IMPROVED DROUGHT EARLY WARNING AND FORECASTING TO STRENGTHEN PREPAREDNESS AND ADAPTATION TO DROUGHTS IN AFRICA

DEWFORA

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Implementation of improved methodologies in comparative case studies

Final report for the Oum er-Rbia case study

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SUMMARY

The objective of the Oum er-Rbia case study is to test different approaches that can improve drought mitigation and preparedness strategies in the region. To reach this goal, three different analyses were performed: The implementation and skill assessment of medium range to seasonal forecasts, a test on statistical drought agricultural forecasts, and a drought vulnerability assessment at the rural commune level.

The first objective (section 2) was to assess the skill of medium range weather forecasts. The analysis focused on the growing season in rainfed areas planted with cereal crops. Those regions were selected given their predominance and socio-economic importance around the basin and throughout Morocco.

Both, daily and medium-range forecasts appears not to be able to predict rainfall amount, but seemed to show better skills in forecasting dry periods. Indeed, some significant potential exist both for early warning and mitigation operations; this is particularly true for herders which cannot afford major food purchases to save their cattle, but also for crop imports, subsidies, and some agricultural practices. An efficient drought early warning system would allow farmers to evaluate more accurately their production options and insurance companies anticipate payments to farmers.

In section 3, a statistical-dynamical approach to estimate durum wheat yield over the Oum er-Rbia basin was outlined. Different low level circulation fields were used as predictors using a principal component regression to test the predictability of seasonal crop yields in the region. Both deterministic and stochastic approaches hold a good potential for yield predictions over the mountains and coastal areas. Particularly, with a two months lead-time, high and low yield are well discriminated for both areas. On the other hand a very low predictability was identified over the basin plains.

The drought vulnerability study in section 4 aimed to assess and map agricultural drought vulnerability at the rural commune level in the Oum er-Rbia basin in order to assist and guide drought management authorities in the development of efficient mitigation actions, tailored to the needs and specificities of each rural community. This has been achieved through the implementation of the improved methodology developed in DEWFORA Work Package 3. It consists in computing a Drought Vulnerability Index (DVI) that integrates several variables into four dimensions: Renewable Natural Capital; Economic capacity; Human and Civic Resources; Infrastructure and Technology.

The drought vulnerability map that was derived from the computation of the DVI shows that except for the provinces of Azilal, Khenifra, Settat and El Kelaa, most of the other parts of the Oum er Rbia basin are highly vulnerable to drought. The provinces of Azilal and Khenifra are mountainous areas that present the most favorable annual rainfall. That contributes to explain their low DVI. Although being more arid than coastal areas, the inner plains of Settat and El kelaa have lower DVI's. This should be considered carefully and should be object of further analysis.

The analysis of the four dimensions (Renewable Capital, Economic Capacity, Human and Civic Resources, Infrastructure and Technology) of the drought vulnerability index showed

that at the river basin level, the following sub-indicators represent the major drivers of vulnerability that may therefore be targeted in prioritizing mitigation and adaptation actions:

- The mean annual rainfall and the percentage of irrigated lands as well as the belonging to a big irrigated perimeter,
- The Cereal / Fruit trees and market crops ratio, the land status and the farms size,
- The adult literacy rate and the access to improved drinking water.

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1. INTRODUCTION: OUM ER-RBIA BASIN CASE STUDY

1.1 DESCRIPTION OF THE CASE STUDY

Oum Er-Rbia river (*the Mother of Spring*), is 550 km long flowing east to west in central Morocco (Figure 1-1). With an average water flow of 105 m^3/s, it is the second largest river in Morocco after the Sebou River. It takes source in the Middle Atlas, at 1800 m altitude, passes through the chain of the Middle Atlas, the Tadla plain and the coastal plateau and sheds in the Atlantic Ocean in Azemmour city, at 70 km south of Casablanca, and 16 km north of El Jadida city.

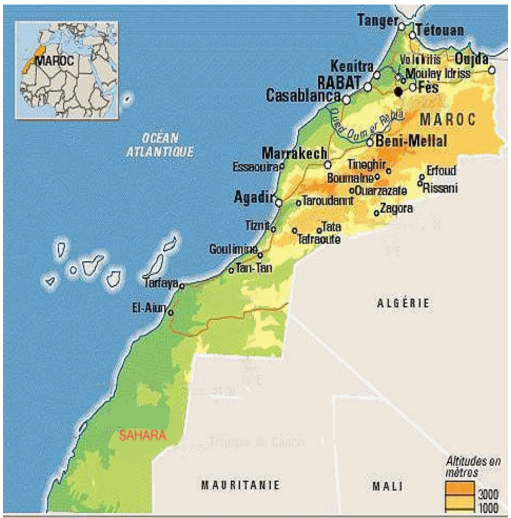


Figure 1-1: Location of Oum Er-Rbia river in Morocco

The management of the hydrological basin of the Oum Er Rbia river is under the responsibility of the Hydraulic basin Agency of Oum Er-Rbia (ABHOER) which action area covers an area of 48070 km2, corresponding to 7% of the Morocco land area (Figure 1-2).

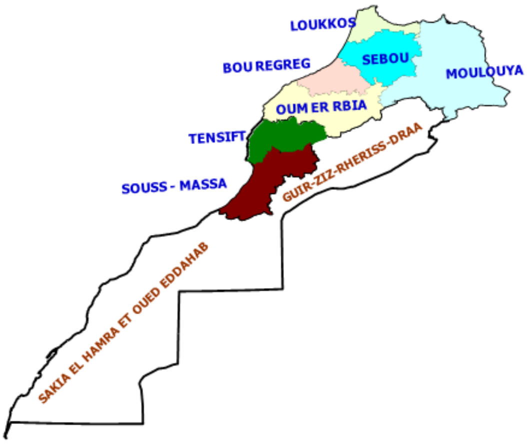


Figure 1-2: The location of the Oum Er- Rbia Hydrologic Basin

In fact, the ABHOER covers the hydrologic basin of the Oum Er Rbia river (35000 km^2) but also the Atlantic coastal basins situated between El Jadida and Safi (13070 km^2). At the administrative level, this area covered initially 11 different provinces divided in rural communes and urban municipalities. Figure 1-3 shows these initial administrative boundaries. However, in 2009 new borders were adopted, several provinces were split in two and the basin now covers 16 different provinces.

Figure 1-3: Administrative divisions covered by the Oum Er-Rbia basin

Regarding Moroccan social and natural indicators at the National level, the Oum Er Rbia basin represents:

- 7% of the national area
- 17% of the population
- 19% of water resources
- 36% of water storage capacity
- 33% of irrigated areas

In itself, it represents:

- a global population of 4,96 million inhabitants of which 61% live in rural areas
- a total irrigated area of 464 530 hectares
- Mean surface water resources of 3250 Mm^3/year
- 20 dams with a total storage capacity of 5100 Mm^3
- Annual drinking and industrial water needs of 337 Mm^3/year
- Annual irrigation water needs of 3891 Mm^3/year

However, since its a large area and the fact that it extends from the Middle- Atlas mountains to the Atlantic ocean coast and covers also the inner plains, the Oum er Rbia basin is a very contrasted area where we encounter various agro-ecological environments including:

- **Mountainous areas of Middle and High Atlas** (Provinces of Khenifra and Azilal) that benefit from relatively high annual rainfall with the exception of some specific areas. The result is a well-developed natural vegetation (forests and pastures) that cover more than 70% of the area. Crops represent less than 30 % of the area (mainly cereals, legumes and fruit trees). It is essentially areas of subsistence farming relying a lot on livestock (sheep, goats and some cattle).

- **Semi-arid coastal and inner plains, plateaus and hills with less than 400 mm of rainfall.** These areas have a strong agricultural activity mainly rainfed with limited islands of irrigated areas and associated livestock (cattle and sheep).
- **Semi-arid coastal and inner plains, plateaus and hill with large irrigated areas or high irrigation potential**. Irrigated perimeters of Tadla (Province of Fquih Ben Salah), Doukkala (Province of Sidi Bennour) and Tassaout (Province of Kelaat Sraghna) caracterised by intensive cropping and livestock systems.

1.2 OBJECTIVES OF THE CASE STUDY

Morocco has diverse climatic conditions with generally low and highly variable annual rainfall and high degree of aridity. The typically prevailing climatic conditions are characterized by extended periods of dry spells and wet periods with a regime of irregular precipitation. Inter-annual rainfall variability is also high. As a result of aridity and rainfall variability, the country is extremely vulnerable to drought which represents a structural recurrent phenomenon. Moreover, the vulnerability to climate variability has intensified with today's demographic, economic growth and resource use patterns. Several studies indicate also that global climate change will add more to the existing problems resulting from drought and desertification, especially since water resources are already limited and fragile. Indeed, during the three last decades, Morocco faced more frequent, more intense and longer drought episodes (see DEWFORA D6.1).

In the case of the Oum Er Rbia basin, the water balance is characterized by a global deficit, due to the combined effects of drought and overuse. The gap reached in some sub-basins is 50%. In the last 20 years, the most important droughts were recorded from 1980-81 to 1985-86, from 1991-92 to 1994-95 and from 2000 - 2001 to 2002-2003.

The Oum Er-Rbia basin faces therefore various natural and technical constraints, mostly concerning the sustainability and availability of water in terms of both quantity and quality. The biggest equation to resolve is the widening gap between supply and demand. Indeed, due to urban growth, the development of the industrial and agricultural sectors, and the development of tourism, water demand is growing whereas, due to the decrease of precipitation, water supply is decreasing. Thus, a 30% reduction in rainfall has already been observed during the 1980-2002 period and this decrease may reach 60% by 2020 assuming that the decreased trend will be maintained. In addition, there is no possibility for further hydraulic infrastructure development, as more than 90% of available water resources have already been exploited. Consequently, there is a need for a more integrated water resources management oriented towards:

- Water saving and valuation
- Preservation of underground water resources both in quantity and quality
- **The mitigation and adaptation to extreme situations such as droughts and floods.**

The last point is of crucial importance. Indeed, in Morocco, 50% of the population lives in rural areas and this value reaches 61 % in the Oum er Rbia basin. They are mostly small subsistent farmers whose production remains almost entirely on rainfall. They are therefore very sensitive to drought episodes that may dramatically affect their incomes.

However, at the time being, although Moroccan government decided in the late 90's, as a consequence to the increasing frequency, length and severity of drought episodes, to move on from a crisis to a risk approach, drought management remains mainly reactive and often ineffective and drought mitigation strategies and action stay very scarce and uncommon.
The objective of the Oum er-Rbia case study was to further agricultural drought forecasting by means of the newly developed indicators (WP 3) and model techniques (WP 4). First of all the medium range and seasonal forecasting of agricultural drought in the basin are proposed to gain lead time for effective drought mitigation. Second, drought vulnerability assessment and mapping was conducted at the rural community level in order to provide decision makers and water resources managers with a decision tool allowing developing efficient mitigation actions, tailored to the needs and specificities of each rural community.

2. MEDIUM RANGE FORECASTS OF PRECIPITATION

2.1 FOLLOWED APPROACH

Weather plays an important role in agricultural production. It influences growth, development and yields of a crop, incidence of pests and diseases, fertilizer requirements and mainly water needs. The exacerbated fluctuations in rainfall regimes over the arid and semi-arid areas, and the associated threats in the agricultural sector highlight the need for reliable climate forecasts. This need is even greater in countries like Morocco, where agriculture is the main pillar of economic development.
However, Moroccan farmers still depend on their local knowledge to predict the rainfall situation in their areas. We believe nevertheless that agricultural and socio-economic development here, as in similar areas, depends to a large extent on the availability and use of accurate and timely climate forecast information. Indeed, seasonal or medium range weather forecasts can provide an indication of the occurrence, duration and severity of dry periods and thus reduce impacts by triggering early warnings and mitigation measures.
Moreover, during the growing season, a prolonged drought spell can damage cereal crop production in rain feed areas. In the basin, some of the rain feed areas can access to temporary irrigation systems. In this situation, medium range precipitation forecasts could provide an early warning system allowing the farmers to prepare such irrigation systems.
In line with that, one of the objectives of the Oum er-Rbia case study is to improve agricultural drought management on both the rainfed and irrigated sectors of the basin by providing and testing medium range and seasonal weather forecasts in order to implement effective drought **mitigation** through a better planning of irrigation scheduling.

The main objectives of this study are therefore to:

- Assess the skills of medium range weather forecasts in the Oum Er-Rbia basin
- Assess their potential use for the mitigation of intra-annual dry-spell episodes

This study has been conducted in collaboration between two partners of the Dewfora project: Institut Agronomique et Vétérinaire Hassan II (IAV) and the European center for Medium Range Weather Forecasts (ECMWF)

2.2 DATA COLLECTION

This study was conducted in three steps. Specific rainfall data sets (observed and forecasted) were collected by IAV and generated by ECMWF for the two first steps.

2.2.1 Daily rainfall (observed and forecasted)

In this first step, daily rainfall data were collected from 4 different stations in the Oum er Rbia basin. Figure 2-1 shows the location of these stations which are representative of the different parts of the basin. Indeed, Khmiss Mettouh and Khmiss Zemamra are located in the western part of the basin while Oulad Gnaou is located in the inner plain of Tadla and Aghbala is a mountainous station.

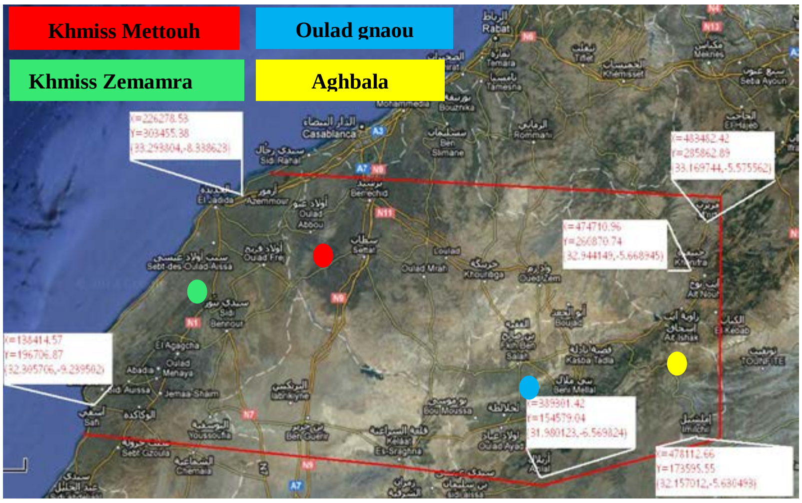


Figure 2-1 Location of the meteorological stations used for observed data collection

At the same time, partners from ECMWF retrieved precipitation forecasted rainfall with a lead time of 15 days, on the Lat/Lon box corresponding to the coverage of the Oum Er Rbia basin:

Daily forecasts, 15 days lead time, 1 forecast of total precipitation issued each day on a 0.25°x0.25° regular grid in the following domain: [09°W - 4.5°W] X [31°N - 34°N].

The data were prepared in two formats:

a) The full data including all forecast members;
b) Resuming the 51 ensemble members to the following percentiles: 10 30 50 70 90.

Forecasts were restricted to the following periods: 15 September to 30 November and 1 February to 15 April that correspond to two important phases of the cereal cycle, i.e. planting and yield elaboration periods. The analysis was conducted for the year 2011.

2.2.2 Seven days accumulated precipitation data (observed and forecasted)

The second phase of the study was designed after the analysis of the preliminary verification of daily forecasts. Indeed, as we will describe it later, the preliminary results seemed to show better forecast performance in dry periods and this second part is aimed to verify this hypothesis. Therefore in order to assess the skills of the forecasts to identify end-season dry spells, data analysis was restricted from mid-February to mid-April since it corresponds to the cereal's grain formation and filling period. In addition, instead of using daily rainfall data, the analysis was performed on 7 days accumulated forecasts.

2.2.3 Forecasts: ECMWF data:

- EPS forecasts for each location performing the 7 days accumulation up to 9 days lead time (i.e.: day 9 corresponds to the accumulated precipitation between days

9 and 15 of the forecast), the forecasts were delivered in MS Excel format and including the 51 ensemble members;

- Calculation of the 7 days accumulated precipitation distribution (different percentiles) using the available hindcast data: last 18 years every Thursday, from 15 February to 15 April, 5 ensemble members.

- Calculation of the forecast probability of below normal (< 30th percentile), normal (30th percentile <> 70th percentile), and above normal (> 70th percentile) conditions for each lead time.

2.2.4 Observed data

For this part of the study, partners from IAV collected daily rainfall data on an 18 years long period for the Oulad Gnaou and Khmiss Mettouh stations. Aghbala and Khmiss Zemamara stations were not considered in this analysis because they are relatively new stations and could not provide such long series.

2.2.5 Information on irrigation scheduling and farmers behaviour during the mid-February to mid-April 2012 period.

In order to assess the potential use of the medium range forecasts of precipitation for drought mitigation in the basin and especially in the case of end-season dry spell, information on irrigation scheduling and farmers behaviour during the mid-February to mid-April 2012 period were collected from the rainfed and extension services of the basin.

2.3 METHODS AND TOOLS

2.3.1 Comparison of daily observed and forecasted rainfall

In order to compare the daily observed and forecasted rainfall we have:

- Compared the mean of the 51 ensembles to the observed rainfall. That gives an idea about the capability of predicting rain when it actually occurs.
- Compared the 10 percentiles, the 50 percentiles, the mean of the 51 ensembles, the 90 percentiles with the observed rainfall.
- Created with the 51 members a bar and plot on top the observed precipitation as a line. That gives an idea of how many realizations of the forecast were close to the observations and the 'precision' of the forecast for that day. If the bar is small then the 51 realizations of the forecast were in agreement otherwise there was larger uncertainty. In general you want your observed line to be in the middle of the 51 forecast bars.
- Compiled the different forecasts given during 15 days for a specific day.

2.3.2 Comparison of the 7 days accumulated observed and forecasted rainfall

Using all the daily data from Khmiss Mettouh and Oulad Gnaou Stations (years 2008, 2010 and 2012), we have:

- Computed the 7 days accumulated precipitation for all the days between 15 February and 15 April.
- Built the observed climatology of each station on a 18 years period by computing for each 7 days accumulated period (i.e. 15-21 Feb, 16-22 Feb....until 15-21 Apr) the 5, 10, ...50, ..., 95 percentiles.
- Considered 3 conditions: below normal (accumulated rainfall below the percentile 30), normal (accumulated rainfall between percentiles 30 and 70), and above normal (accumulated rainfall above the percentile 70). The percentiles are calculated for both observations and forecasts independently.
- Compared, for each 7 days accumulated period, the climatology and the observed amount of rainfall to determine in which category: dry, normal or wet it fells. The observations are transformed to a binary variable, reaching values of 1 (if the event occurred) and 0 (if the event did not occurred). For example, if the observed accumulation rainfall was below the percentile 30, we gave a '1' to the dry category and 0 to the normal and wet ones.
- Computed the observed Brier score (http://en.wikipedia.org/wiki/Brier_score, Brier, 1950) for each category to assess the skill of the forecasts. The observed accumulated precipitations are compared to the forecasted probabilities of being in a "dry", "normal" or "wet" event.
- Computed the Brier score of reference. For the reference BS, we used a constant probability equal to the probability of the climatological forecast event: lower tercile (between 0 and percentile 30) : reference forecast probability == 0.3 upper tercile (between 70 and 100 percentile) : reference forecast probability == 0.3; normal event (between 30 and 70 percentile) : reference forecast probability == 0.4
- Computed the brier skill score as: BSS = 1-BS/BS (Murphy, 1973)

2.4 RESULTS AND OUTCOMES

2.4.1 Medium range forecasts of daily rainfall

Overall, More than 600 daily forecasts were analysed. We present here examples of selected rainy days (rain > 1 mm) and dry days.

- **Rainy days**

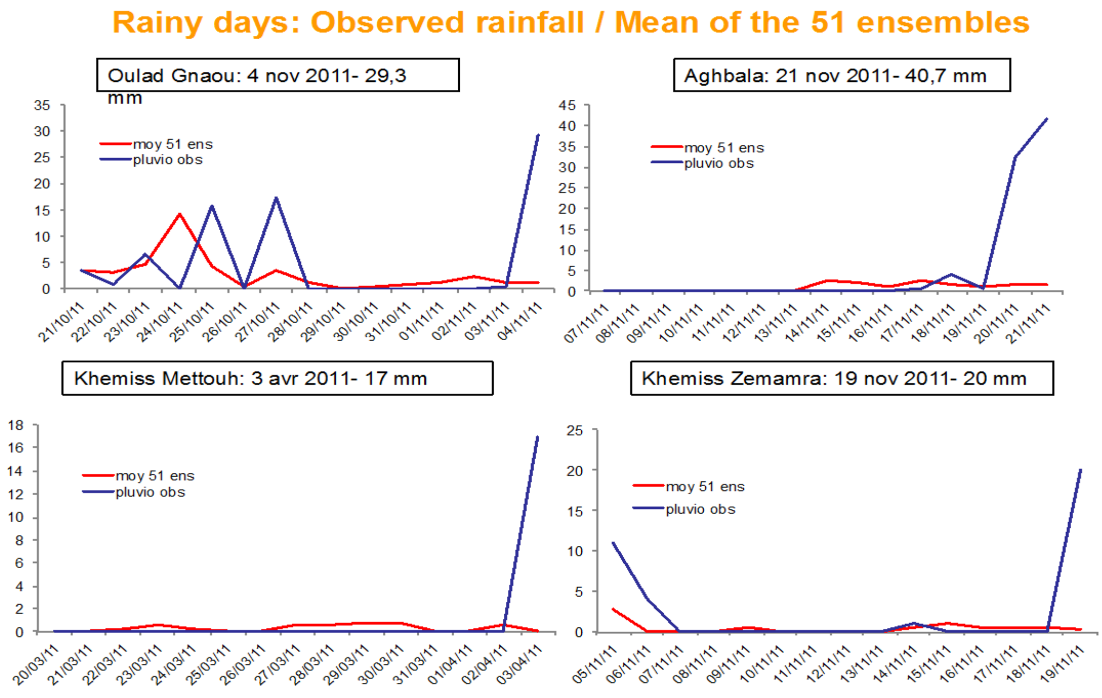


Figure 2-2: Comparison of observed rainfall and mean of the 51 ensembles of forecasts (case of rainy days)

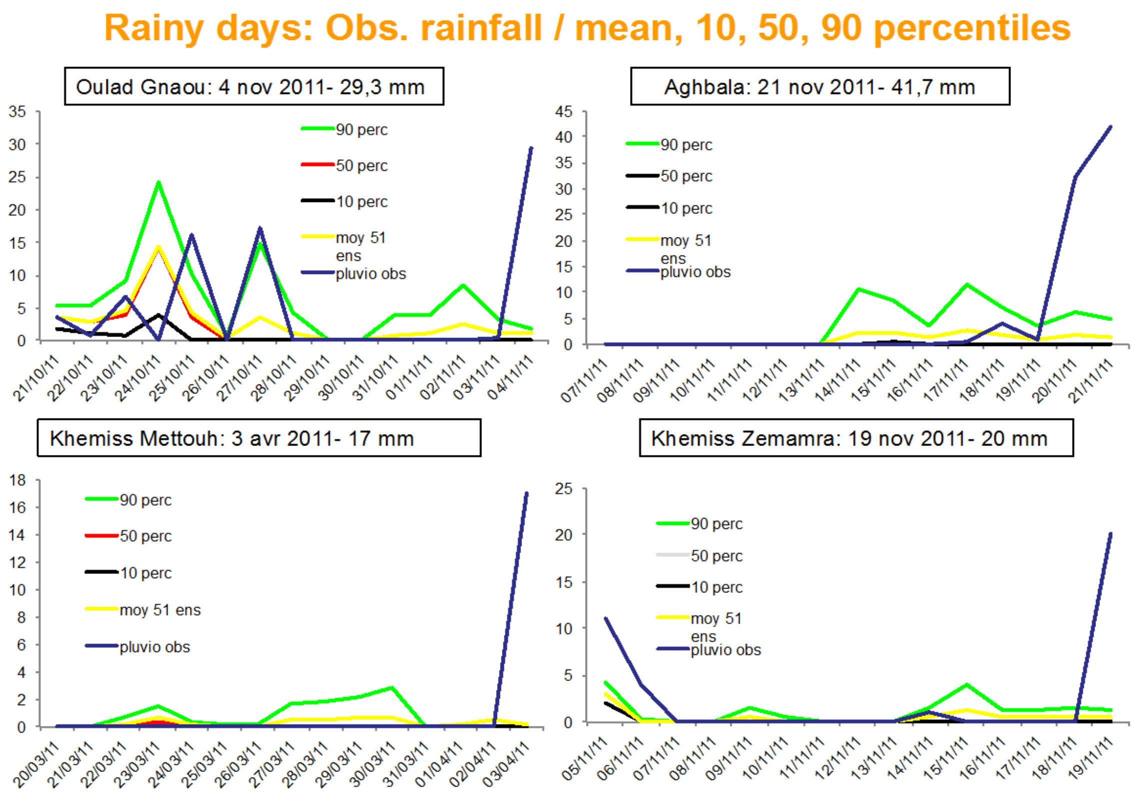


Figure 2-3 Comparison between observed rainfall and mean of the 51 ensembles,10, 50 and 90 percentiles of forecasts (case of rainy days)

