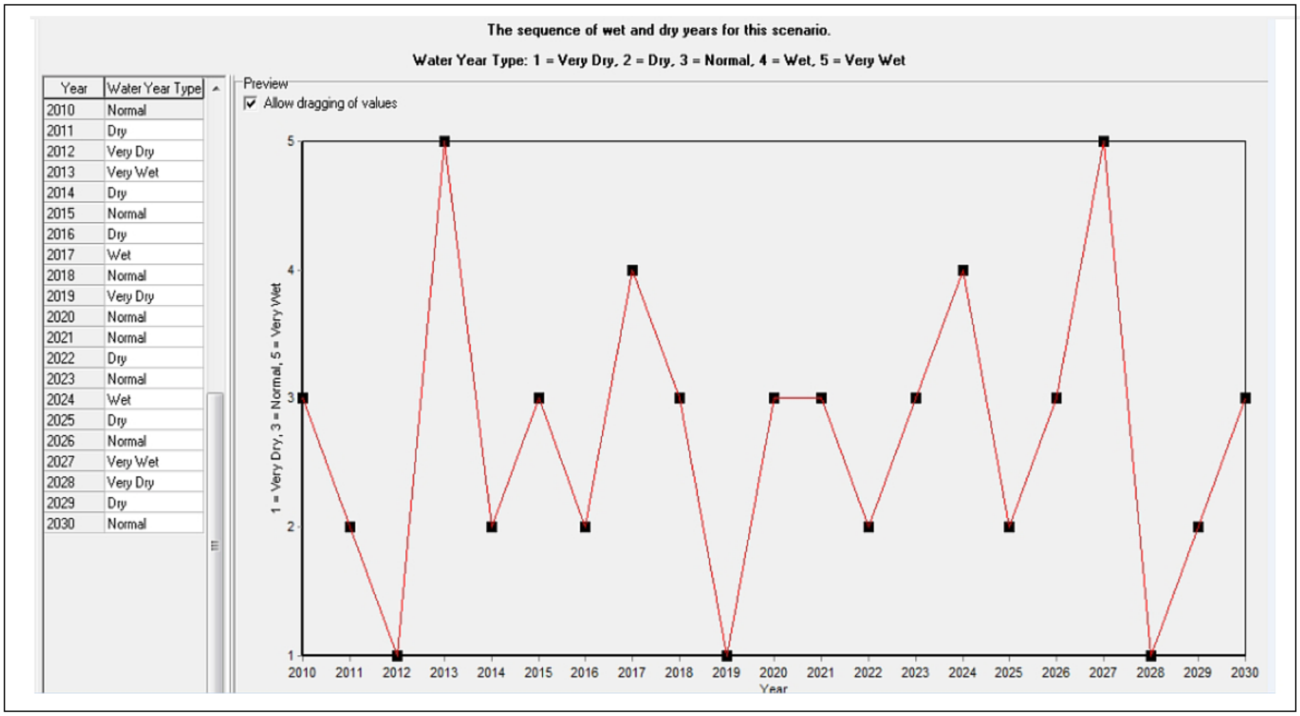

Figure 4. Climate Sequence.