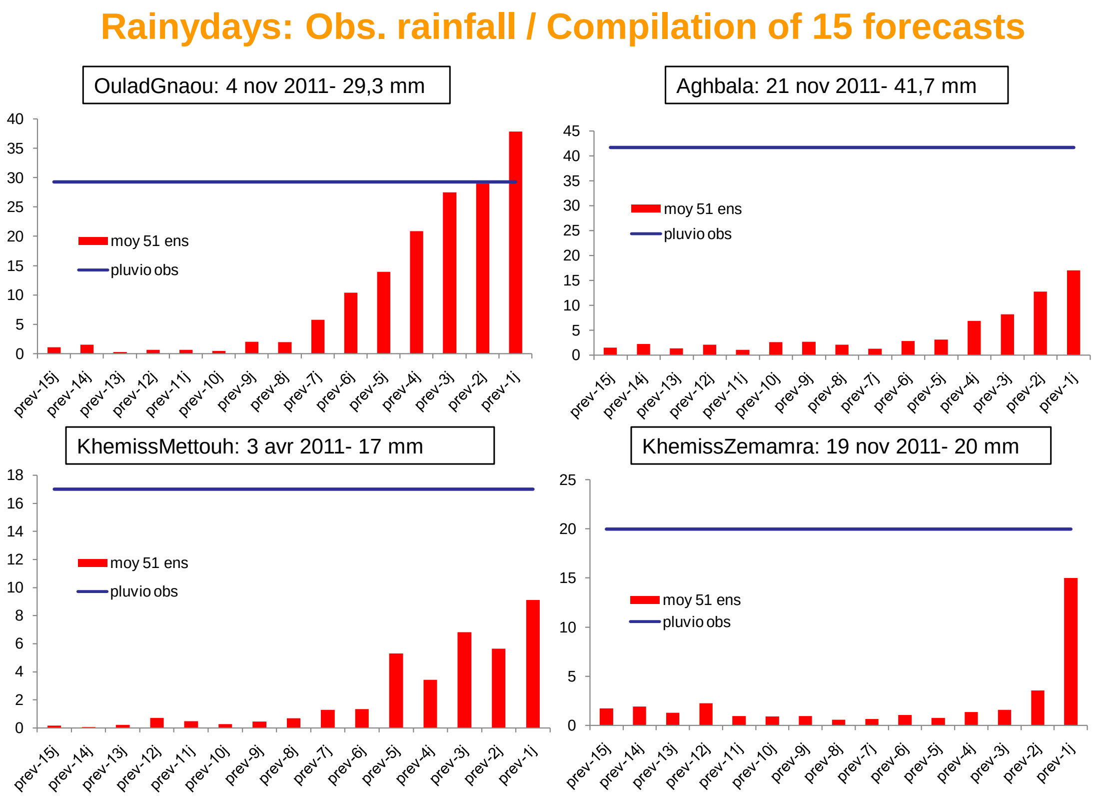


Figure 2-4 Comparison between the observed rainfall and the different forecast (1 day to 15 days lead time) issued for the same day (case of rainy days)

- **Dry days:**

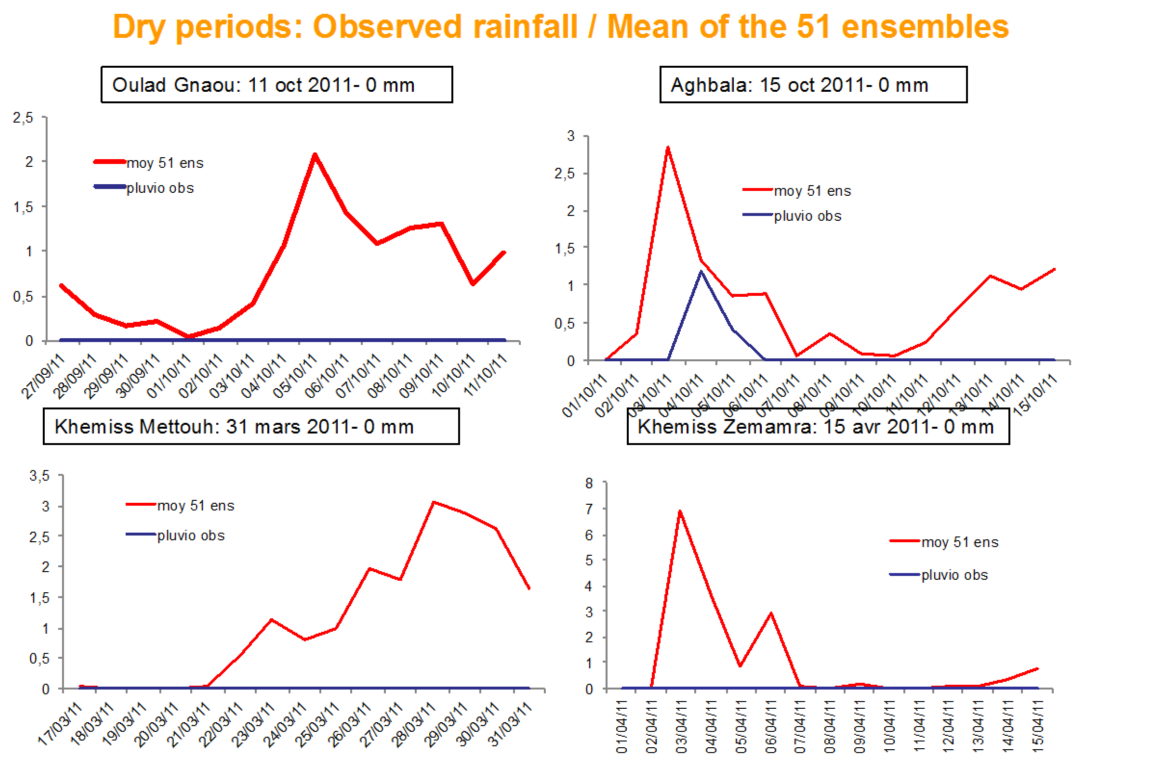


Figure 2-5 Comparison of observed rainfall and mean of the 51 ensembles of forecasts (case of dry days)

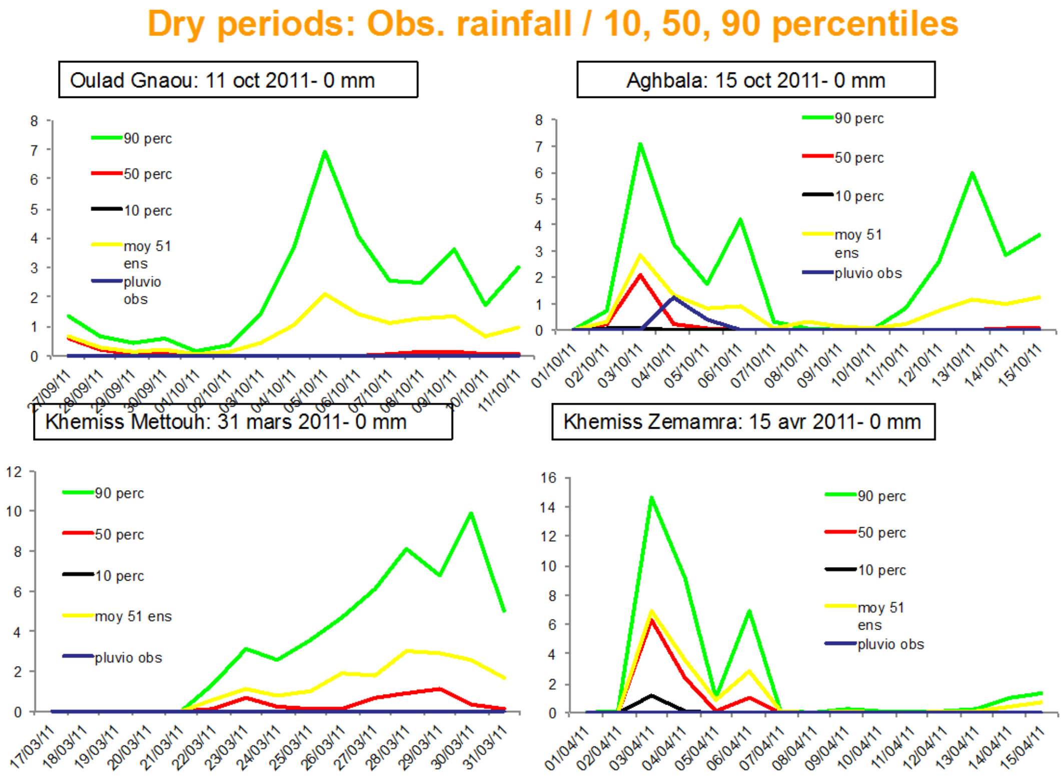


Figure 2-6 Comparison between observed rainfall and mean of the 51 ensembles,10, 50 and 90 percentiles of forecasts (case of dry days)

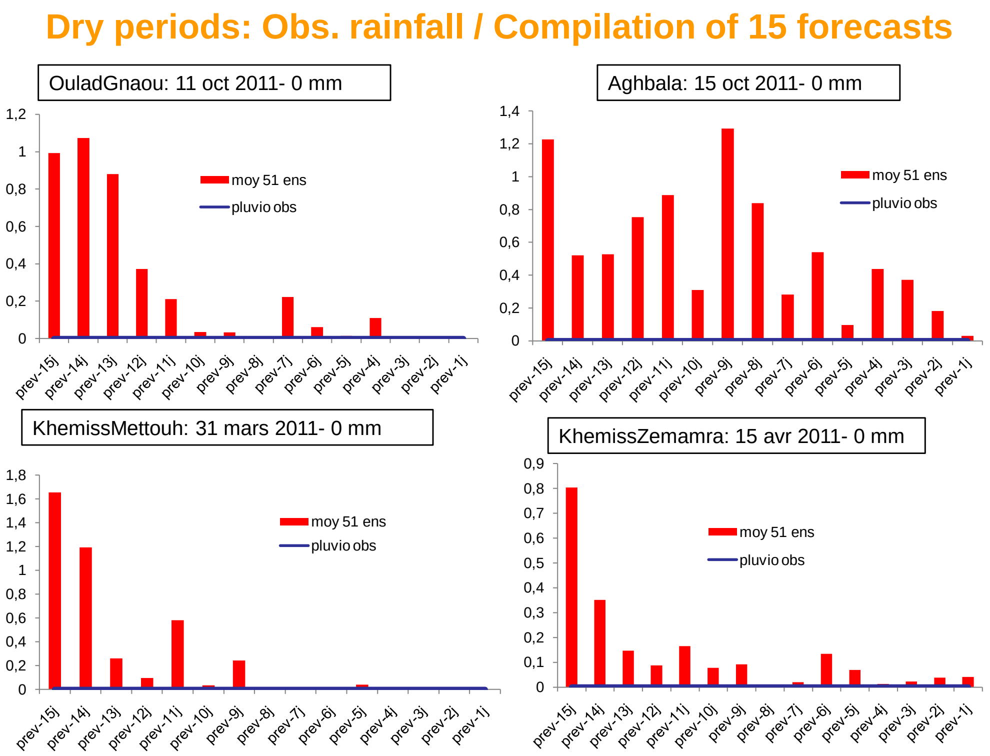


Figure 2-7 Comparison between the observed rainfall and the different forecast (1 day to 15 days lead time) issued for the same day (case of dry days)

The analysis of the results shows:

- The forecasts are not able to detect rainy days 15 days ahead. Indeed, among all the rainy days analysed, none of the forecasts was able to predict either the occurrence of rain or the amount of rain (whatever it was a small, moderate or important rainfall amount).
- On the contrary, the forecasts seem good to predict dry periods, as shown by the fairly good concordance between the observed rainfall and the 50 percentiles.
- Concerning rainy days, the results show that globally, they are not detected from 10 to 15 days ahead. In the best cases, the occurrence of rain starts to be forecasted around 6 days ahead. However, this is not verified for all the forecasts. Then, even when the rainy episodes are forecasted, the amount of rainfall is very often underestimated, especially for important rainfalls.
- Concerning rainy days, the 90 percentiles are the closer to the observed rainfall.

Therefore, the main conclusions from these first sets of analysis are that the medium range forecasts are not able to forecast rain but seem to have better skill in forecasting dry periods. Consequently, in a second step, we conducted analysis on probabilistic forecasts of 7 days accumulated rainfall in order to confirm this trend and assess, thanks to the Brier score, their skill for forecasting dry periods.

2.4.2 Medium range forecasts of 7 days accumulated rainfall

The following figures (Figure 2-8, Figure 2-9, Figure 2-10 and Figure 2-11) present the results obtained while comparing the probabilistic forecasts and the observed 7 days accumulated precipitations for two stations (Oulad Gnaou and Khmiss Metthouh), 3 years (2008, 2010 and 2012) over a period of two months (15 February -15 April), corresponding to a period where cereal yields are strongly correlated to the amount of rainfall.

Figure 2-8 and Figure 2-9 present the Brier Score for each of the 3 categories tested: dry (below normal), normal and wet (above normal) conditions. Figure 2-10 and Figure 2-11 show the Brier score skills for the same data. Results show, that overall, Brier score indicates that the drier periods seem to perform better on average, although there is a significant variation between years.

Most interesting are the Brier Skill scores where we always have skill in predicting dry conditions (values are above 0), but not much skill in predicting wet conditions (less than climatology).

Consequently, these results come to confirm the hypothesis stated after the analysis of the daily forecasts and show that, under the conditions of the Oum er Rbia basin, the medium range rainfall forecasts can be used to predict dry spells.

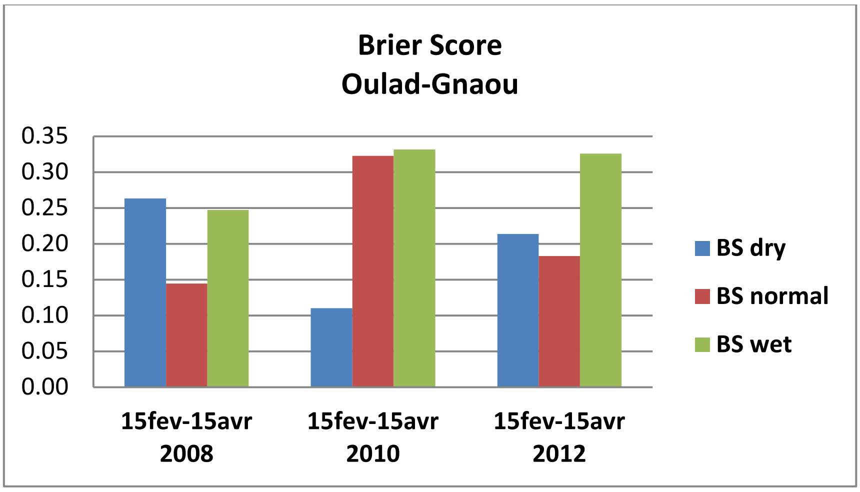


Figure 2-8 Brier score for dry, normal and wet conditions Oulad Gnaou station (2008, 2010, 2012; 15 Feb-15 Apr periods)

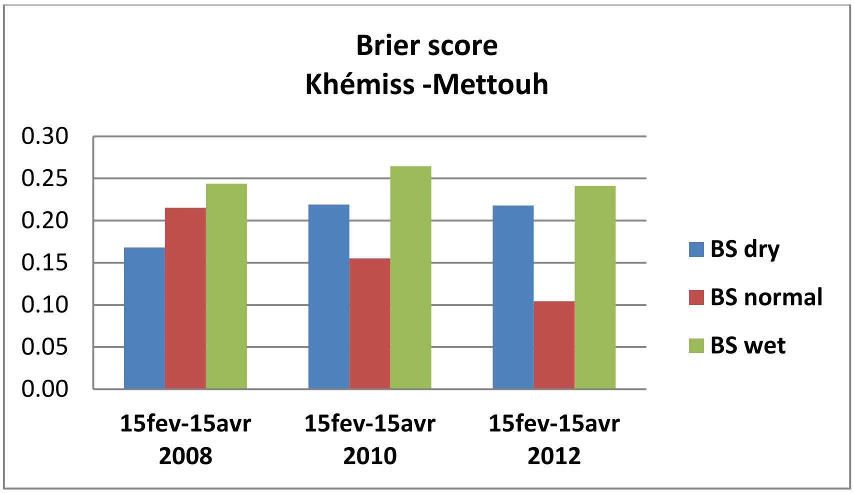


Figure 2-9 Brier score for dry, normal and wet conditions Khmiss Mettouh station (2008, 2010, 2012 15Feb-15Apr periods)

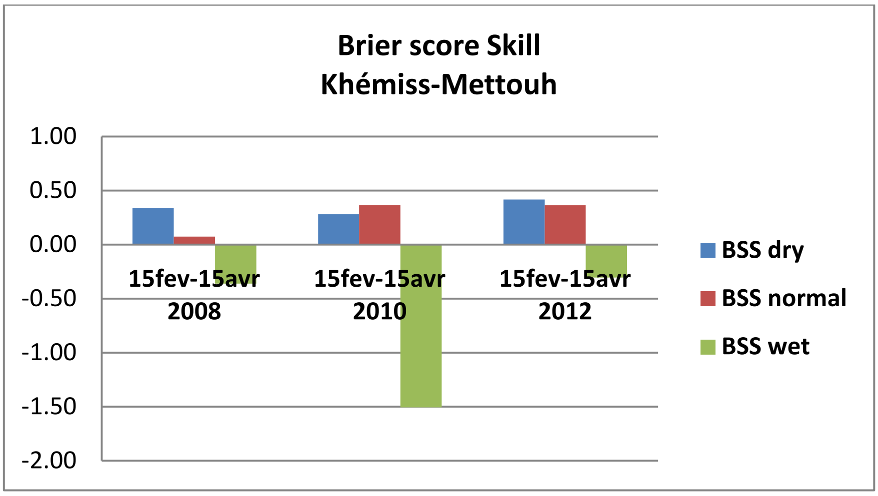


Figure 2-10Brier score skill for dry, normal and wet conditions Khmiss Mettouh station (2008, 2010, 2012; 15 Feb-15 Apr periods)

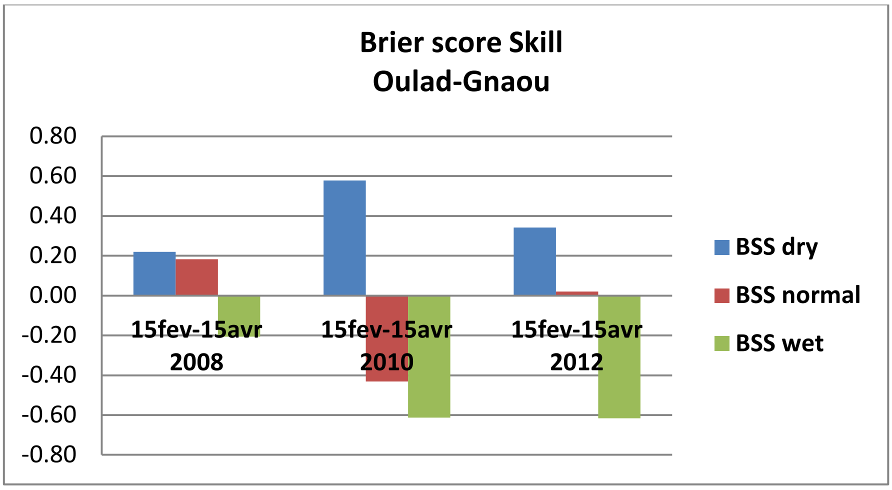


Figure 2-11 Brier score skill for dry, normal and wet conditions Oulad Gnaou station (2008, 2010, 2012; 15 Feb-15 Apr periods)

2.5 ASSESSMENT OF THE POTENTIAL USE OF MEDIUM RANGE FORECASTS OF PRECIPITATION FOR DROUGHT MITIGATION

The objectives of this section of the report are to assess the skills of medium range weather forecasts in the Oum er-Rbia basin and their potential use for the mitigation of intra-annual dry-spell episodes. It focuses on the mid-February-mid-April period corresponding to the grain-filling period that is determinant for cereals yields.

The analysis of the Brier Skill scores results confirm the hypothesis stated after the analysis of the daily forecasts and show that, in the Oum er-Rbia basin, the medium range rainfall forecasts can be used to predict dry spells.

Therefore, we will focus on the last agricultural campaign (2011-2012), when an important drought at the end of the cereals cycle (February-April period) occurs.

In that sense, figure 2-12 and figure 2-13 present the forecasted probabilities for dry days for the two stations issued during the first fifteen days of March 2012 and covering in fact the first three weeks of March. During the same period, the observed rainfall was equal to 0 (probability of 100% of being dry)

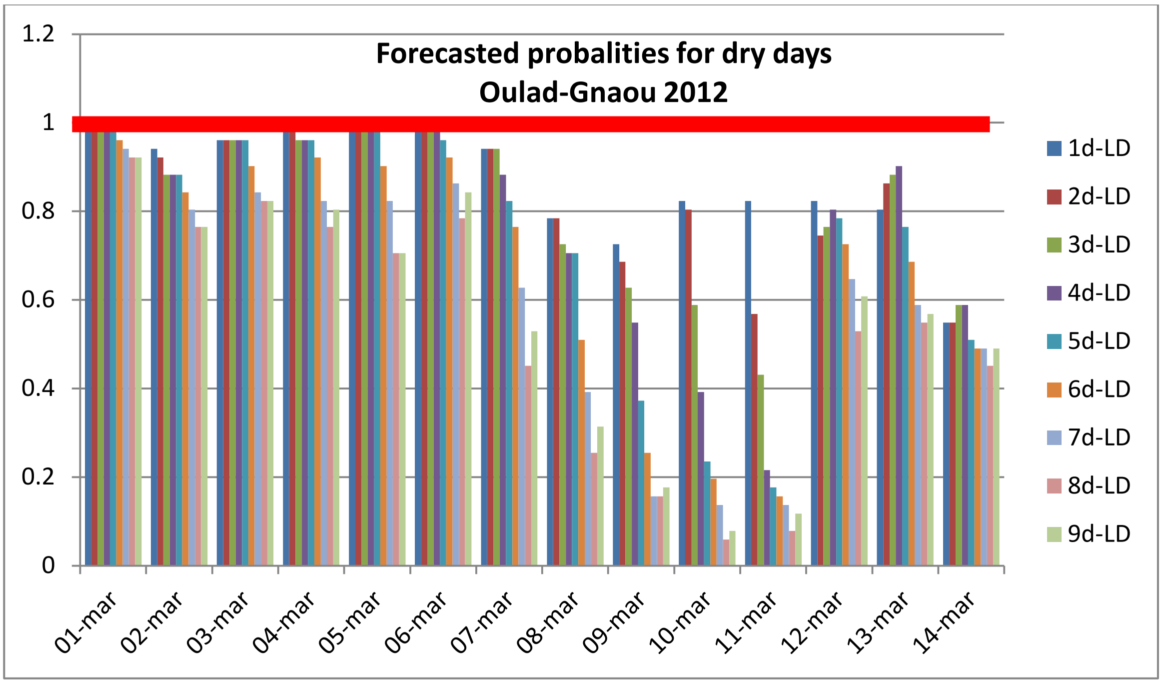


Figure 2-12: Forecasted probabilities for dry days for Oulad Gnaou station in March 2012

(1d-LD= 1day lead time)

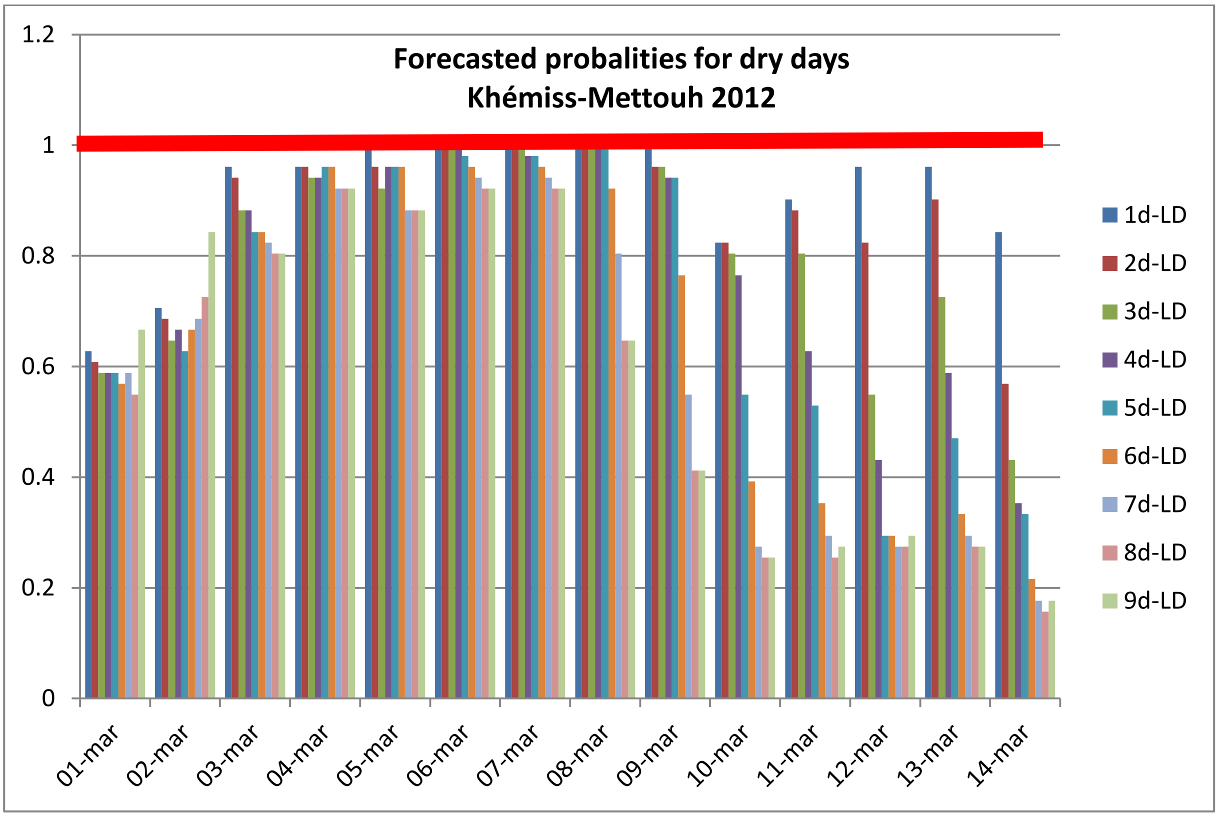
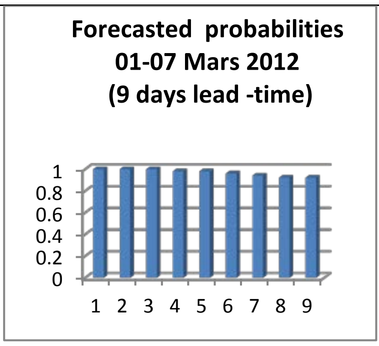
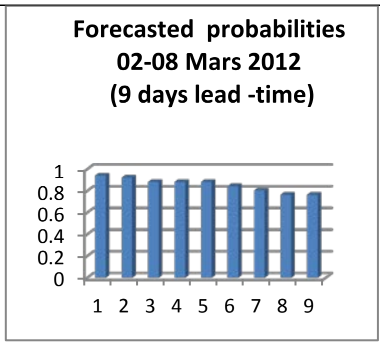


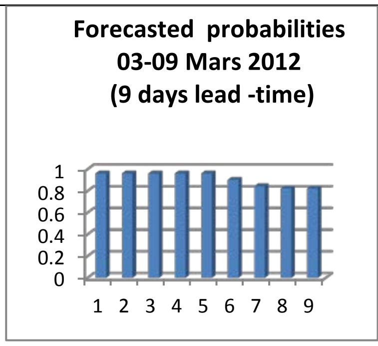
Figure 2-13: Forecasted probabilities for dry days for Khmiss Mettouh station in March 2012

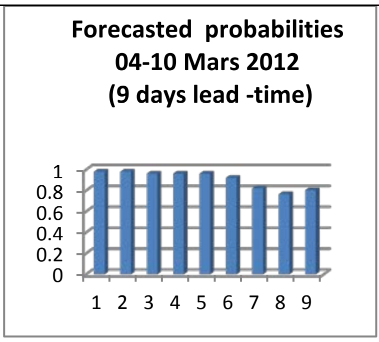
(1d-LD= 1day lead time)

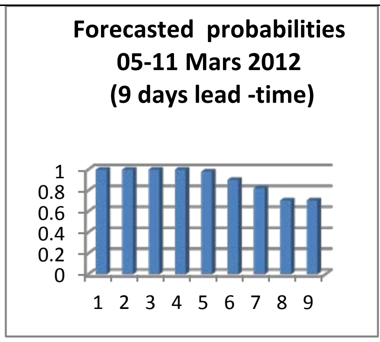
The forecasted probabilities for dry days varied between 0,6 and 1, except for 2 or 3 days within the considered period where the probabilities were lower for the last days lead-time, both, in Oulad-Gnaou and Khmiss- Mettouh. Figures 2-14 and 2-15 show details for each day.

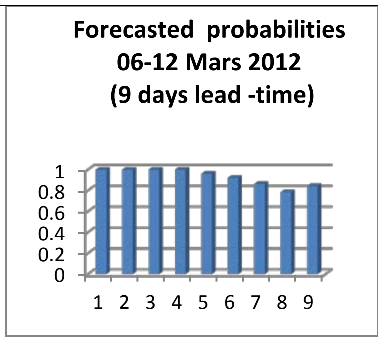


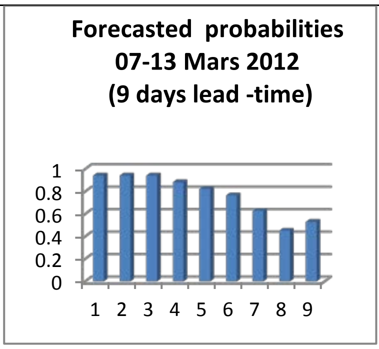


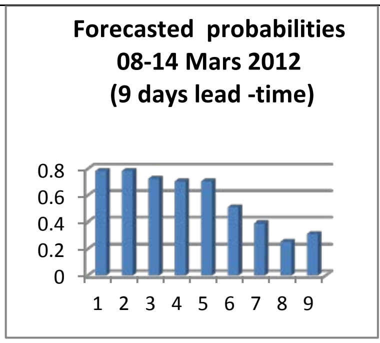


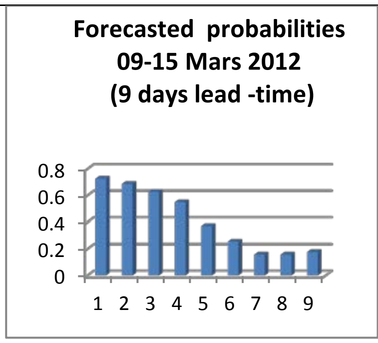


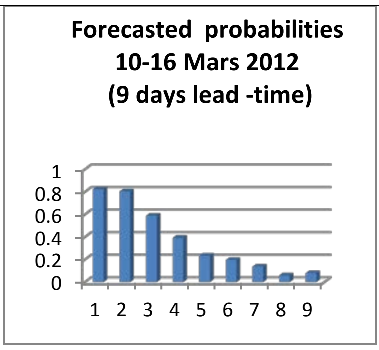


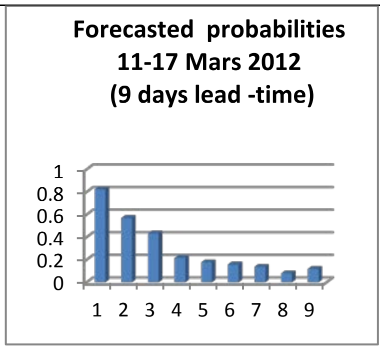


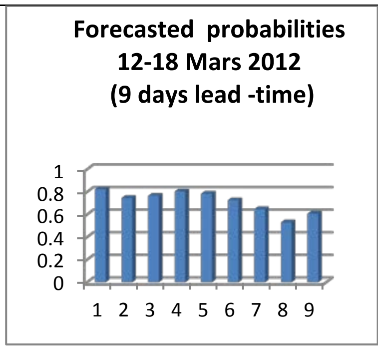


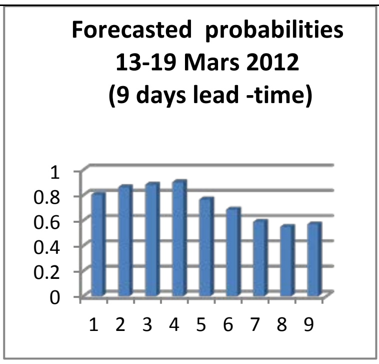












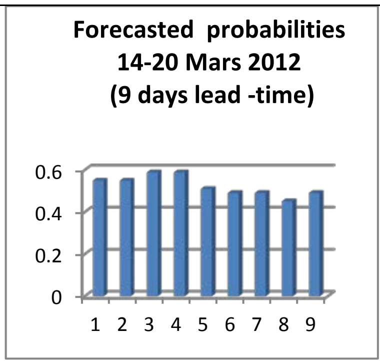
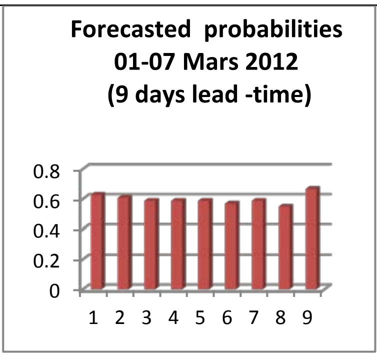
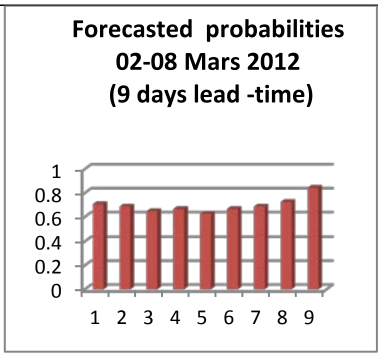
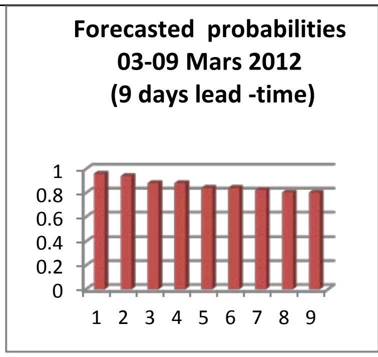
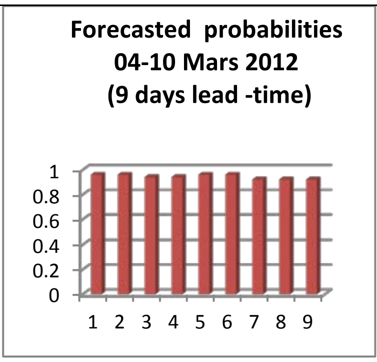


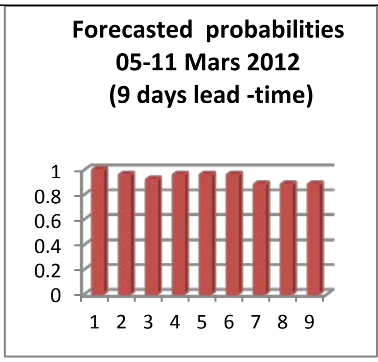
Figure 2-14: Forecasted probabilities for each considered day in Oulad-Gnaou

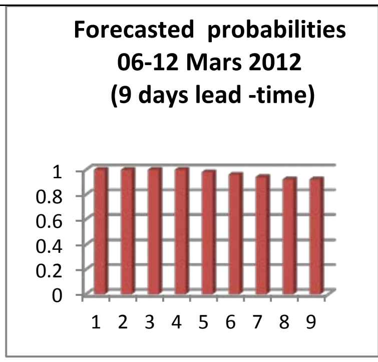


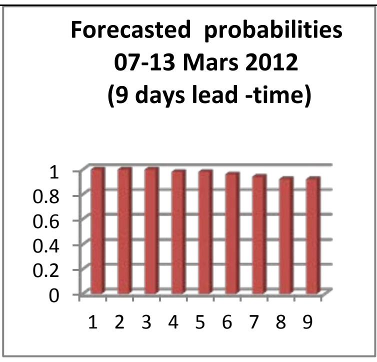


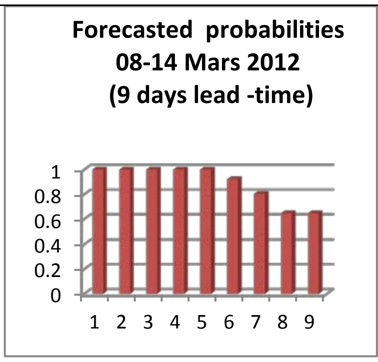


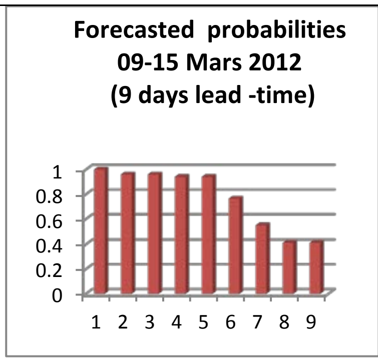


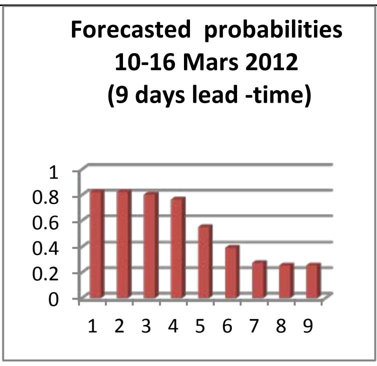


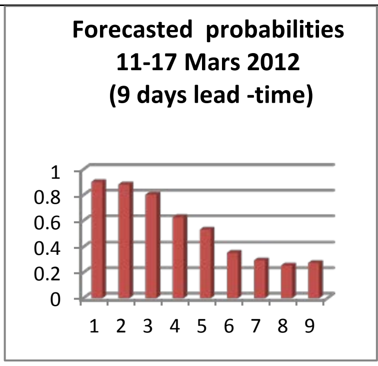


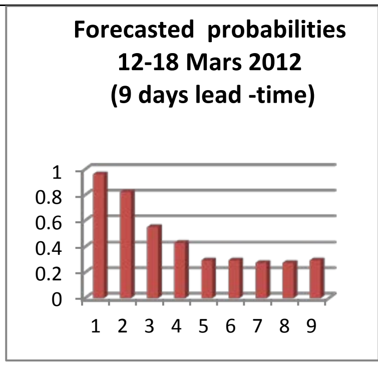


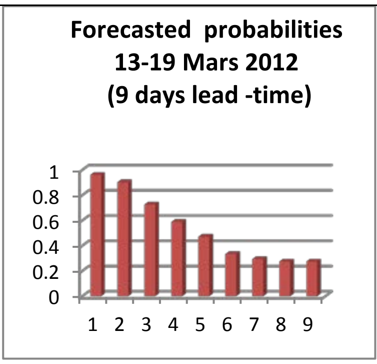












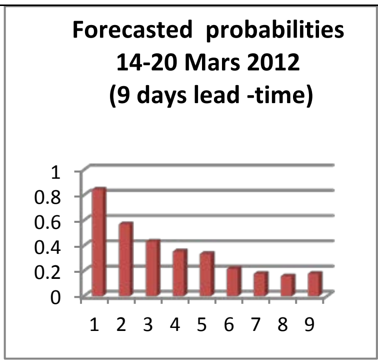


Figure 2-15: Forecasted probabilities for each considered day in Khémiss Mettouh

In the next section, we will determine how these 2 weeks dry forecasts can be used in the context of Moroccan agriculture to mitigate drought consequences on cereals, livestock and water needs. We will determine how these forecasts could have been used if decision-makers and farmers have had this information.

Moroccan agriculture is strongly dependent on rainfall, as rainfed areas represent 85% of agricultural lands (7.9 million hectares). Cereals are a strategic food in Morocco with a consumption of 210 kg per capita, one of the highest in the world (159 kg at world level), which is still not entirely covered by local production. For these reasons, we will focus our discussion on the rainfed areas and cereal crops.

2.6 MEDIUM-RANGE FORECAST AND EARLY WARNING

Long before weather events occur (during the rainy season), agricultural producers need to decide what type, where and how many surfaces of crops will be planted, and/or how many cattle will be sold or bought. These decisions are based on their resources and needs. However, a critical component of planning is the provision of climate information, including drought forecasts as droughts are the biggest threat under the Moroccan conditions. Timely and reliable drought forecast will allow decision makers to set an early drought warning and to take, consequently, the more appropriate decisions.

The drought management plan in Morocco is mainly proactive, that’s why any time saved can have occasionally some decrease in the drought vulnerability. In addition, because the drought management plan involves several administrations, as shown in DEWFORA D 2.1 and D 2.2 a reliable prediction of a drought period 15 days before it’s occurrence, will allow this collaborative process to be shorter. This fact is very important, especially for the remote areas where often the needed help comes late.

Once the drought is declared, the Moroccan government implements several actions, farmers and herders, at their side, handle drought through many strategies:

2.6.1 Seed supply

The objective in this action is the improvement of seed availability for the next cropping season, which is related to the expected yields of the current year, forecasted during March. If a dry period is expected during this period and can be predicted, a more reliable estimation of the needs can be done. In this process, to gain seeds two weeks earlier could secure the purchases and give a chance to government to get a lower price given the high cost of the imported seeds. For their part, farmers can provide some of the stored seeds for animal feed.

2.6.2 Measures for livestock

The governmental program of livestock protection is developing based on the estimated fodder deficit due to the expected drought. Advancing such information and the assistance that follows, will allow farmers to receive subsidies in time to save their cash, which they would have to use in case of late assistance. Moreover, for their own mitigation strategies, herders have developed tactics, which include:

- Diversifying into different animal species and different breeds;
- Carrying extra animals that can be liquidated easily during a drought, either for food or cash;
- Maintaining feed reserves or purchasing supplementary forage, to compensate the deficit of

grazing;

- Investing in cisterns for watering livestock;
- Diversifying into non-agriculture, particularly seasonal migration and non-farm employment.

Being aware of the drought two weeks before its occurrence could help farmers to better manage these strategies, especially increasing supplemental feeding, and/or reducing livestock (especially sheep in the case of Morocco) size prior to inflation and/or decline in market prices. Indeed, animal's liquidation in response to drought often forces herders to sell during a non-optimal market conditions.

Moreover the authorization request grazing fallow and the organization of transport feed can be made earlier which is reflected positively on cash farm.

Thus, it appears clearly that improved drought forecasting will allow herders to better avoid regional financial "booms and busts" generated by drought.

2.6.3 Measures for water supply

When drought is forecasted, a reactive action plan can be adopted to mitigate its effects. In such situations, the relative portion of water used for agriculture declines because domestic and industrial water are priority and served first.

With a medium range forecasts, decision-makers and farmers can focus on an operationally oriented short-term program with relief operations as:

- The collection and conservation of water;
- The minimization of water losses;
- The improvement of water harvest and storage at farm and parcel levels;
- The mobilization of groundwater resources for supplementary irrigation;
- The early mobilization of water resources for drinking and livestock watering.

However, a structurally program, focusing on the long-term proactive approach to drought mitigation needs seasonal forecasting.

2.6.4 Drought insurance

In Morocco, drought insurance has been implemented since 1993. A committee gathering the ministry of agriculture and MAMDA (Moroccan Agricultural mutual) staff manage this insurance and implement a payment scheme for farmers based on the cereals yield decline. In 2011, Morocco has enlarged the drought insurance to multi-hazard crop insurance, including drought.

Thanks to a reliable drought forecast, the involved decision-makers for drought insurance, will improve the preparedness and the building of the human and financial resources for farmer payment.

In addition, part of the risk is reinsured in international weather markets. When drought is severe and the payment must exceed a certain threshold, MAMDA relies on these international companies for reinsurance, which pays on the basis of specific weather indices observed in Morocco. Reinsurers usually require an objective, reliable and transparent index measurement operated by the national weather service.

A reliable 2 weeks drought forecast may help in speeding this process by advancing the assessment of the situation and the establishment of the needed indicators and indexes. Insurance companies will be notified early enough to address farmer's needs and by proceeding with payments earlier may improve their resilience at a moment when they are the most vulnerable.

Morocco is taking action to help farmers suffering from the drought.

Prime Minister Abdelilah Benkirane on March 27th met a delegation from the Moroccan Agriculture and Rural Development Confederation to discuss a plan to help farmers and save livestock.

The government plans to implement a 1.53 billion dirham programme for the affected areas. The government will waive customs duty on imported barley, implement a livestock assistance programme, supply seed, boost subsidies granted for certified seeds and ensure that insured farmers whose crops and legumes have been harmed are compensated for their losses.

(*Magharebia, 24-04-12*)

Morocco is taking action to help farmers suffering from the drought.

Hmida El Mhaidi, a farmer in Kenitra, said that the most pressing issue was the need to save livestock. "Farmers are eagerly waiting to receive subsidies from the government to help them deal with the lack of rainfall and the high prices of animal feed and fodder," he said.

(*Magharebia, 24-04-12*)

2.7 MEDIUM-RANGE FORECAST AND SUPPLEMENTARY IRRIGATION

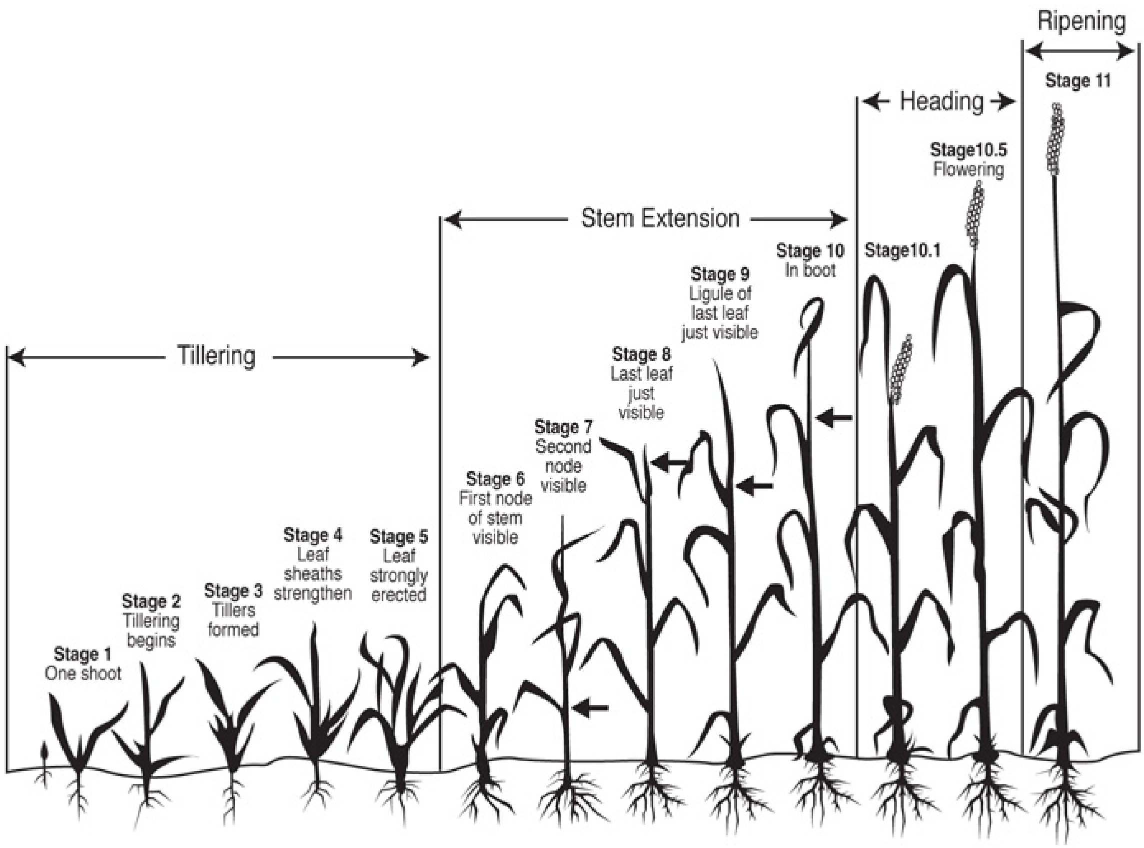
During the growing season, a prolonged drought spell can damage cereal crop production in rainfed areas. In the basin, as in many parts of Morocco and MENA region, some of the rainfed areas can access to temporary irrigation systems. In this situation, medium range precipitation forecasts could provide an early warning system allowing the farmers to prepare such supplementary irrigation.

Supplementary irrigation (SI) means the addition of small amounts of water to essentially rainfed crops during times when rainfall fails to provide sufficient moisture for normal plant growth, in order to improve and stabilize yields. SI in areas with limited water resources is based on the following three premises:

- Water is applied to a rainfed crop, which would normally produce some yield without irrigation.
- Since precipitation is the principal source of moisture for rainfed crops, SI is only applied when precipitation fails to provide essential moisture for improved and stabilized production.
- The amount and timing of SI are not scheduled to provide moisture-stress-free conditions throughout the growing season, but to ensure that the minimum amount of water required for optimal (not maximum) yield is available during the critical stages

of crop growth.

According to these information, we can see that we are facing a challenge, on one hand, we need to secure the critical stages, and on the other hand, we have a very limited quantity of water that we could apply on the most dry period during one of the most critical stages; A medium range forecast could be very useful for this decision.



<table>
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<tr><td colspan="10">Vegetative phase</td><td colspan="6">Reproductive phase</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="2">P1</td><td></td><td></td><td colspan="2">P2</td><td colspan="2">P3</td><td></td><td></td><td></td></tr>
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Figure 2-16: growing stages and critical phases for wheat

As shown by figure 2-16, there are three critical stages for cereal production: Tillering (P1) Anthesis (P2) and grain filling (P3). Most of time, farmers have the possibility to apply only one SI, sometimes two, and they need a decision tool system to fix on the driest periods within the 3 critical stages.

Farmers must succeed the vegetative phase, that's why a SI during the period P1 is required. However, in many cases, when a significant rain follows this water supply, farmers tend to foster the vegetative phase versus the reproductive phase, which affects negatively yields. Indeed, an optimum must be maintained between the two phases. That's one of the reasons a 2 weeks forecast can help users and farmers to decide about this first SI, which they mobilize only if a drought period is forecasted. Concerning the SI needed during P2 and/or P3, we believe that seasonal forecasts must be integrated to provide farmers with a comprehensive representation of current conditions and future outlooks to determine the most appropriate irrigation.