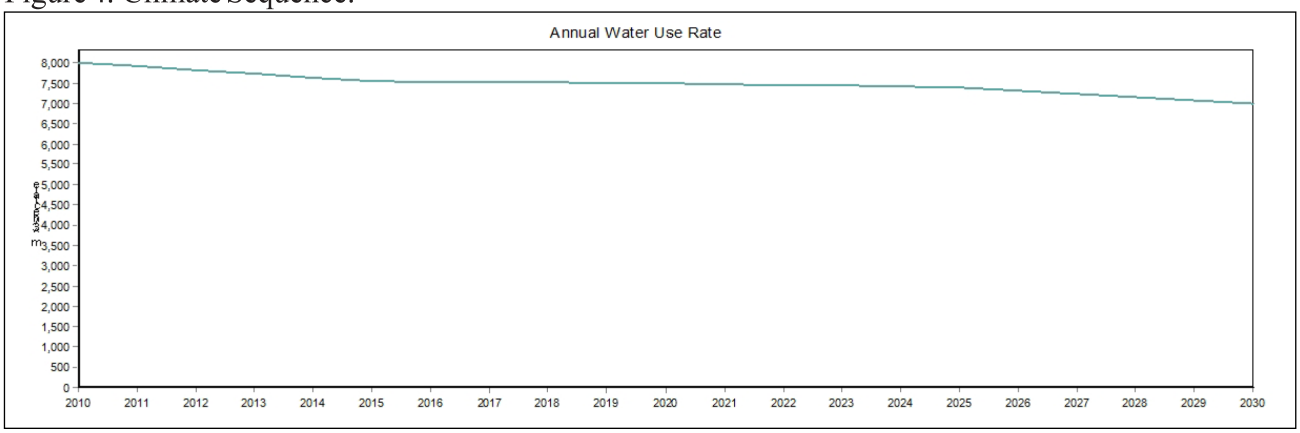

Figure 5. Water use reduction projection.

According to Hoekstra et al. (2002), the Niger's Net virtual water import was estimated at 106 Million Cubic Meters (MCM), (a considerable amount), water footprint at 734 MCM, Niger's water scarcity was estimated at 1.9% and Niger's water dependency was estimated at 14.5%. So Niger is classified in class I in the scarcity-dependency graph, which means that currently Niger does not have enough water.

2 - The consumption of the population and livestock are much lower compared to the consumption for irrigation. Total consumption (cattle + population) in 2030 would go beyond the 1 MCM, the consumption for irrigation by 2030 will reach the quantity of 538.2 MCM (Figure 7).

3 - Drought frequency, a consequence of climate change, is a major threat to water resources. The main water source is groundwater. With the drought, groundwater recharge will be affected and will have an impact on long-term availability of this vital resource.

The outlook for future droughts and climate trends highlights the importance of future access to water, especially in areas that currently rely on rainfall or surface water irrigation for agriculture. By 2050, rainfall in SSA could drop by 10%, leading to major water shortages (Nyong,

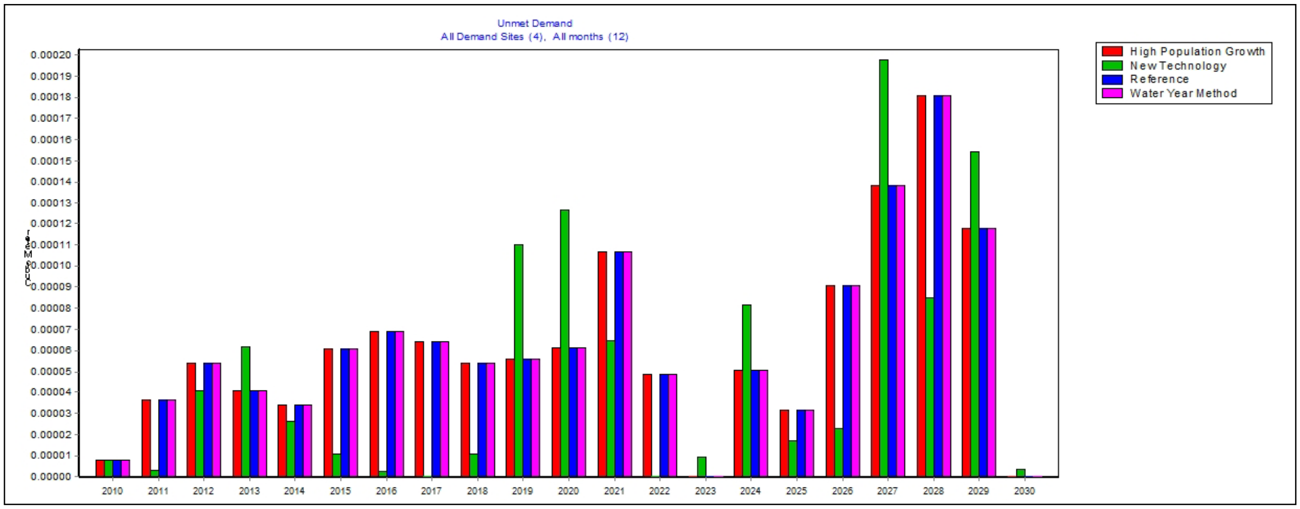

Figure 6. Unmet demands for all scenarios.