2.8 MEDIUM-RANGE FORECAST AND OTHER CROPS TECHNIQUES

In addition to the drought mitigation effects discussed above, a 15 day forecasts can be used for soil labours and sowing, planning of fertilizers and harvesting dates.

If such period of drought is predicted, farmers can delay the crop installation. Indeed, because water and temperature stress are the most critical abiotic stresses for winter cereals in Morocco, the time of sowing is crucial especially in the rainfed areas.

Consequently, sowing dates must be enough early to profit from the rainy season and to escape the high temperatures during the end of the cycle. However, while clear weather is required for sowing operations, it must be preceded or succeeded by seed-zone soil moisture storage. In the case where farmers can't delay the sowing date, drought information will allow them to opt for no till strategy in order to conserve soil moisture, and to opt for a seeding rate increase.

Moreover, with a medium range forecast, farmers can better manage the fertilizers application by avoiding the drought periods which lead to an improper use of nitrogen fertilizers by hindering their dissolution and crop uptake.

Drought also induces physiological stress, increasing plant's susceptibility to disease and insects. A medium-range forecast may help farmers to decide the types, the quantities and the dates of phytosanitary treatments. Thus, weather forecasts can not only help adapt the volume of agrochemicals applied, but also make the applications more effective.

Concerning the harvesting date, with such drought forecast, farmers, can look for an optimal timing to escape the hot temperatures but also, to allow enough time for grain filling without worrying about a probable rain able to initiate germination on ear.

2.9 CONCLUSION

Our main and first objective in this section was to assess the skill of medium range weather forecasts in the Oum-Er Rbia basin. The analysis focused on rainfed areas and cereal crops given their predominance and socio-economic importance around the basin and throughout all the country.

Both, daily and medium-range forecasts appeared not able to predict rain, but seemed to show better skills in forecasting dry periods.

The second objective was to investigate whether medium range forecasts can be used for a better drought mitigation and/or early warning, in the context of what they are meant to offer to the agricultural sector vis-a-vis user needs. Emphasis was placed on farmers of rainfed areas. Indeed, under North African conditions where drought is the worst threat, a reliable drought forecast system would provide farmers with a more comprehensive decision tool system for their decision-making.

We developed in this chapter some examples of medium-range forecasting use in the context of our case study. As discussed, some significant potential exist both for early warning and mitigation operations, especially for herders which are in financial inability to cope with major food purchases to save their cattle, but also for crop imports, subsidies and some agricultural practices.

However, knowing that in rainfed agriculture, there is little room for adjusting decisions once the crops are planted, some of the measures, such as pre-season agronomic corrections, control operations against pests and diseases, supplementary irrigation, and the scheduling of harvests, will be high-cost decisions. That's why improved forecasting of drought onset, frequency and intensity would allow farmers to make better choices.

Moreover, for an actual increasing of rainfed farming resilience, the integration of seasonal forecasts appears to be essential. Such scale of forecast may allow governments and relief agencies to position themselves for more effective and cost-efficient drought interventions. Producers could more accurately evaluate their production options and insurance companies anticipate payments to farmers, while herders could better sell their livestock.

The experiences of forecasts in many countries where there are fundamental difficulties in understanding and applying probabilistic information for decision-making showed that even if forecasts have little observable value, good communication provides farmers with valuable collateral benefits.

3. SEASONAL FORECASTS FOR CEREAL YIELDS PREDICTION

A statistical-dynamical approach to estimate crop yields over the Oum er-Rbia basin was outlined in DEWFORA deliverables D4.10 and 4.11. This section presents a brief description of the main findings of this study.

The main assumption of the analysis is that if a global model is able to represent seasonal rainfall, the same model output can be used in a statistical forecast system to predict rain fed commodities such as crops. The atmospheric low level circulation fields were used as predictors of crop yields using a principal component regression. In that way the predictability of seasonal crop yields were tested in the region.

The ECMWF System S4 seasonal hindcasts (see WP4-D4.2 for details) were used as the input data (predictors). Three-month averaged sea-level pressure (SLP) and 850 hPa geopotential height for the season prior of harvesting were selected as predictors for the statistical model. On the other hand, the durum wheat yield data (predictand) was divided into three different regions (coasts, plains and mountains) during the period 1979-2008.

The methodology used to post-process ECMWF S4 data to crop yields is the Model Output Statistics (MOS; Wilks, 2011). MOS is developed by applying principal component regression from the Climate Predictability Tool (CPT) of the international Research Institute for Climate and Society (IRI). The low-level circulation variables were selected over a domain that includes the equatorial Pacific and Atlantic Oceans (Figure 3-1). This selection comprises the influences of both oceans as well as hemispheric circulation patterns (e.g. the North Atlantic Oscillation).

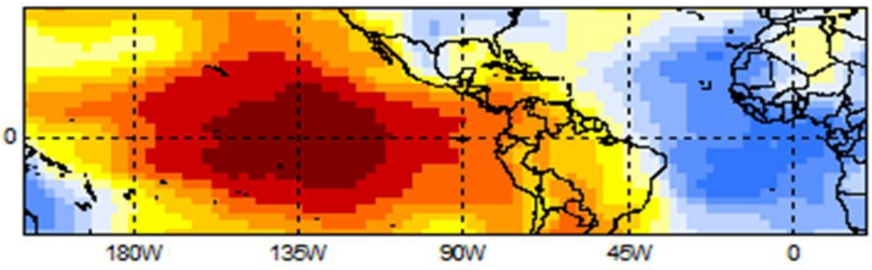

Figure 3-1: SLP domain used for the Oum er-Rbia wheat yield predictions.

The statistical model ability to skilfully produce downscaled forecasts was also tested. A potential for making yield predictions over the mountains and coastal areas was detected using both deterministic and stochastic approaches. Particularly, with a two months lead-time, high and low yield are well discriminated for both areas (See Figure 3-2). On the other hand a very low predictability was identified over the plains of the basin.

Forecasts with lead-times of up to four months (but mainly up to two months) using ECMWF S4 hindcasts were analysed showing that low-level circulation data can be successfully downscaled for predicting durum wheat yield for the mountain and coastal areas.

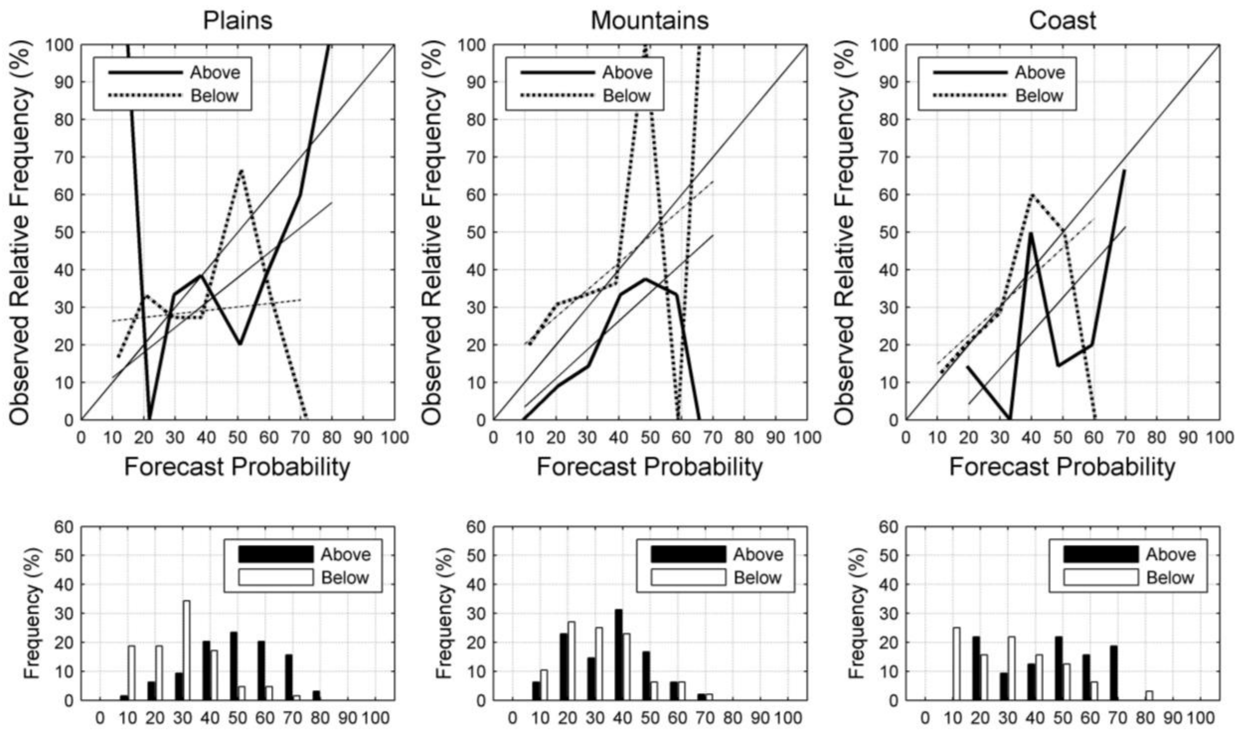

Figure 3-2: Reliability diagram and frequency histogram for high (>67th percentile) and low (<33rd percentile) yields for the three Oumer-Rbia areas at a 2-month lead-time obtained from 16 years of hindcasts produced by downscaling the ECMWF S4 coupled model. The thin solid (dashed) line is the weighted least squares regression line of the high (low) yield reliability curve. Black and white bars of the frequency histogram are respectively for high and low yields.

4. DROUGHT VULNERABILITY MAPPING AT THE RURAL COMMUNE LEVEL

4.1 FOLLOWED APPROACH

4.1.1 Evaluating vulnerability

In attempts to move more towards a proactive risk management approach, a more concerted effort towards planning for drought involves vulnerability assessment (Wilhite, 1993, 1997, 2000; Wilhelmi and Wilhite, 2002).

The objective of the vulnerability assessment is to identify underlying causes of risk derived from inadequate structures, management, and technology, or by economic, environmental, and social factors. Vulnerability refers therefore to the characteristics of a group in terms of its capacity to anticipate, cope with, resistand recover from the impact of drought. Vulnerability assessment aims to identify characteristics of the systems that modify the level of risk derived from inadequate structures, management, and technology, or caused by economic, environmental, and social factors (Iglesias et al., 2007).

Vulnerability is not something that can be directly observed or quantified on its own. Rather, it is a relative term comprised of many dimensions. As a result, it is necessary to identify proxy variables or indicators that can be used to assess vulnerability. Ideally these indicators will simplify complex phenomena and then transform them into a usable form. The idea is to identify a small yet comprehensive set of indicators that can be tracked over time and disaggregated to the relevant social unit (Brenkert and Malone, 2005 artcivle brésil).

Several previous attempts have been made to create a quantitative index of vulnerability. These indices seek to provide scores that describe the relative vulnerability of countries, regions or communities. Several examples of this type of index are available in the literature:

Yohe and Tol (2002) proposed a method for developing indicators for social and economic coping capacity in the context of climate change. Later, a simple index to quantify adaptive capacity was used by Ionescu *et al.* (2007) including only GDP, literacy rate, and labour participation rate of women.

Examples of this type of index include also O'Brien et. al. (2004), Moss, Brenkert and Malone (2001, 2005) and Vincent (2004). O'Brien et al. (2004) build maps of agricultural vulnerability to climate change and globalization in India by creating indices of adaptive capacity, climate sensitivity, climate change vulnerability and import-sensitivity by district. These indices are comprised of biophysical, socioeconomic and technological factors that affect agricultural production such as soil conditions, ground water availability, and levels of human and social capital, presence of alternative economic activities, literacy rates and gender equity (O'Brien et al., 2004). These maps can then be used to characterize relative vulnerability of the districts by overlaying vulnerability to climate and other societal changes.

Iglesias *et al.* (2007a) develop an Adaptive Capacity index (ACI) with three major components that characterize the economic capacity, human and civic resources, and agricultural innovation. A similar approach has been taken in the context of drought (Moneo, 2007) and aimed to develop a drought vulnerability index (DVI). The approach is flexible and can be applied to managed and natural ecosystems as well as to socio-economic systems.

In Work package 3, this latter approach was proposed for mapping drought vulnerability at different levels. In D 6.4, these methods were used to map drought vulnerability at the continental level. Here, they will be applied in the case study of the Oum Er Rbia basin at rural commune level, using local data.

4.1.2 Drought Vulnerability Index (DVI)

The Drought Vulnerability Index (DVI) can be applied locally or spatially and with different aggregation levels of the input data. The intermediate components can be evaluated independently, allowing comprehensive interpretation of the strengths and weaknesses of each system. The sequential steps taken for the quantification of the DVI are: (a) select variables that are relevant; (b) normalize the variable values with respect to some common baseline; (c) combine the sub-component variables within each category by weighted averages; and (d) quantify DVI as the weighted average of the components. The scores of the DVI range on a scale of 0 to 1, with the total being generated as the average of each component.

The DVI integrates severable variables that fall under 4 dimensions named as:

- Renewable Natural Capital
- Economic capacity
- Human and Civic Resources
- Infrastructure and Technology

The DVI is calculated with a similar methodology as the Human Development Indicator (HDI). Before calculating the overall DVI, an indicator for each of the dimensions needs to be computed.

4.2 SELECTION AND RELEVANCE OF INDICATORS

Table 4-1 presents all the indicators selected for the drought vulnerability assessment and mapping in the Oum Er Rbia basin.

Table 4-1: Vulnerability and adaptive factors identified for the assessment of rural drought vulnerability in the Oum er Rbia basin:

Indicator	Source	Weight	Type
Renewable Natural Capital			
Agricultural water needs in MM^3 (at provincial level)	Provincial Direction of Agriculture, ORMVAS	__	V
Drinking water counsumptions In MM^3 (at provincial level)	Provincial Direction of Agriculture, ORMVAS	__	V
Average precipitation (mm/year)	Extension services of the Ministry of Agriculture	__	A
Irrigated area (% of arable land)	Extension services of the Ministry of Agriculture	__	A
large scale irrigation (% of irrigated land)	Extension services of the Ministry of Agriculture	__	A

	Economic capacity		
Rangelands and Forests (% of total lands)	Extension services of the Ministry of Agriculture	__	A
Cereals and legumes (% of arable lands)	Extension services of the Ministry of Agriculture	__	V
fruit trees and garden crops (% of arable lands)	Extension services of the Ministry of Agriculture	__	A
Importance and composition of livestock - Cattle (units per number of farms) - Sheep (units per number of farms) - Goats (units per number of farms)	Extension services of the Ministry of Agriculture	__	A
Poverty index (% of households under the level of 3569 Dh/person/year)	Haut Commissariat au plan (National Statistics Ministry)	__	V
Vulnerability to poverty index (% of households with incomes between 3569 and 5353 Dh/person/year)	Haut Commissariat au plan (National Statistics Ministry)	__	V
Land status (% of melk)	Extension services of the Ministry of Agriculture	__	A
Farms size (% of farms with less than 5 ha)	Extension services of the Ministry of Agriculture	__	V
Additional incomes from emigration '% of households)	Haut Commissariat au plan (National Statistics Ministry)	__	A
	Human and Civic resources		
Adult illliteracy rate (%)	Haut Commissariat au plan (National Statistics Ministry)	__	V
Population without access to tap water but with access to improved water (% of rural households)	Haut Commissariat au plan (National Statistics Ministry), ABH	__	V
Population age (> 45 years)	Haut Commissariat au plan (National Statistics Ministry)	__	V
	Infrastructure and Technology		
Agricultural machinery (number of tractors per Km^2 of cropland)	Extension services of the Ministry of Agriculture	__	A
Water infrastructure In MM^3 (at provincial level)	ABH	__	A

The variables included were selected because of:

- They are drought dependant.
- The availability of most of them at the rural commune level

4.2.1 Indicators of Renewable Natural Capital

Natural capital is understood as a set of renewable and non-renewable natural resources, including agricultural land, fisheries, fossil fuels, forest resources, water, biodiversity and minerals.

In this study, five indicators relate to natural capital were selected:

- agricultural water needs and drinking water consumptions:

The agricultural water needs and drinking water consumptions are expressed at the provincial level. in fact, Iglesias *et al*., (2007) reported the agricultural water use (%) and the total water use (% of renewable) as proxy parameters for drought vulnerability assessment. but in our case study, due to the unavailability of these data at the commune or even provincial level, we assumed that the available parameters of drinking water consumptions (since they usually represent about 10% of total water use) and agricultural water needs (since they are also correlated to agricultural water use), are also linked to drought vulnerability and we hypothesized that vulnerability increases with an increase of irrigation water needs and drinking water consumptions.

- average precipitation (mm/year)

In rainfed agriculture and land marked by recurrent drought, the amount of rainfall clearly impacts a farmer's success. when considering the vulnerability of farmers, "the climate is first," according to the discussions held with local experts and farmers during the local dewfora end-user's workshop. in addition, they reported that variability in the distribution and timing of rainfall is as much of a threat as lack of rainfall. indeed, even in years with adequate average rainfall, some areas may receive very little rain. it is therefore important to assess how rainfall varies "not just each year but in each locality since it may be very diverse in time and space.

- Irrigated areas (% of cropland) and large scale irrigation (% of irrigated areas).

The ability of the people and the land to withstand rainfall and therefore to be less vulnerable to drought episodes is clearly linked to the capacity of providing additional water through irrigation, making consequently the % of irrigated area a good proxy for drought vulnerability assessment. In addition, in Morocco, there are both small and medium scale (SMI) and large scale (LSI) irrigation systems. The SMI projects range from few to several thousand hectares. They are mainly traditional systems some of which have been developed for centuries and rely mainly on ground water resources or non regularised water resources. Thus, they often know inter-annual and seasonal variations. Large scale irrigation is the centerpiece of the irrigated agricultural development of the country. LSI projects represent new investments in major civil works for water regulation, conveyance and distribution systems (including on farm) using modern technologies. Irrigated areas under the scope of LSI are therefore less vulnerable to drought since they beneficiate from more regular water resources.

4.2.2 Indicators of Economic capacity

Land cover and land use:

- *Cereals, Fruit trees and Garden crops*

The first set of indicators of economic capacity represent the land cover and use patterns and are the percentage of rangelands and forests, the percentage of cereals and the percentage of fruit trees and garden crops. Among these parameters, the last two quantify the percentage of subsistence crops (cereals) mainly conducted under rainfed conditions versus cash crops that usually beneficiate from more favorable environments (fruit trees in mountainous areas, irrigated garden crops on coastal areas). Indeed, In morocco, irrigated cereals represent less than 9% of the total acreage and contribute to less than 17% of the total production. Moreover, Jlibene and Balaghi (2009) studied land vulnerability for cereal production to drought using the NDVI/Rainfall ratio and found that different areas of morocco present different levels of vulnerabilities. According to their study, provinces covered by the Oum er Rbia basin are at middle to high risk. Consequently, we assumed that in our area of concern, communities with high cereals acreages are more vulnerable to droughts while communities with higher fruit trees or garden crops acreages have a higher adaptative capacity

- *Rangelands and Forests*

Rangelands suffered a lot during the past decades from recurrent drought periods and overgrazing, they still represent for many small farmers the main feed supply for small ruminants and are still considered as a factor of drought resilience. In the same way, , although forests represent natural ecosystems vulnerable to drought, are playing a major socio-economic and environmental role that may increase drought resilience, especially in mountainous areas of the basin.

- Importance and composition of livestock

Several studies have reported the use of livestock ownership as a proxy for drought vulnerability. In the Oum er rbia basin, livestock keeping is an important activity in many agro-pastoralists communities. This is partly due to livestock's ability to withstand the harsh semi-arid conditions and thus provide a more 'secure' source of livelihood compared to farming. Subsequently, households strive to accumulate as many animals as possible, especially sheep, and can better cope with drought.

- Poverty index and vulnerability to poverty index

According to Adger (1998), poverty is an important aspect of vulnerability because of its direct association with *access* to resources which affects both baseline vulnerability and coping from the impacts of extreme events.
Vulnerability to poverty on the other hand, measures the threat of poverty (Calvo and Dercon, 2005). It is a concept that aims to capture the movement of households in and out of poverty, making it also an appropriate measure in drought-stricken communities.

- Land status (% of melk = % of land ownership)

In Morocco, the legal system concerning property is complex and agricultural lands have various juridical statuses ranging from Melk (land owner ship) to state, collective and religious orders' landholdings. However, only the lands that fall under the 'melk' status can be given a land title after recording and registration. Then, only farmers that possess arable lands with titles can have a reliable access to credit; reducing therefore their vulnerability during and after drought episodes.

- Farm size (% of farms with less than 5 hectares)

In Morocco, another underlying indicator of drought vulnerability may be the small farm size. Indeed, according to the general census of agriculture (RGA 1996), about 70% of farmer have less than 5 hectares. In **normal years**, 5 hectares cultivated under rainfed conditions which account for nearly 90% of arable lands in Morocco emerge an income **of less than 120 euros/month** which is very weak. Consequently, under drought conditions these incomes may be even far lower and traduces the vulnerability of these small farmers to drought.

- Additional incomes from emigration (% of households)

According to Fuhr (2003), factors characterized as affecting quality of life are similar to those theoretically linked to vulnerability although they are not explicitly a measure of vulnerability. Among these factors, Outcome variables and especially out emigration in search of non-farm incomes can also be used as an indicator of the aptitude of farmers community to cope with drought episodes.
Here, the % of households that have emigrated outside the country do not give a accurate estimation of the proportion of the population that have emigrated since it considers the number of households but not husbands, sons or daughters that have emigrated while their families still live in the country. However, it provides a fairly good estimation of the trend towards emigration in the rural commune.

4.2.3 Indicators of human and civic resources

In this study, the indicators of human and civic resources used to assess drought vulnerability are:

- Adult illiteracy rate:

Illiteracy rate indicates low quality of primary education and needs for policies in organising adult literacy programs. Those without literacy skills may have problems taking advantage of health, educational, political, economic and cultural opportunities (UNESCO 2006). Moreover, illiterate people may have difficulty in understanding warnings and access to recovery information (Cutter et al. 2003). Therefore communities with high illiteracy rates are more vulnerable to droughts.

- Age of the population:

O'brien and Mileti (1992) examined the vulnerability to climate change and stated that in addition to economic well-being and stability, being important in the resilience of populations to environmental shocks, the structure and health of the population may play a key role in determining vulnerability. Age is an important consideration as the elderly and young persons tends to be inherently more susceptible to environmental risk and hazard exposure.

- Population with access to an improved water source but not directly connected to the public network.

Unsafe or unimproved water (sources include among others: vendors, tanker trucks and unprotected wells and springs) is one direct cause of many diseases. In other words, people without improved water sources are vulnerable to diseases caused by unclean water and could become more vulnerable. Therefore, this variable is recognized as an important indicator for susceptibility to harm from natural hazards and among them droughts by different authors (e.g. Brooks et al. 2005; Bollin & Hidajat 2006)

In the field of access of rural population to improved drinking water sources, Morocco has achieved major realizations during the past years. Indeed, it increased from 14% in 1990 to 92% by the end of 2012. Consequently, this variable does not represent a major component of drought vulnerability. However, at the time being, most of rural households are asking for individual connections which remain on the opposite very low in rural areas essentially because of the high costs of individual connections. Thus, rural communes with higher individual connections present a better socio-economic adaptive capacity.

4.2.4 Indicators of infrastructure and technology

- Hydraulic infrastructure (Water storage capacity)

Faced to the unequal distribution of water resources in the country, both in time and space and to the necessity of its economic and social development, the government from the 1960s onwards implemented a deliberate policy directed to building a series of large reservoir dams. Thus, nowadays, Morocco has 128 big dams in activity, which are able to mobilize 17.2 billion m^3 which represents in an average year, nearly 90% of the potential surface water resources (DGH, SEEE) while in 1956, the total storage capacity was only 1.8 billion m^3. The benefits that Morocco's network of dams has brought to the national economy as a whole may be measured in terms of increased food security and access to both energy and drinking water. They also contribute in a significant manner to the mitigation of extreme weather phenomena such as droughts and floods. In this study, the water storage capacity (at the province level), was used as an indicator of drought adaptative capacity.

- Mechanization (agricultural innovation)

The use of agricultural innovation through mechanization, chemicals (fertilizers or phytosanitary treatments) or improved seeds reduces agricultural vulnerability to climate variability and represents therefore indicators of adaptive capacity. Thus, several authors reported the quantification of these parameters as proxy variables for drought vulnerability assessment. Unfortunately, for our study, the quantification of the use of chemical fertilizers or improved seeds was available only in some communes. Consequently, we selected agricultural machinery and in particular the number of tractors per Km^2 of arable land, as reported by Iglesias et al. (2007).

4.3 DATA COLLECTION

In Morocco, rainfed areas are under the responsibility of the Provincial Directions of Agriculture (DPA) which coordinate the action of the extension services (Work centers, Centres de travaux). Each work center is in charge of a specific area corresponding to several rural communes. The Regional Offices of Agricultural land promotion (ORMVA's) are in charge of irrigated perimeters but manage also the rainfed communes that fall under their jurisdiction.

In this study, rainfall data, agricultural and land status data come from the Work centers, the DPA's and the ORMVAs':

Table 4-2 presents the surveyed institutions within the Oum er Rbia basin:

ORMVA	DPA	Work centers (CT)
Tadla	El Jadida	CT 13-01 Azemour
Doukkala		CT 13-02 Oulad Hcine
Haouz	Safi	CT 16-01 Jemaa Shaim
		CT 16-02 Sebt Gzoula
		CT 16-03 Chemaia
		CT 16-04 Kasba Eyer
	Settat	CT 10-02 Berrechid
		CT 10-04 Settat
		CT 10-09 Ouled Said
		CT 10-10 Borouj
	Azilal	CT 18-01 Ouaouizirt
		CT 18-02 Azilal
		CT 18-03 Demnate
		CT 18-04 Aïn Aattab
	Beni-Mellal	CT 11-01 El Ksiba
		CT 11-05 Zaouia cheikh
		CT 11-04 Tadla
		CT 11-06 Aghbala
		CT 11-07 Tagzirt
	El Kella	CT 19-02 Benguerir
		CT 19-03 Bouatmane
		CT 19-04 Rhamna
	Khenifra	CT 24-02 Khenifra
		CT 24-03 Beni Khlil
		CT 24-04 Aguelmouz
		CT 24-05 Boumia
	Khouribga	CT 17-01 Khouribga
		CT 17-02 Oued Zem
		CT 17-03 Bejaad

Figures 4.1 and 4.2 present the location of the different extension services (Centres de Travaux agricoles) and ORMVA's (Tadla, Doukkala and haouz) surveyed.

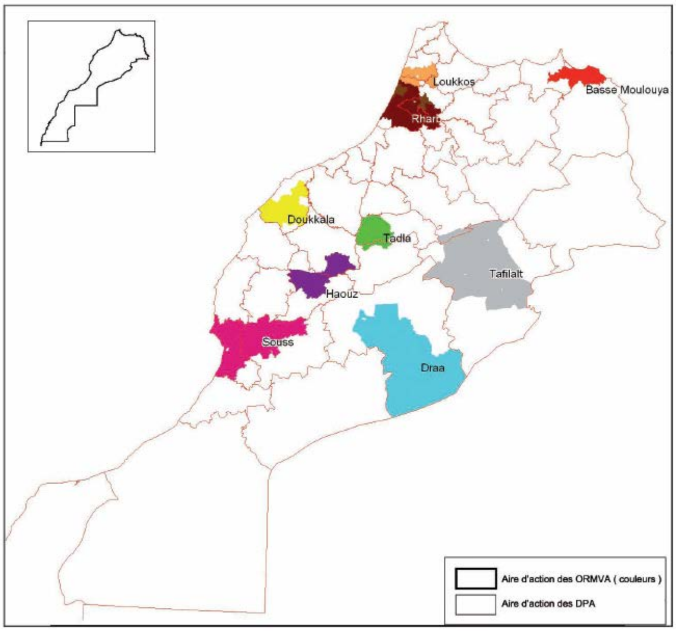

Figure 4-1: Location of the action areas of the ORMVA's of Tadla, Doukkala and Haouz

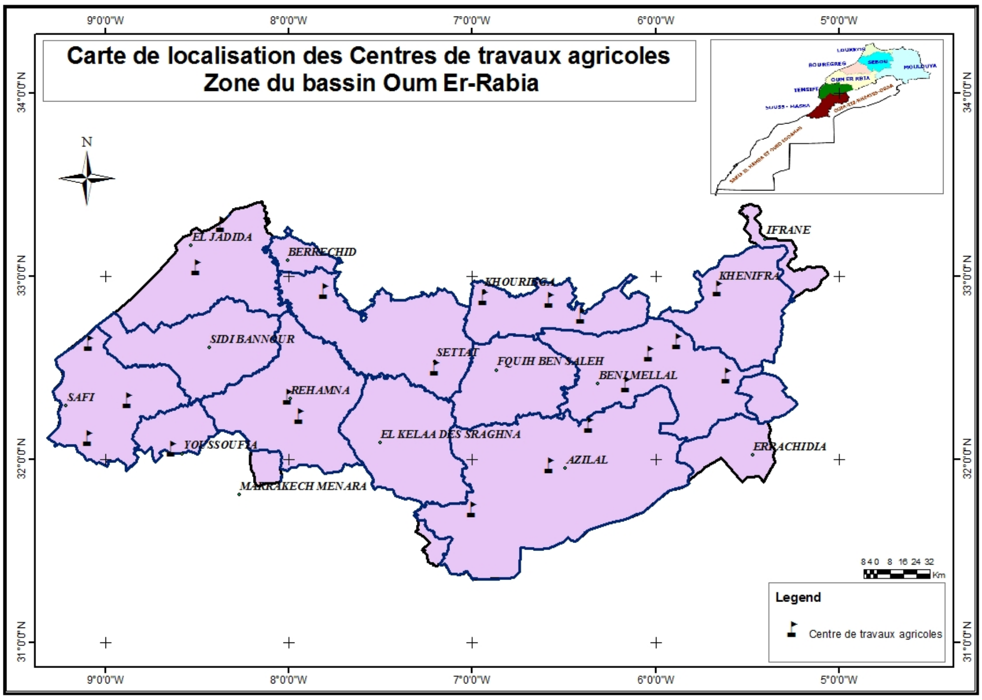

Figure 4-2: Location of the surveyed service extensions (Centres de Travaux Agricoles)

Irrigation water needs, drinking water consumptions and Storage Capacity data were obtained from the web site of the Oum Er Rbia river basin agency. (www.abhoer.ma)

Socio-economic data regarding adult illiteracy rate, access to drinking water and population age were obtained from the web site of the National Department of Statistics (Haut Commissariat au plan) and correspond to the data of the last national sensor of the 2004. (www.hcp.ma)

Data on poverty and vulnerability to poverty were obtained from the same source and emerge from a 2007 survey.

The shapes files of the administrative map of Morocco were obtained from the national department of Cartography (Agence Nationale de la Conservation Foncière, du Cadastre et de la Cartographie). Vulnerability maps were derived using Arc GIS software.

4.4 DROUGHT VULNERABILITY INDICATORS

4.4.1 Missing data

Figure 4.3 presents the percentage of missing-data per sub-indicator. For most of them, values range between 0 and 5%. For water infrastructure, this value is missing for about 21% of the communes. This component was considered in the analysis because in this framework, it is important for determining the vulnerability of infrastructure and technology. However, regarding all the missing data, the DVI can be updated when data becomes available.

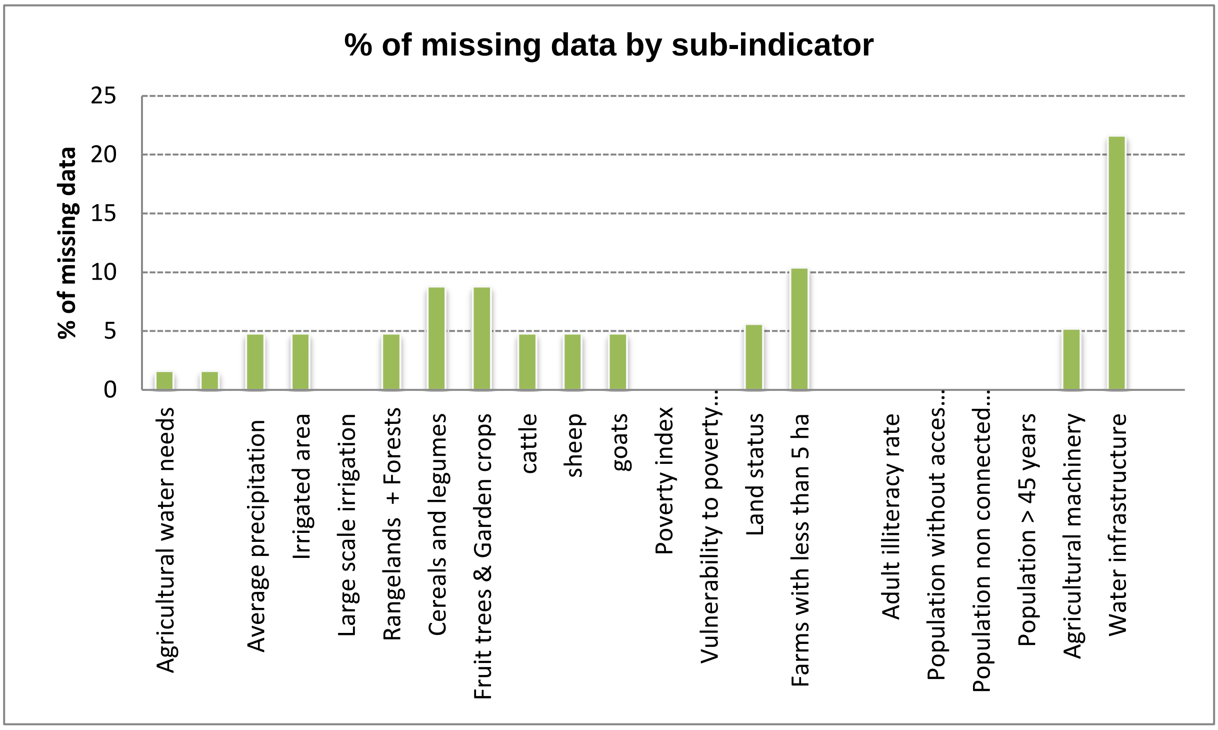

Figure 4-3: Percentage of missing data per sub-indicator

After the data completion, the provinces of Settat, and El kelaa present more than one missing indicator. For these provinces, the comparison should therefore be done carefully
The results of the DVI at provincial and at basin level are presented below. In order to understand the source of vulnerability in each case, it is usefull to first analyse each dimension and sub-index separately. For the aggregation of the four dimensions, weights taking into account the number of indicators of each dimension were considered to avoid giving too much importance to a dimension with only a few sub-indicators.

4.4.2 Vulnerability of Renewable Natural Capital to Droughts

In this section, the drought vulnerability of the renewable capital is analyzed at the provincial and basin levels. It is also important to underline the fact that for computing the DVI, we have considered the values of the different sub-indicators for all the communes of all the provinces. Therefore, the values presented at the provincial level should be considered relatively to the whole basin since the minimal and maximal values considered for each sub-indicator counts for the whole basin.

4.4.3 Vulnerability of Renewable Natural Capital to Droughts At provincial level

- Provinces of El Jadida and Sidi Bennour

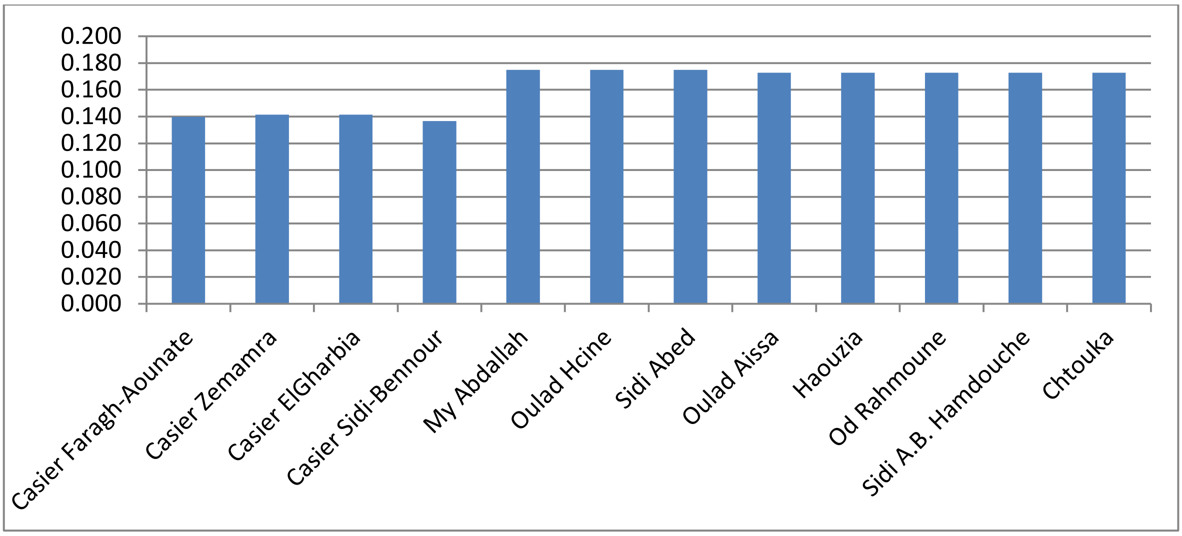

Figure 4-4: Drought Vulnerability of Renewable capital in the provinces of El Jadida and Sidi Bennour

Figure 4.4 presents the Drought vulnerability of the Renewable capital in the provinces of El Jadida and Sidi Bennour. Results are presented by rural commune for the province of El jadida and by ‘casier’ which are a group of communes for the province of Sidi Bennour. Results clearly show that, regarding the renewable capital, the province of Sidi Bennour has a smaller drought vulnerability. Inside each province, the values do not differ and stay in the same range. When considering each sub-indicator of this component, one can see that although the annual rainfall is more important in the communes of El Jadida province, the main determinant of the renewable capital to drought seems to be the percentage of irrigated areas and the percentage of irrigated area that belong to the big irrigated perimeter of Doukkala. Indeed, the casiers of Faragh-Aounate, Zemamra, El Gharbia and Sidi-Bennour are all under the supervision of the Ormva of Doukkala whereas the province of El Jadida is under the supervision of the DPA and is mainly rainfed. Nevertheless, the coastal zone of the basin named the “Sahel Zone” (between Azemmour and Oualidia) is known to be an important horticultural area mainly irrigated by private wells and relying therefore on the underground resources of the basin. This component was not considered for the computation of the drought vulnerability indice and results should therefore be tempered in this part of the basin.

- Provinces of Safi and Youssoufia

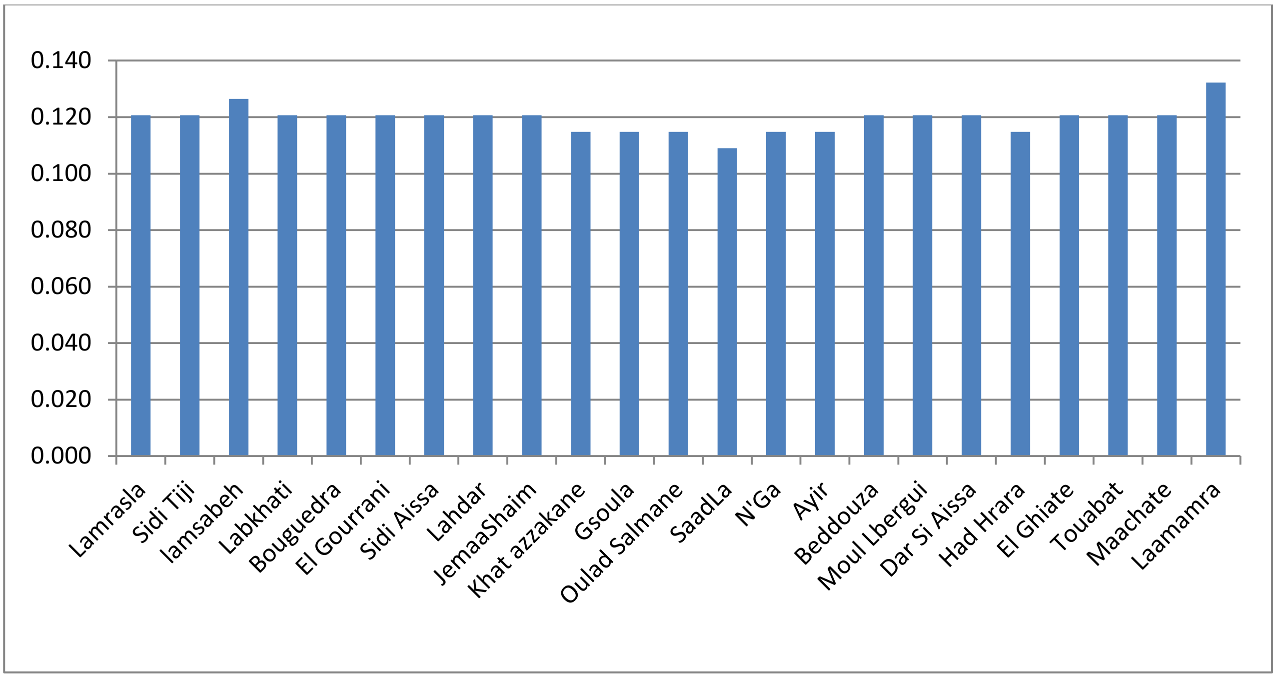

Figure 4-5: Drought Vulnerability of Renewable capital in the province of Safi

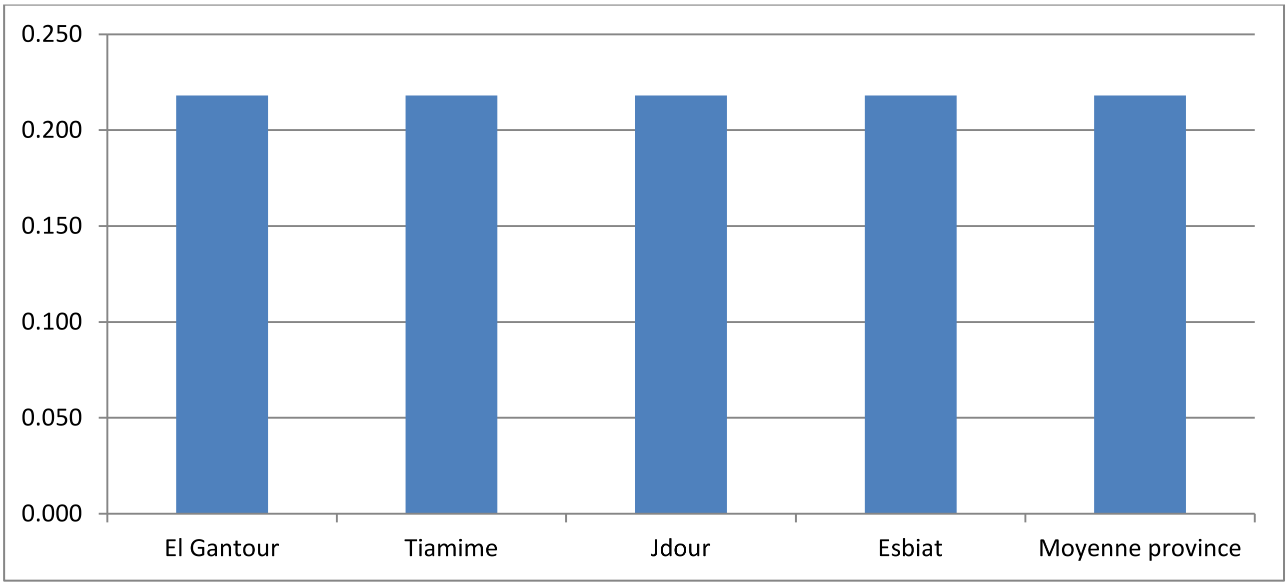

Figure 4-6: Drought Vulnerability of Renewable capital in the province of Youssoufia

In the provinces of Safi and Youssoufia, as shown by figures 4.5 and 4.6, there is no much difference between the different communes in terms of vulnerability of renewable capital. In fact, since agriculture in these provinces are mainly conducted under rainfed conditions, the amount of annual rainfall is the main determinant sub-indicator. Indeed, in the province of Safi, the commune of Saadla with a an annual rainfall of 400 mm is the less vulnerable while the commune of Laamamra with an annual rainfall of 200 mm is the most vulnerable.

- Provinces of El Kelaa and Rhamna

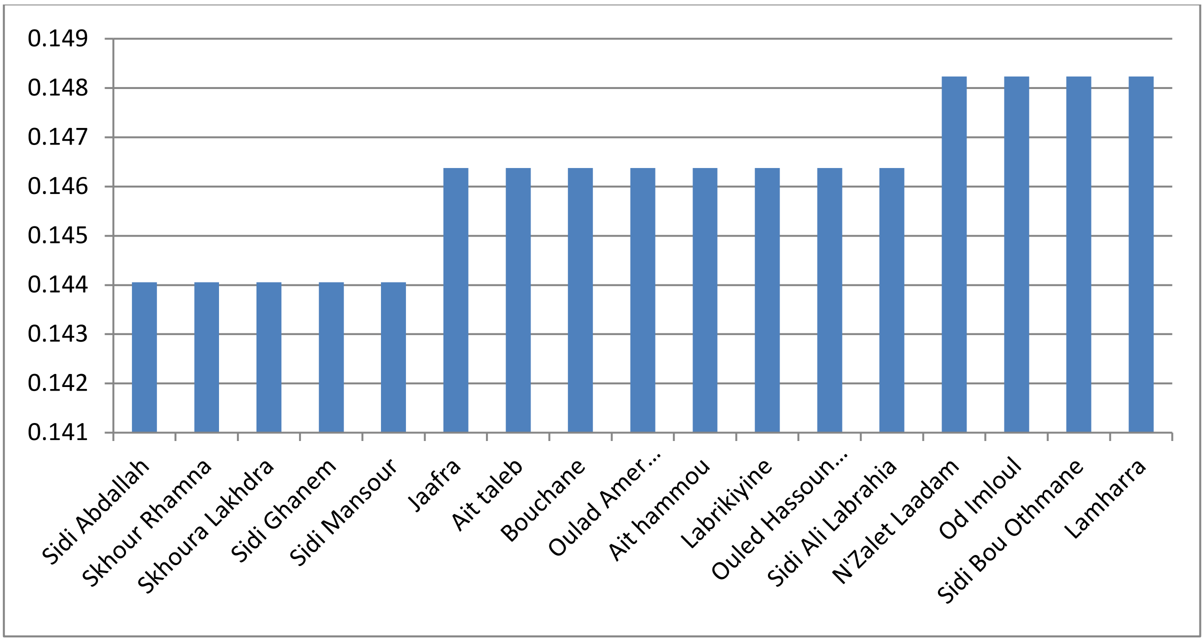

Figure 4-7: Drought Vulnerability of Renewable capital in the province of Rehamna

As shown by figure 4.7, regarding vulnerability of the renewable capital to drought in the province of Rehamna, communes can be divided in 3 groups of increasing drought vulnerability with annual rainfall being the major driver of vulnerability.

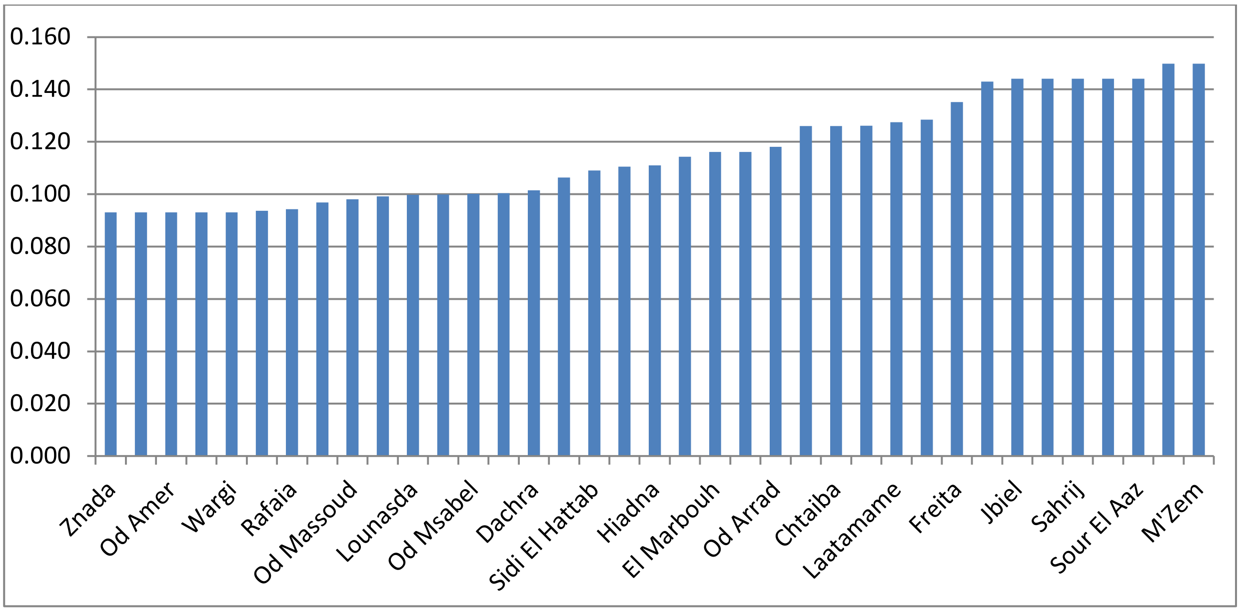

Figure 4-8: Drought Vulnerability of Renewable capital in the province of El kelaa

In the province of El kelaa which is mainly under the supervision of the ORMVA of el Haouz, the Drought vulnerability of Renewable capital ranges from less than 0.1 in the less vulnerable communes to more than 0.14 in the most vulnerable ones (Figure 4.8). When analyzing the different sub-indicators, results show that in this case, the percentage of irrigated acreage and the percentage of irrigated lands belonging to the big irrigated perimeter are the major driver of drought vulnerability.