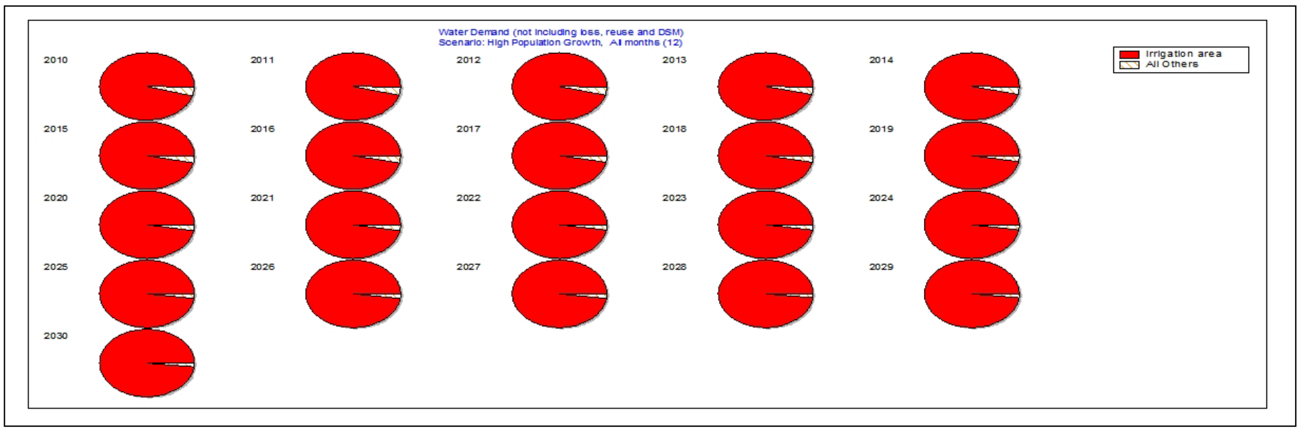

Figure 7. Comparison of water demands by sector.

2005). A general decrease in annual rainfall is predicted to significantly affect access to surface water across 25% of Africa by 2100 (De Wit et al., 2006). By considering the Reference Scenario (software prediction "WEAP") that takes into account only the normal years, the good rainfall contributes significantly to recharge the aquifer. This rewards the strong demand for irrigation.

But by comparing the input and output level of the water relative to the reference scenario and the water method year, the record shows that the groundwater recharge decreases by 15% by 2030 (Figure 8).

However, by introducing the economics of water (Scenario new technology), the water decreases only by 3%, which is a considerable effort. This is due to the gain in consumption of irrigation which becomes significant from 2026 and offsets the impact of drought during the study period is shown in Figure 9.

According to Perry (2010) development of the irrigation subsector in sub-Saharan Africa has been constrained by the high cost of irrigation schemes constructed until now as well as their management complexity. The investment cost of a full-control irrigation scheme in Niger is US$ 10,000 - 25,000/ha. These investments are costly for the population, the support of political authorities and donors is essential to meet the challenge. In this simulation, we did not consider the quality of the water. Still, recent work by Adamou (2010) has shown that groundwater in the BVT in some cases is contaminated by nitrate and nitrite levels which exceed the WHO standard because of the increasing use of fertilizers. It is the same in the microbiological degradation of

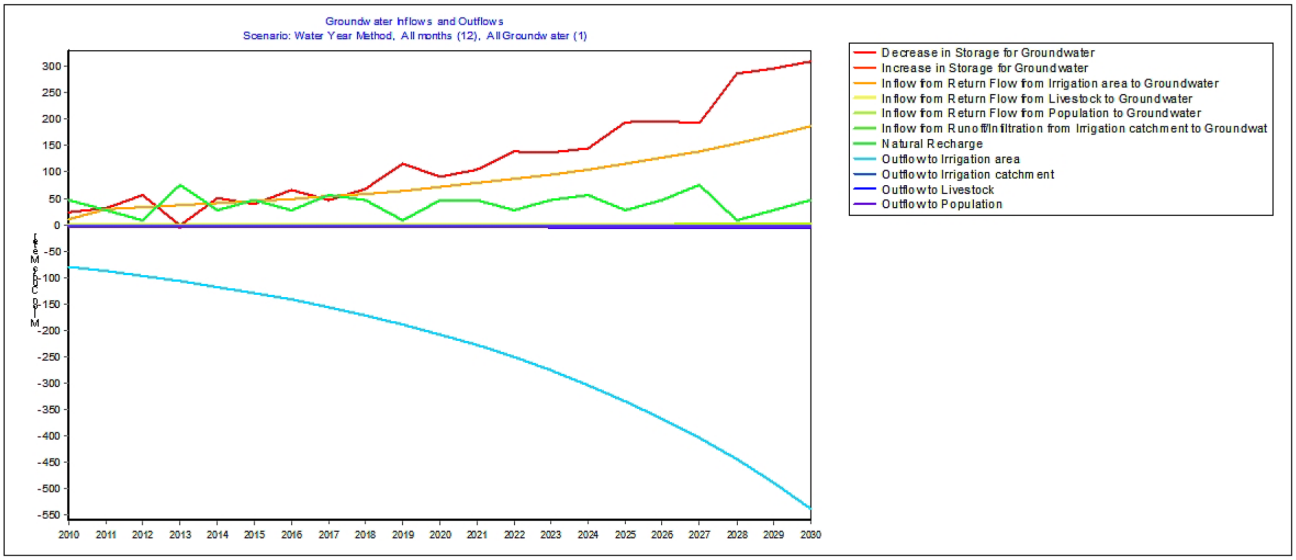

Figure 8. Water balance using water year method.

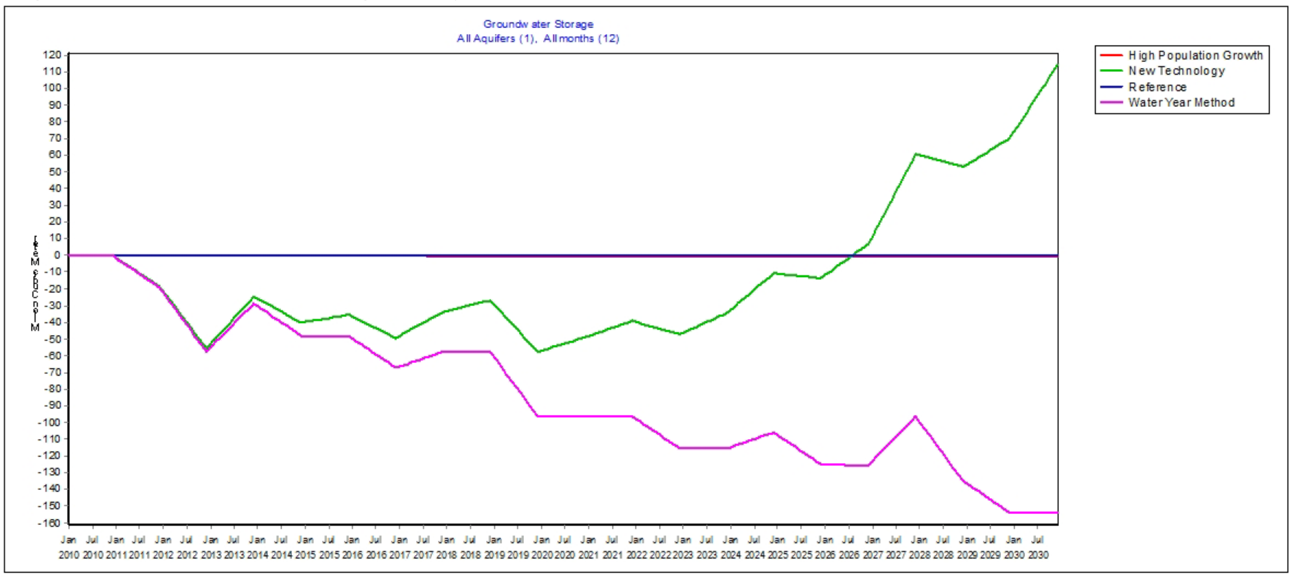

Figure 9. Groundwater storage for all scenarios.

the quality found in several wells in the basin. Others consider pressures on the BVT as overgrazing and deforestation.

CONCLUSION

Water management and control is a priority in Niger since water is closely linked to the success of agriculture. However the techniques used in irrigation consume huge amounts of water with a production yield of onion of 29.8 t ha^{-1}. To improve the performance and reduce the amount of water used, it is important to invest in and upgrade the technology of irrigation. The WEAP program concluded with useful insights that show planning for the future of BVT water management for maximal exploitation and environmental protection of the area can lead to an improvement in the population well-being.

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