- Provinces of Fquih Ben Salah and Beni-Mellal

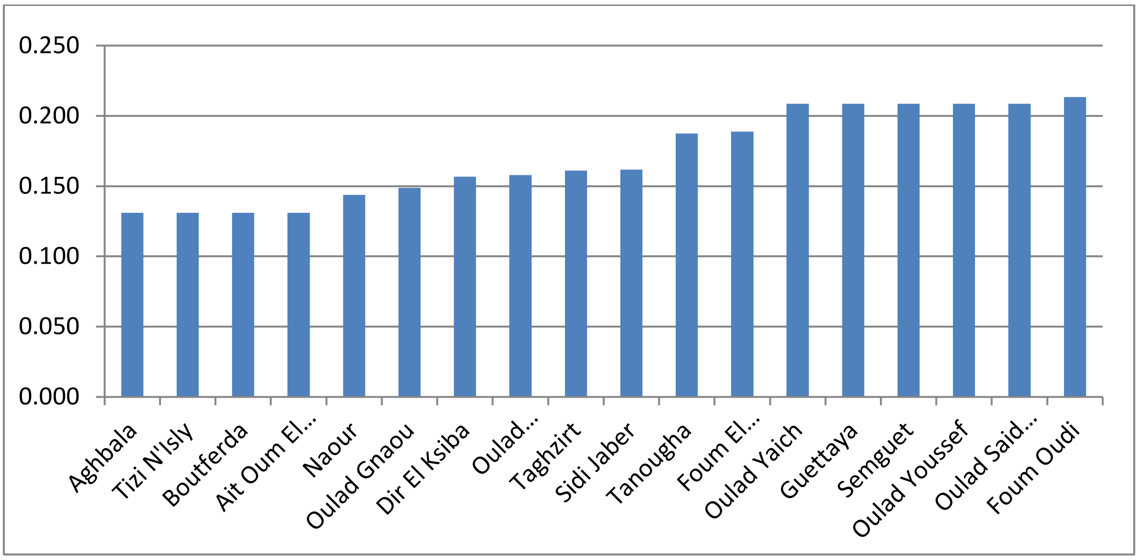

Figure 4-9: Drought Vulnerability of Renewable capital in the province of Beni-Mellal

Among the different provinces covered by the Oum Er Rbia basin, the province of Beni-Mellal is the one that presents the biggest variability and contrast in terms of ecotypes. Indeed, there is an important gradient from east to west, with the eastern part of the province belonging to the plain of Tadla while the middle part represents the foothills of the Atlas Mountains and the western parts are mountainous areas. Consequently, there is a big variability of annual rainfall in the province and it ranges from less than 300 mm in the plain area to more than 600 mm in the mountainous areas. This reflects the gradient of increasing drought vulnerability of renewable capital shown by figure 4.9.

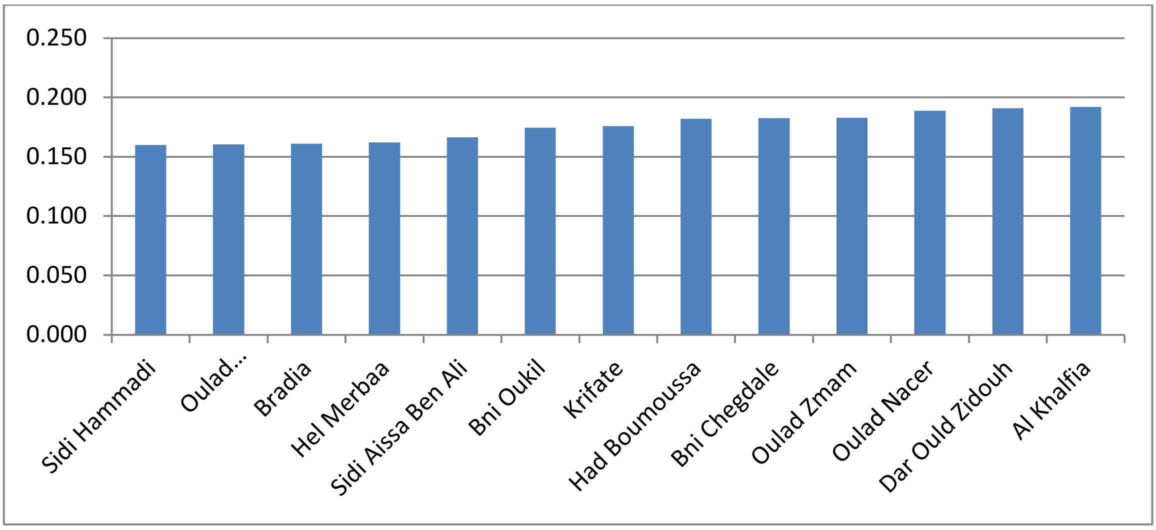

Figure 4-10: Drought Vulnerability of Renewable capital in the province of Fquih Ben Salah

In the province of Fquih Ben Ssalah which is mainly under the supervision of the ORMVA of Tadla and where mainly all the communes belong to the irrigate perimeter, the Drought vulnerability of Renewable capital ranges from nearly 0.16 in the less vulnerable communes to 0.19 in the most vulnerable ones (Figure 4.10). When analyzing the different sub-indicators, results show that once again, as previously shown for the irrigated perimeters of

Doukakala and Haouz, the percentage of irrigated acreage and the percentage of irrigated lands belonging to the big irrigated perimeter are the major driver of drought vulnerability.

- Province of Khénifra

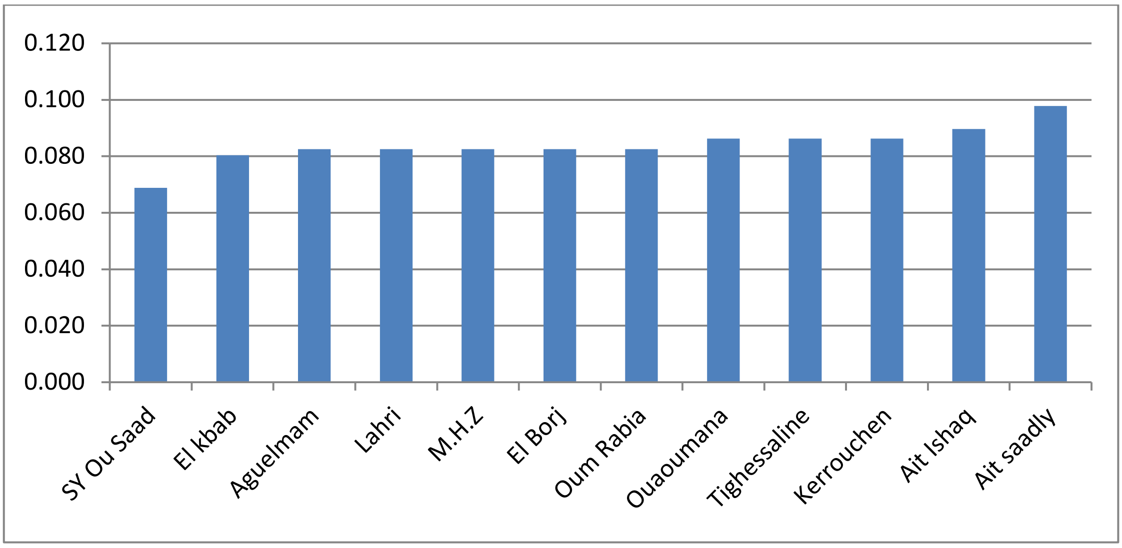

Figure 4-11: Drought Vulnerability of Renewable capital in the province of Khénifra

The part of the Khenifra province that is covered by the Oum Er Rbia basin is mainly mountainous with relatively important annual rainfall. The sources of the Oum er rbia river are located in this part of the basin, in the homonym commune. As shown by figure 4.11, the drought vulnerability of the renewable capital is low and do not differ a lot between rural communes. In addition, on a similar pattern than the other provinces, the least vulnerable commune presents the most important annual rainfall while the most vulnerable one gets fewer precipitations.

- Province of Azilal

The province of Azilal is also a mountainous area, located in the heart of the High-Atlas Mountains. Therefore, as shown by figure 4.12, the Drought Vulnerability of Renewable Capital is relatively low since most of the communes beneficiate from an important annual rainfall. However, a small part of the province is under the supervision of the ORMVA of Tadla and belongs to the big irrigated perimeter which represents the major driver of drought vulnerability.

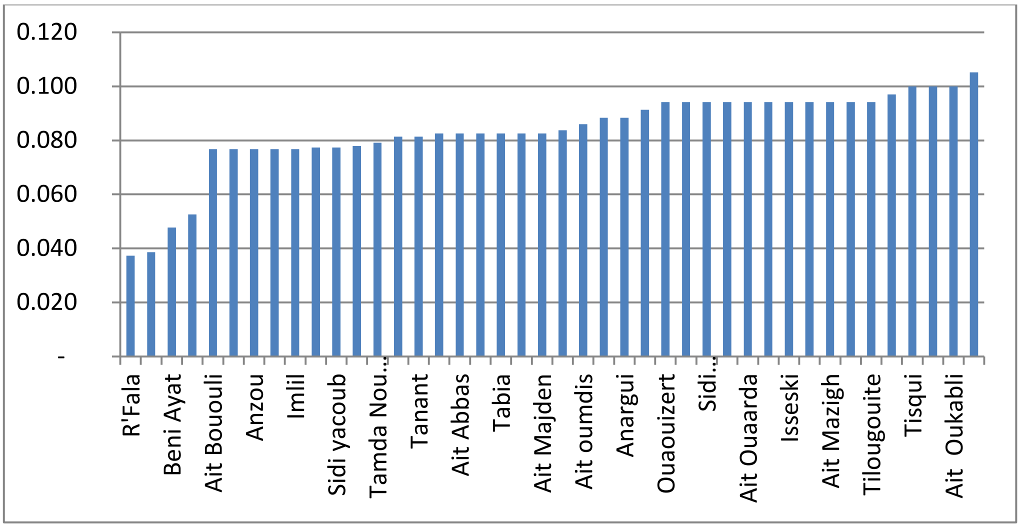

Figure 4-12: Drought Vulnerability of Renewable capital in the province of Azilal

- Province of Khouribga

Regarding Drought Vulnerability of Renewable capital, figure 4.13 shows that for the province of Khouribga, the communes can be divided in two groups: A first one with higer drought vulnerability levels and a second one with lower levels. When regarding in details the sub-indicators, results show once again that a part of their acreage of the least vulnerable communes belong to the big irrigated perimeter of Tadla.

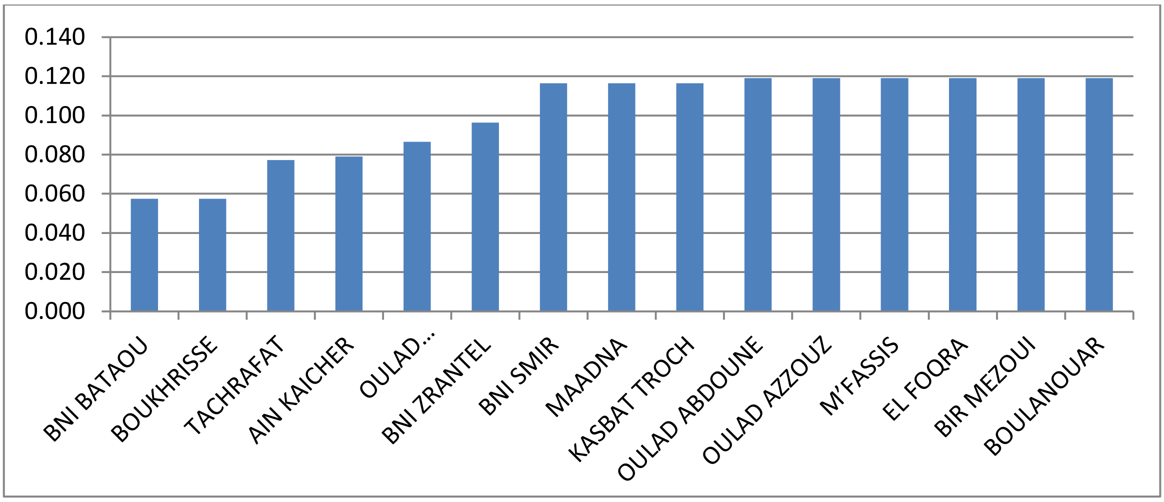

Figure 4-13: Drought Vulnerability of Renewable capital in the province of Khouribga

- Settat

The province of Settat presents a lot of missing data and therefore a lot of communes were discarded from the analysis. Regarding the other ones, results show the drought vulnerability of Renewable capital is globally the same (Figure 4.14). Those communes that were retained for the analysis present an important part of irrigated lands. This explain why their global drought vulnerability of Renewable capital are not very high although they are located in an arid environment where mean annual rainfall do not exceed 300mm.

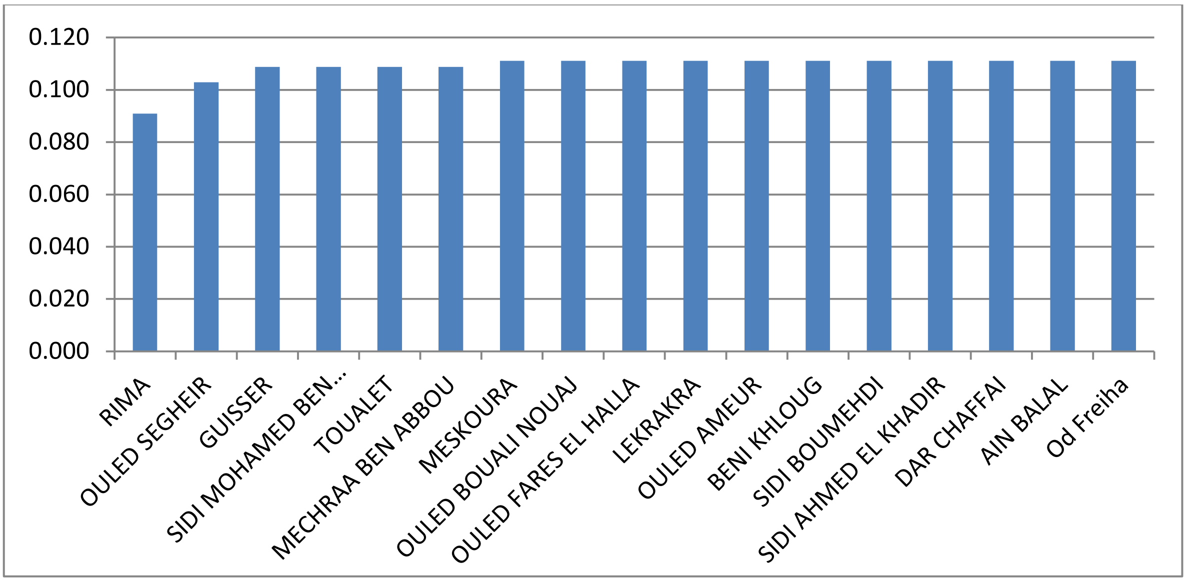

Figure 4-14: Drought Vulnerability of Renewable capital in the provinces of Settat

4.4.4 Vulnerability of Renewable Natural Capital to Droughts At basin level

Figure 4.15 compares the Drought Vulnerability of Renewable capital between the different provinces covered by the Oum Er Rbia basin. Results show that the two mountainous provinces of Azilal and Khenifra that beneficiate from important mean annual rainfall are the least vulnerable. The most vulnerable one is the province of Youssoufia which is very arid (200 mm of mean annual rainfall) and which agriculture is mainly conducted under rainfed conditions. The other provinces range in between. Over all, the drought vulnerability of the Renewable capital is temporized within each province by the part of irrigated area but is also driven at the basin level by the mean annual rainfall and drinking water consumptions. Indeed, this last sub-indicator that were only considered at the provincial level reflect the density of population that increases drought vulnerability.

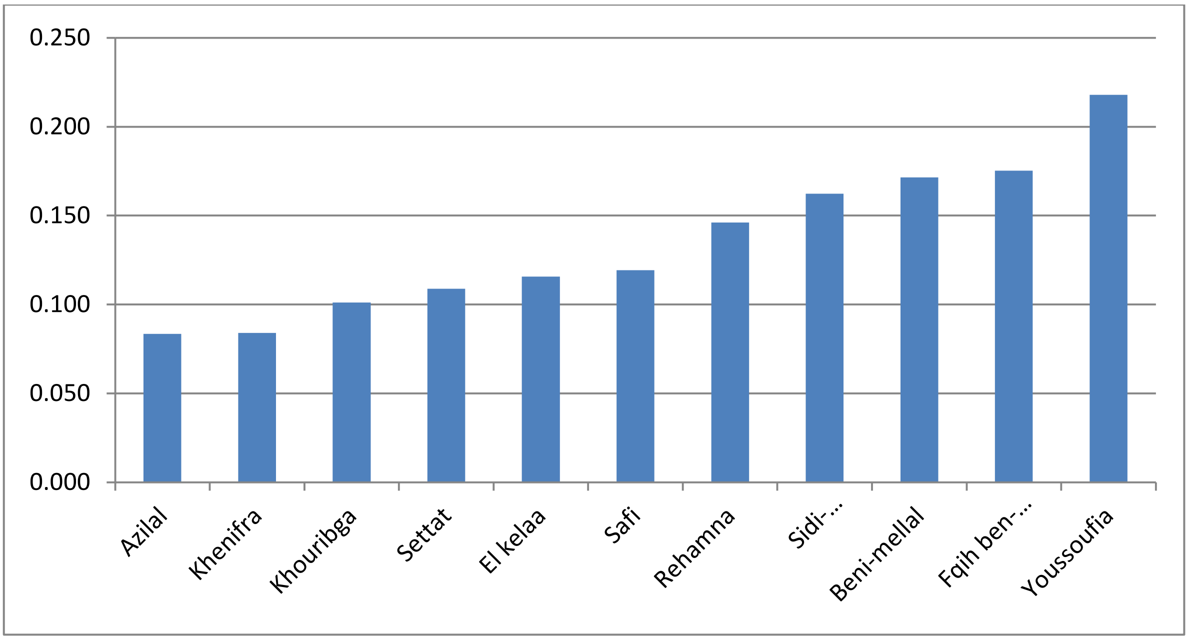

Figure 4-15: Drought Vulnerability of Renewable capital in the provinces covered by the Oum er Rbia basin

4.4.5 Vulnerability of Economic Capacity to Droughts

In this section, the vulnerability of the Economic Capacity to drought is analyzed at the provincial and basin levels.

4.4.6 Vulnerability of Economic Capacity to Droughts At provincial level

- Provinces of El Jadida and Sidi Bennour

Figure 4.16 presents the vulnerability of the economic capacity to drought in the provinces of El Jadida and Sidi Bennour. Values differ slightly between the different 'casiers" and communes with the casier of Zemamra being the less vulnerable and the commune of My Abdallah being the most vulnerable one. When analyzing the sub-indicators, data show that three components seem to make the difference. Indeed, the casier of Zemamra is a part of the irrigated perimeter of Doukkala and therefore the percentage of cereals is smaller and the percentage of fruit trees and cash crops is higher. In addition, the casier of Zemamra is characterized by an important intensive dairy production.

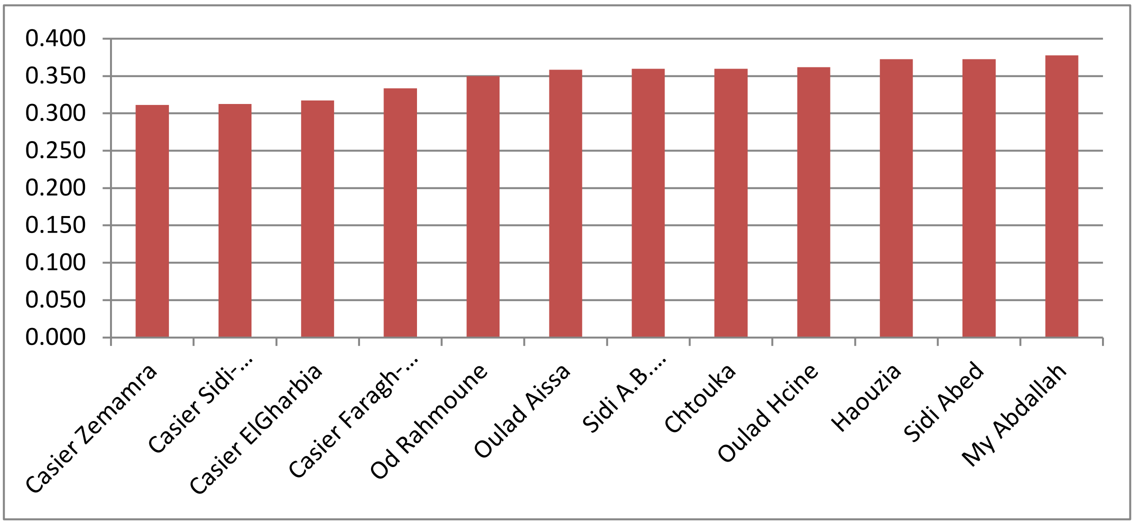

Figure 4-16 Drought Vulnerability of Economic capacity in the provinces of El Jadida and Sidi Bennour

- Provinces of Safi and Youssoufia

Figure 4.17 presents the vulnerability of the economic capacity to drought in the province of Safi. Once again, data show slight differences between communes. Here, the major drivers that explains the difference between the most vulnerable commune and the least vulnerable one are related to the land status and the size of the exploitations.
Figure 4.18 presents the vulnerability of the economic capacity to drought in the province of Youssoufia. In fact, only 4 communes are considered because only a small part of this province belongs to the Oum Er Rbia basin. Here, data shows more significant differences between those communes where the land status is the indicator that plays a major role in increasing the vulnerability , mainly where the % of land ownership is low.

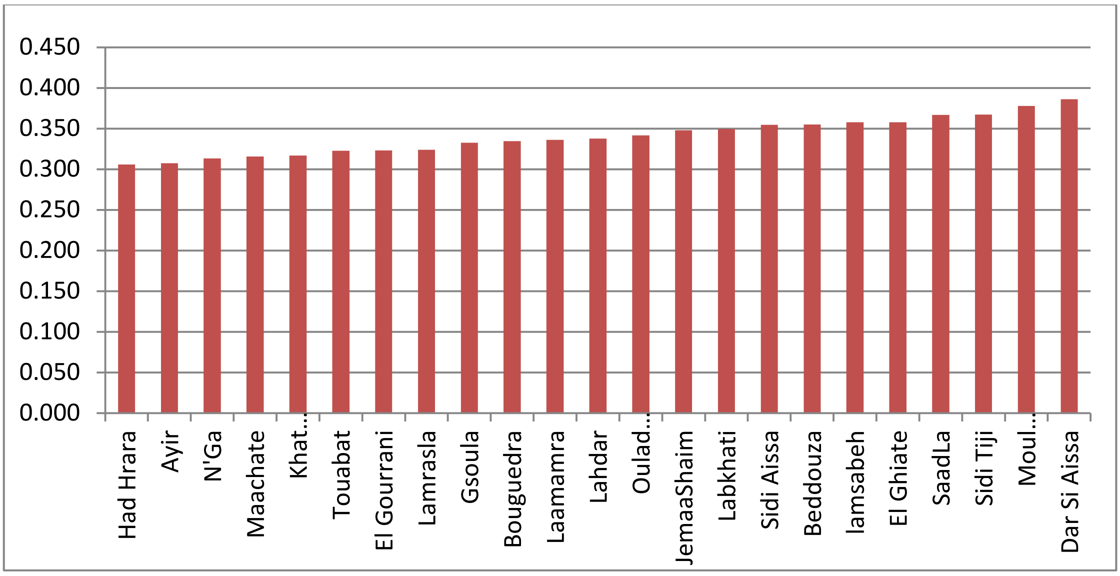

Figure 4-17: Drought Vulnerability of Economic capacity in the province of Safi

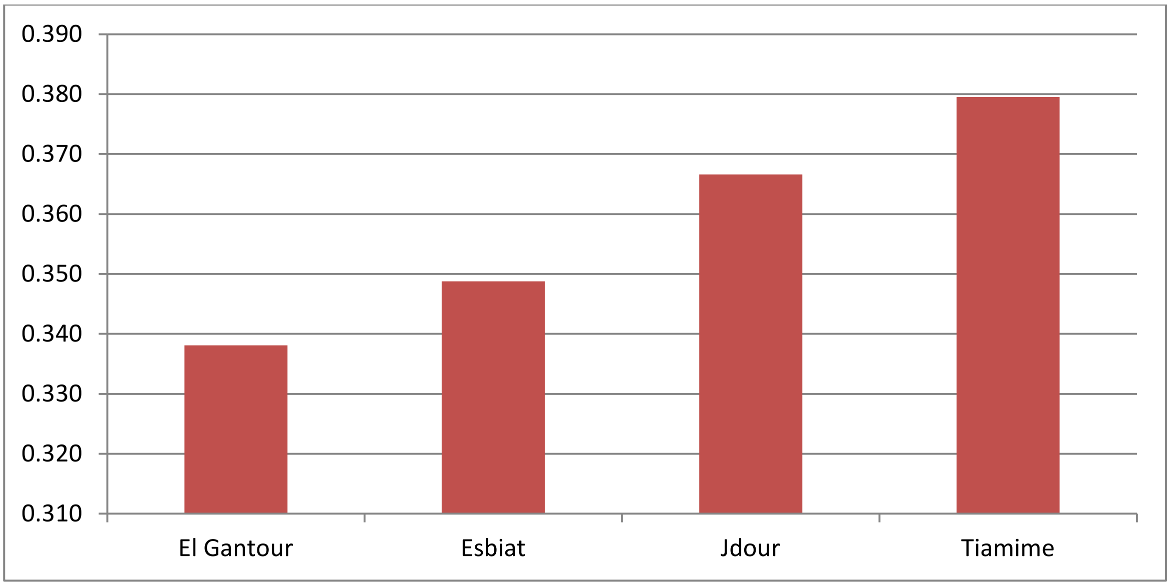

Figure 4-18: Drought Vulnerability of Economic capacity in the province of Youssoufia

- Provinces of El Kelaa and Rehamna

In the province of Rehamna, as shown by figure 4.19, the vulnerability of the economic capacity to drought, differs slightly between the different communes. The land status and the size of the farms contribute to explain those differences.

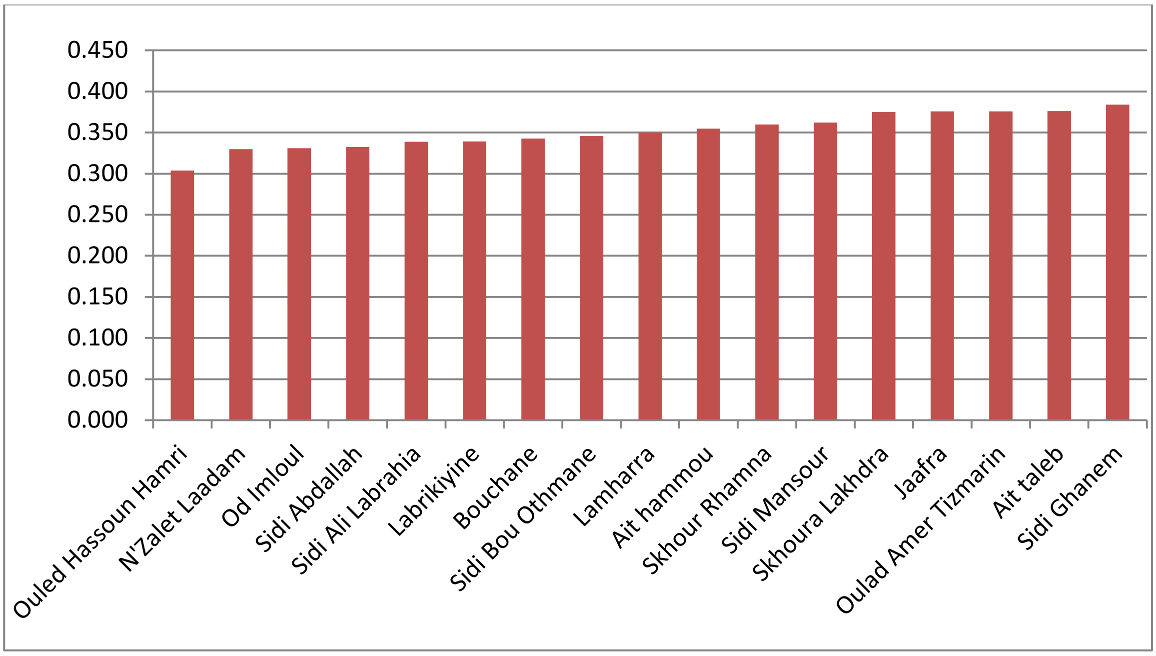

Figure 4-19: Drought Vulnerability of Economic capacity in the province of Rehamna

In the province of El Kelaa (Figure 4.20), the vulnerability of the economic capacity to drought presents more differences between the different communes. The commune of Oulad Arrad has the least drought vulnerability at the province level. It also has one of the lowest drought vulnerability of Economic capacity at the basin level. It is explained by the combination of several factors and reflects the development policy of the ORMVA of El Haouz which enhances the replacement of cereals by olive trees.

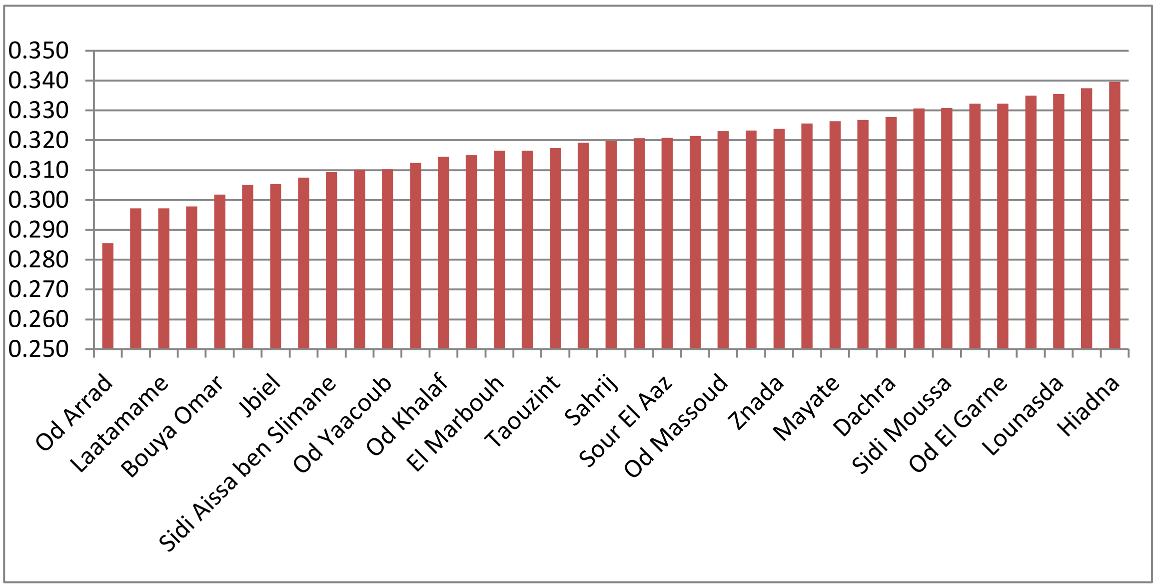

Figure 4-20: Drought Vulnerability of Economic capacity in the provinces of El kelaa

In the provinces of El Kelaa and Rhamna, the additional incomes from emigration are also more important in the less vulnerable communes.

- Provinces of Fquih Ben Salah and Beni-Mellal

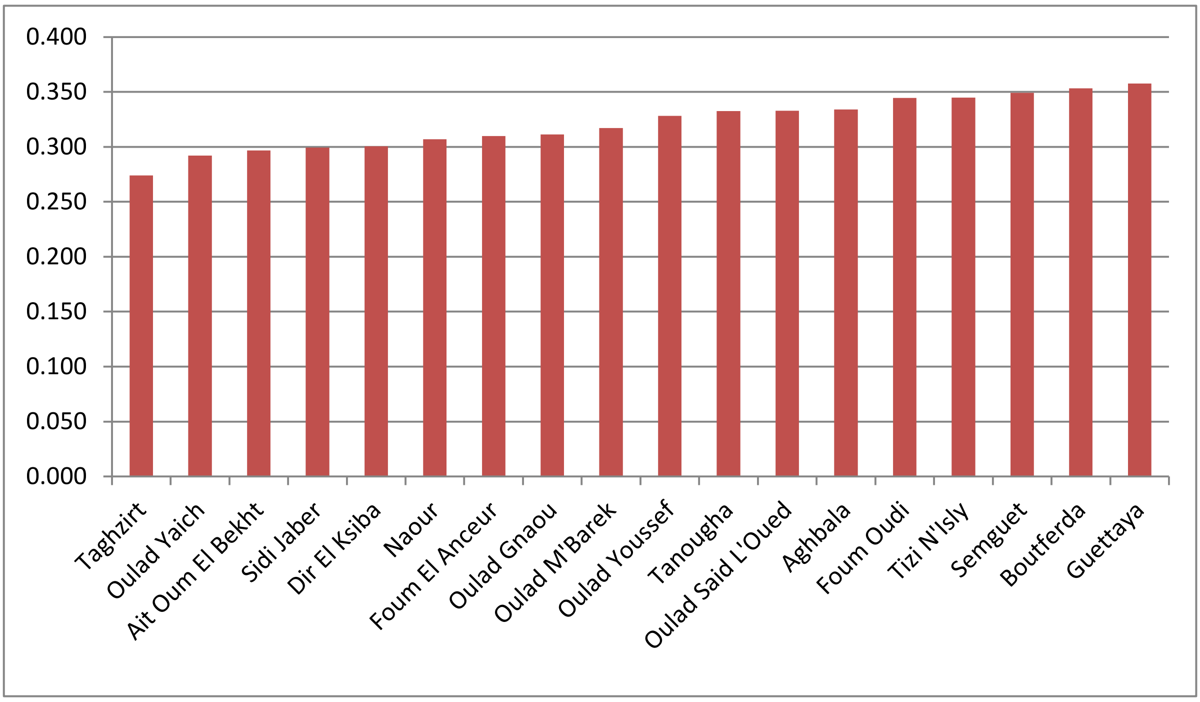

Figure 4-21: Drought Vulnerability of Economic capacity in the province of Beni-Mellal

Figure 4.21 presents the vulnerability of the economic capacity to drought in the province of Beni-Mellal. The rural commune of Taghzirt presents the lowest vulnerability of Economic capacity to drought. It is mainly explained by an important development of fruit trees but also a smaller index of poverty. Additional incomes from emigration are also important.

Figure 4.22 presents the vulnerability of the economic capacity to drought in the province of Fquih Ben Salah. The commune of Hel Merbaa presents the lowest vulnerability of Economic capacity to drought. As seen previously in the commune of Taghziert, the smaller part of cereals among the land cover as well as a more important part of fruit trees contribute to explain this lower vulnerability. On the other hand, the most vulnerable commune presents a low percentage of"Melk" lands.

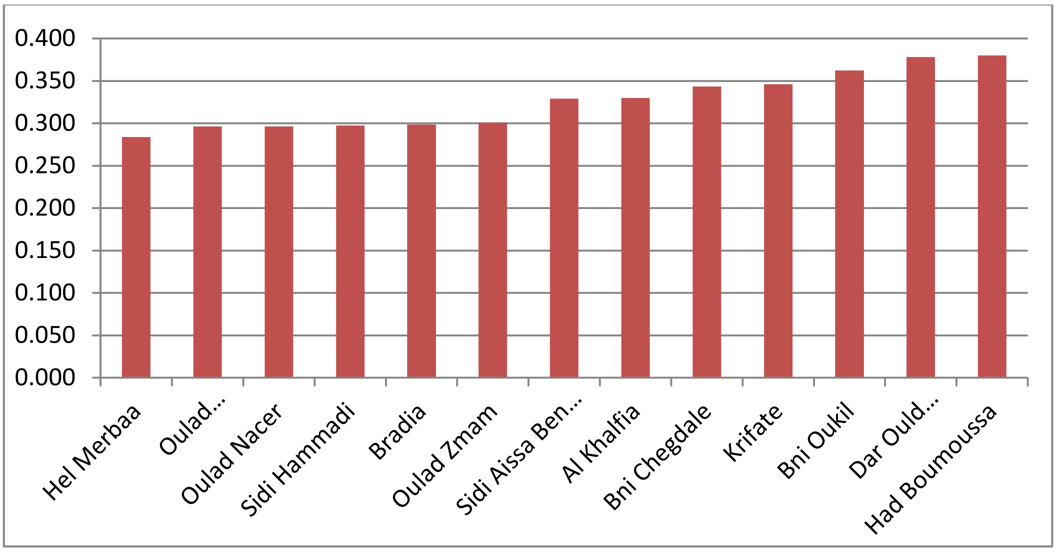

Figure 4-22: Drought Vulnerability of Economic capacity in the province of Fquih Ben Salah

- Province of Khénifra

Figure 4.23 presents the vulnerability of the economic capacity to drought in the province of Khénifra. Here, there is a relatively important difference of vulnerability between the communes of Moha ou Hammou Ziane and Lahri. Differences in land status and farm's sizes contribute to explain these values

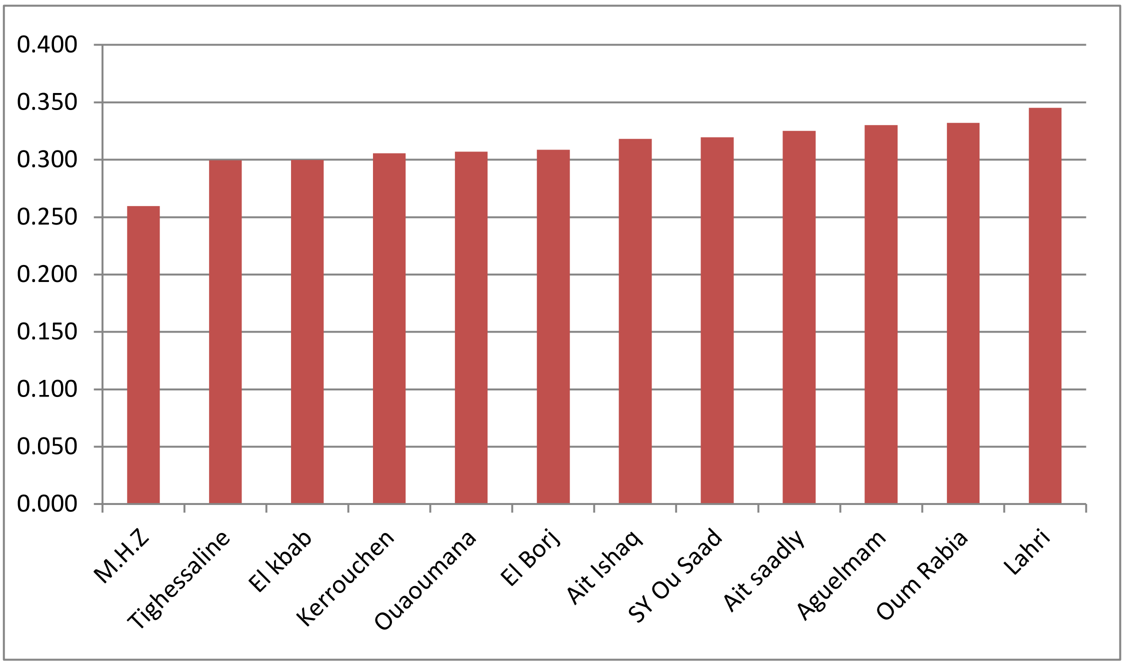

Figure 4-23: Drought Vulnerability of Economic capacity in the province of khénifra

- Province of Azilal

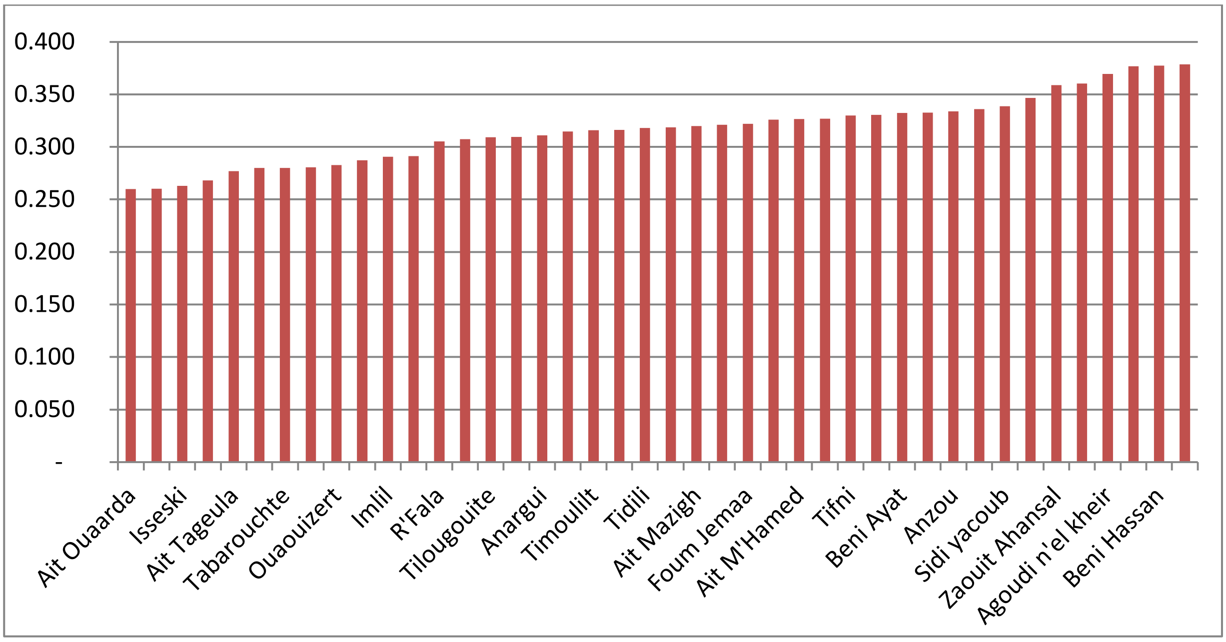

Figure 4-24: Drought Vulnerability of Economic capacity in the province of Azilal

Figure 4.24 presents the vulnerability of the economic capacity to drought in the province of Azilal. Results show an important difference of vulnerability between the communes of Ait Ouaarda and Zaouiat Ahansal, Agoudi n'El Kheir and Beni-Hassan. Land-status and poverty index contribute to explain those differences.

- Province of Khouribga

Figure 4.25 presents the vulnerability of the economic capacity to drought in the province of Khouribga. Results show an important difference of vulnerability between the communes of Ain Kaicher and Oulad Azzouz which is mainly explained by differences in the part of cereal crops, the land status and farm's sizes.

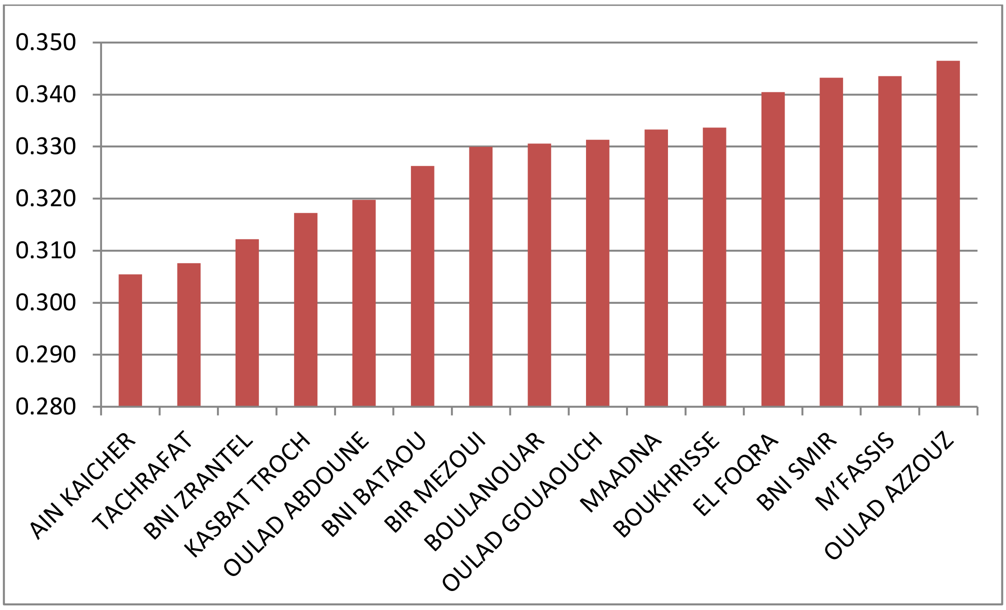

Figure 4-25: Drought Vulnerability of Economic capacity in the province of Khouribga

- Province of Settat

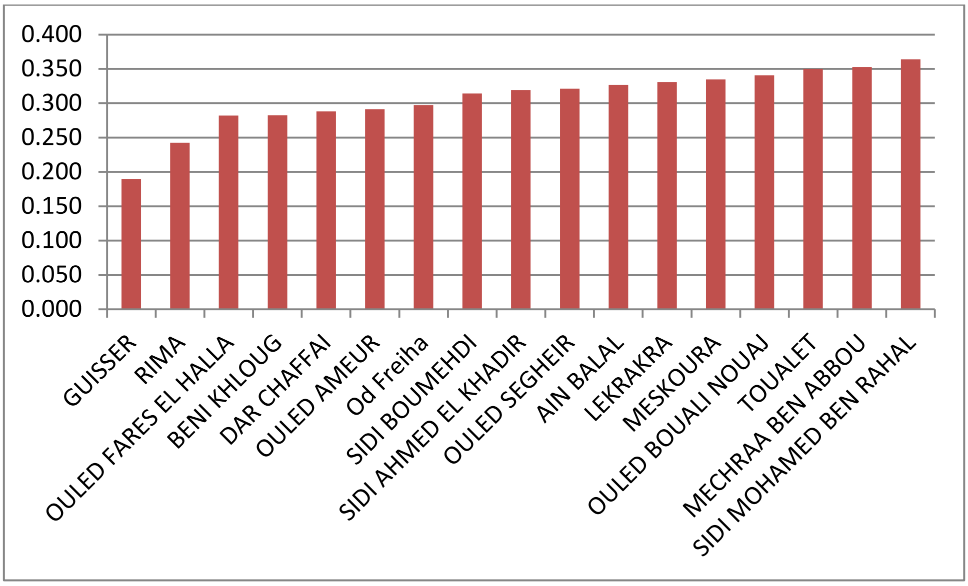

Figure 4-26: Drought Vulnerability of Economic capacity in the province of Settat

Figure 4.26 presents the vulnerability of the economic capacity to drought in the province of Settat. Results show an important difference in drought vulnerability between the most and least vulnerable communes. Guisser is the least vulnerable commune of this province. It is also one of the least vulnerable communes of the basin. When analyzing the sub-indicators, data show that this commune has the most important livestock of the basin (cattle and especially sheep) and important rangelands. It is known in fact as the origin of the sheep bred of 'Sardi' which is one of the famous Moroccan sheep breds. A low poverty index explains also this low vulnerability.

4.4.7 Vulnerability of Economic Capacity to Droughts At basin level

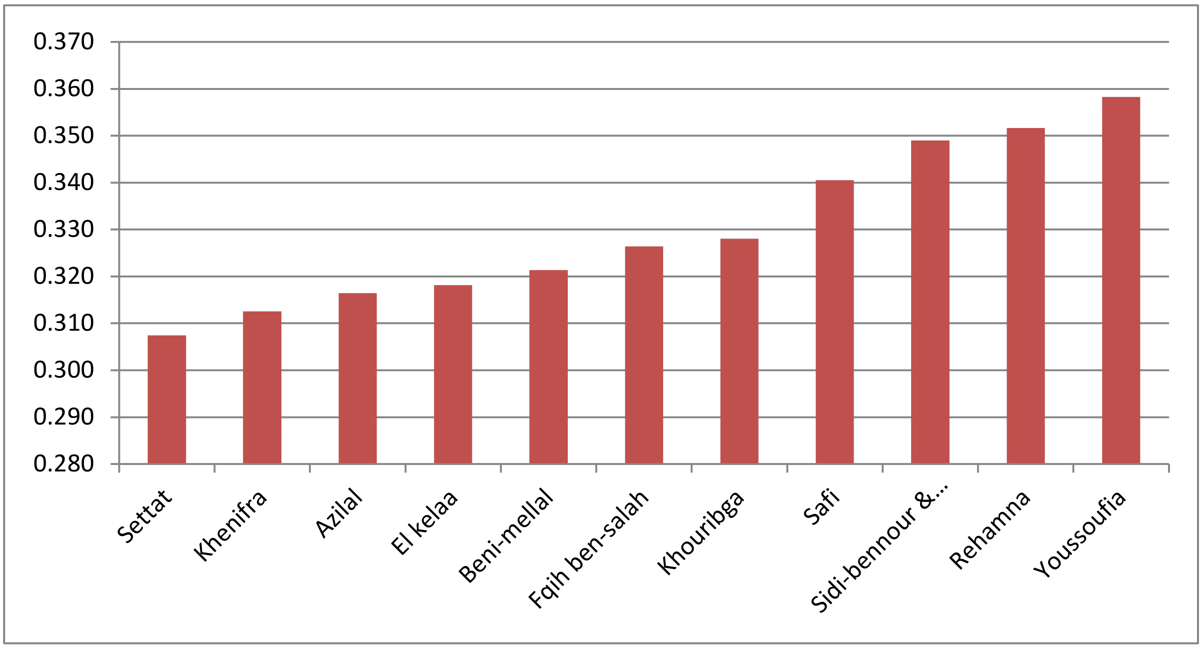

Figure 4-27: Drought Vulnerability of Economic capacity in the provinces covered by the Oum er Rbia basin

Figure 4.27 compares the Drought Vulnerability of the Economic Capacity between the different provinces covered by the Oum Er Rbia basin. Settat province is the least vulnerable but these results must be taken carefully since this province has a lot of missing data. However, at the country level, this province is known to be an important agricultural area where dry land farming techniques such as no-till are already well developed. The mountainous provinces of Khenifra and Azilal present also low levels of vulnerability that are probably linked to the lower vulnerability of their renewable capital and allow the development of important natural resources (rangelands, forests, livestock, and fruit trees).

The province of El Kelaa, which is mainly under the supervision of the ORMVA of Haouz also presents a relative low economic drought vulnerability due to the new trend towards the replacement of cereals acreages by olive trees or other drought resistant species orchards that are water less consuming and more adapted to arid conditions and drought prone areas.

On the other hand, the provinces of Rehamna and Youssoufia are mainly arid and rainfed areas where subsistence and traditional farming still predominate.

4.4.8 Vulnerability of Human and Civic Resources to Droughts At provincial level

- Provinces of El Jadida and Sidi Bennour

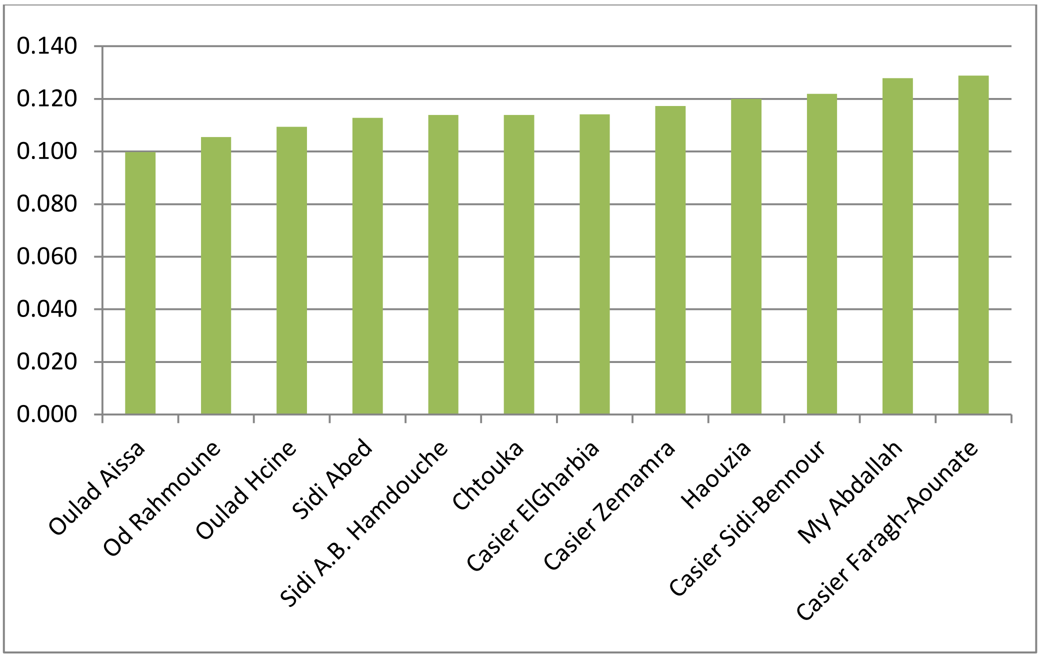

Figure 4-28: Drought Vulnerability of Human and Civic Resources in the provinces of El Jadida and Sidi Bennour

- Provinces of Safi and Youssoufia

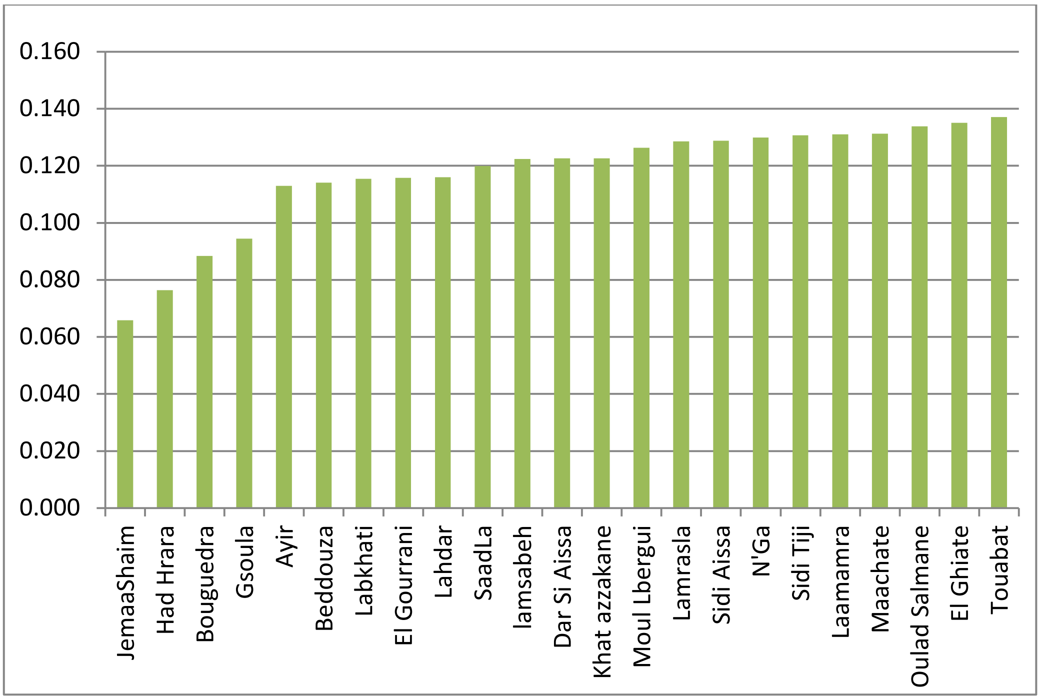

Figure 4-29: Drought Vulnerability of Human and Civic Resources in the province of Safi

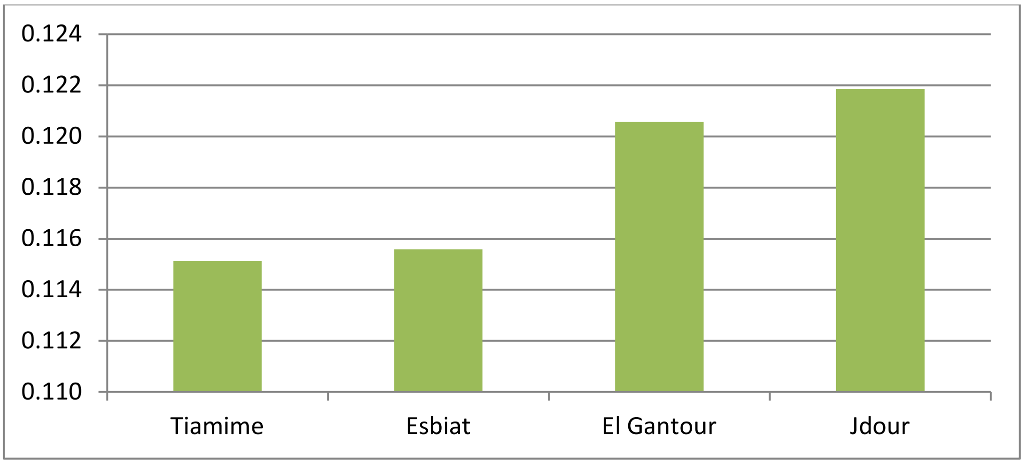

Figure 4-30: Drought Vulnerability of Human and Civic Resources in the province of Youssoufia

- Provinces of El Kelaa and Rhamna

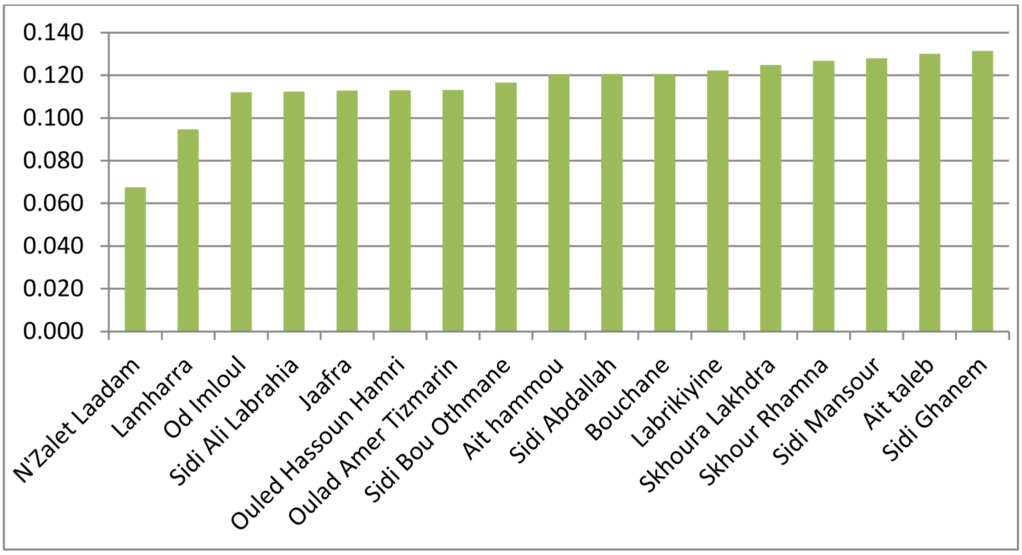

Figure 4-31: Drought Vulnerability of Human and Civic Resources in the province of Rehamna

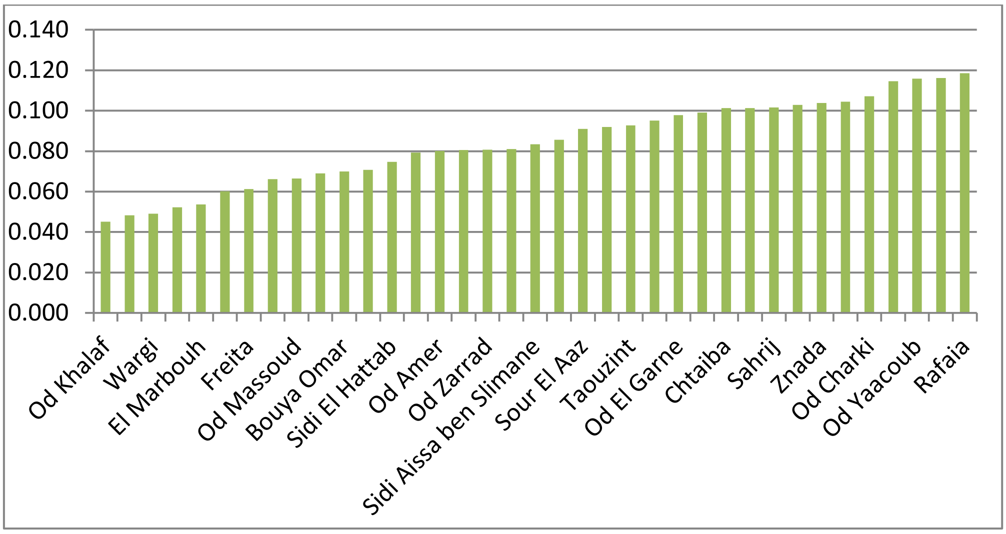

Figure 4-32: Drought Vulnerability of Human and Civic Resources in the province of El kelaa

- Provinces of Fquih Ben Salah and Beni-Mellal

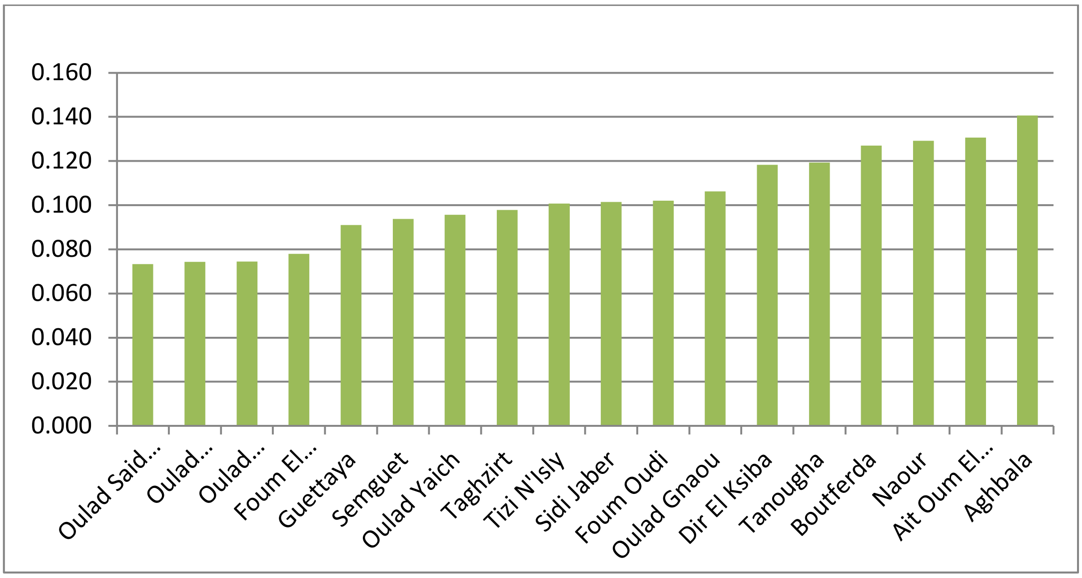

Figure 4-33: Drought Vulnerability of Human and Civic Resources in the province of Beni-Mellal

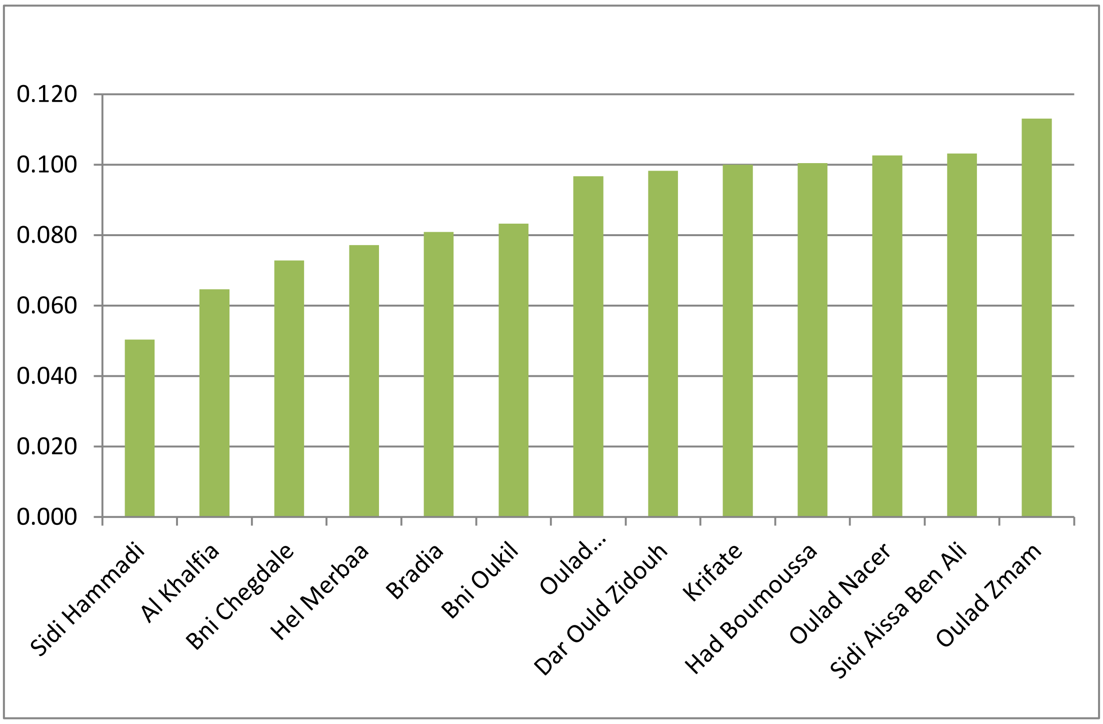

Figure 4-34: Drought Vulnerability of Human and Civic Resources in the province of Fquih Ben Salah

- Province of Khénifra

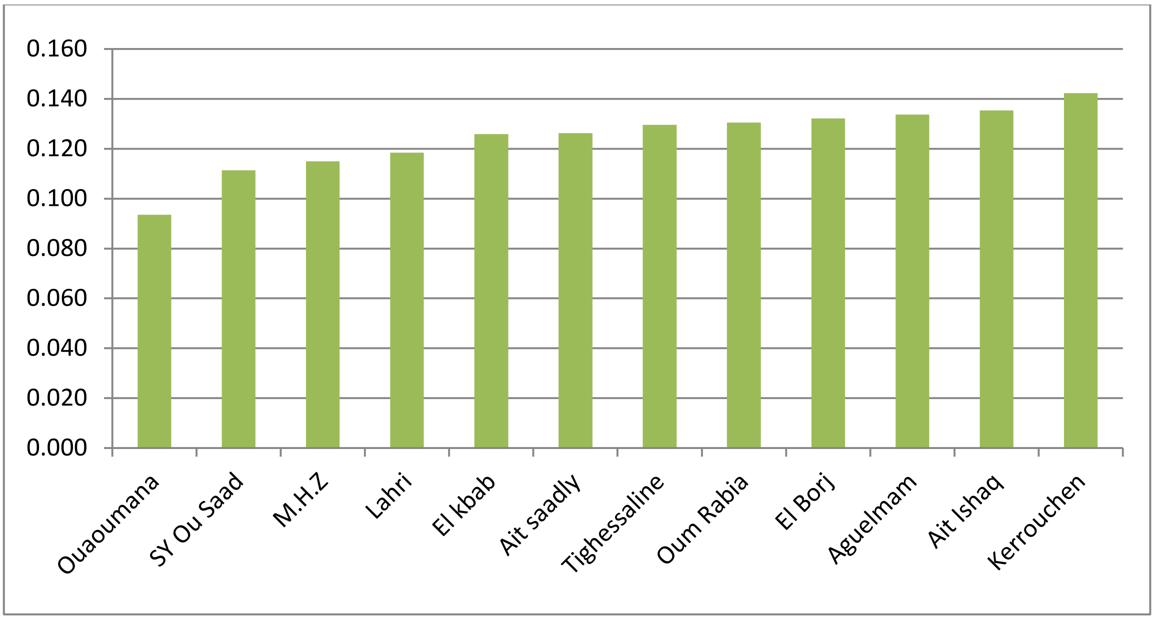

Figure 4-35: Drought Vulnerability of Human and Civic Resources in the province of Khénifra

- Province of Azilal

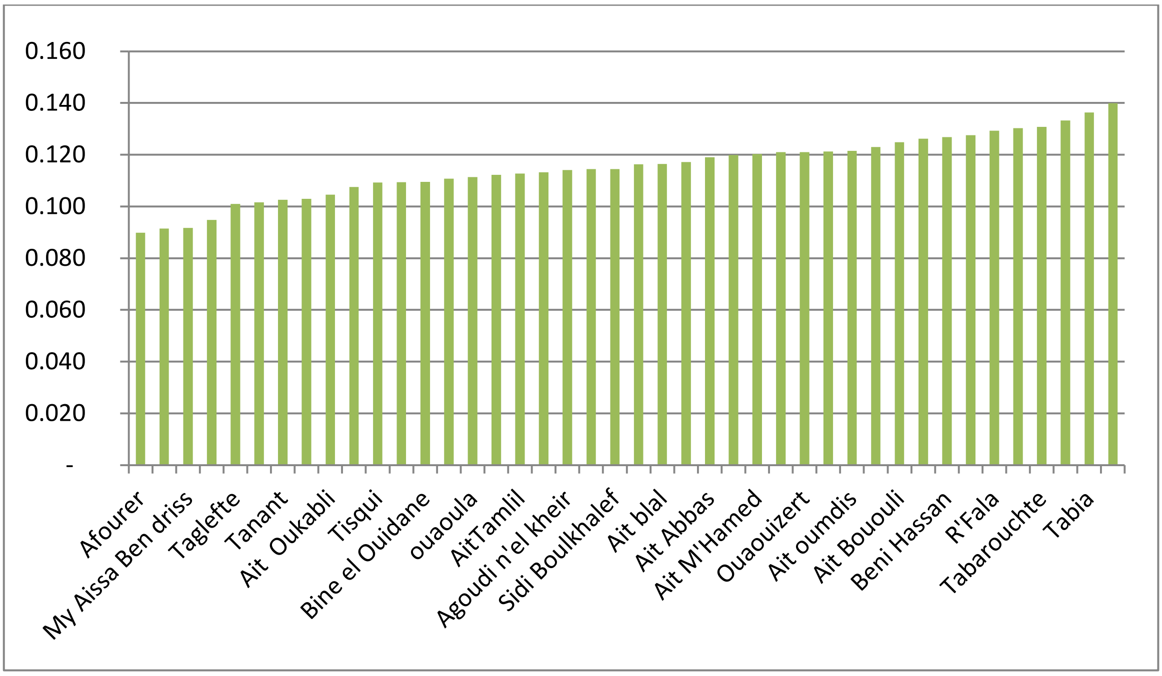

Figure 4-36: Drought Vulnerability of Human and Civic Resources in the province of Azilal

- Province of Khouribga

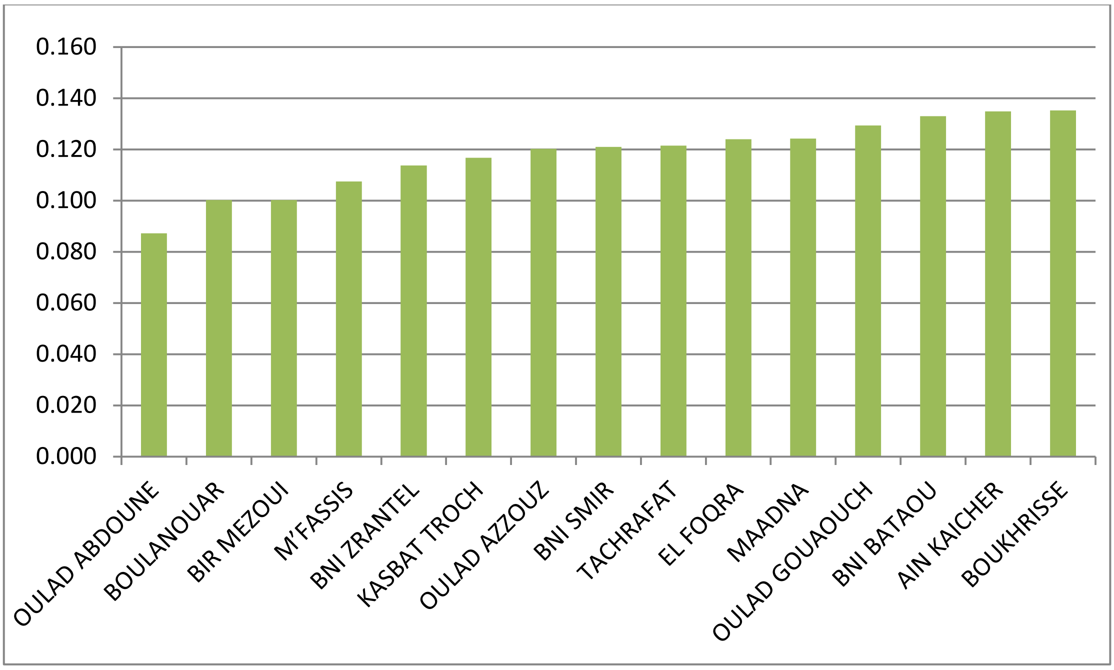

Figure 4-37: Drought Vulnerability of Human and Civic Resources in the province of Khouribga

- Province of Settat

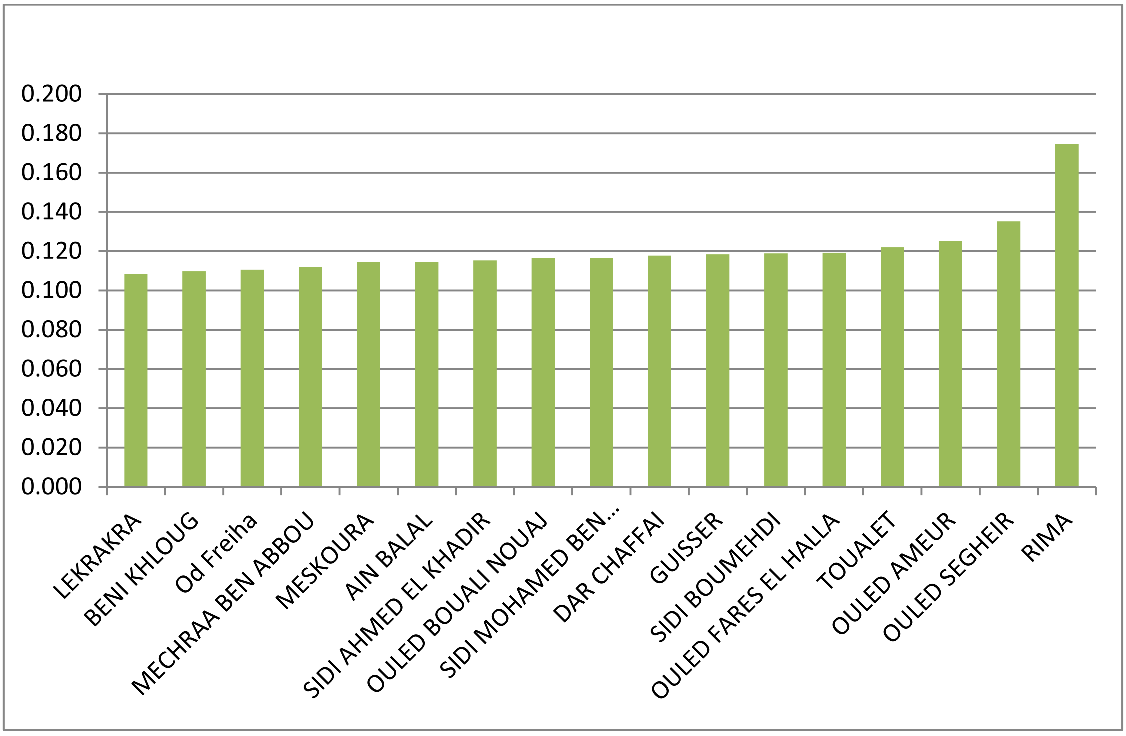

Figure 4-38: Drought Vulnerability of Human and Civic Resources in the province of Settat

Figures 4.28 to 4.38 present the Drought Vulnerability of Human and Civic resources within each province of the Oum er Rbia basin. The analysis of the selected sub-indicators reveals the same trend for all the provinces. Indeed, the adult illiteracy rate and the non-access to improved drinking water are the major drivers of drought vulnerability of Human and Civic Resources.

4.4.9 Vulnerability of Human and Civic Resources to Droughts At basin level

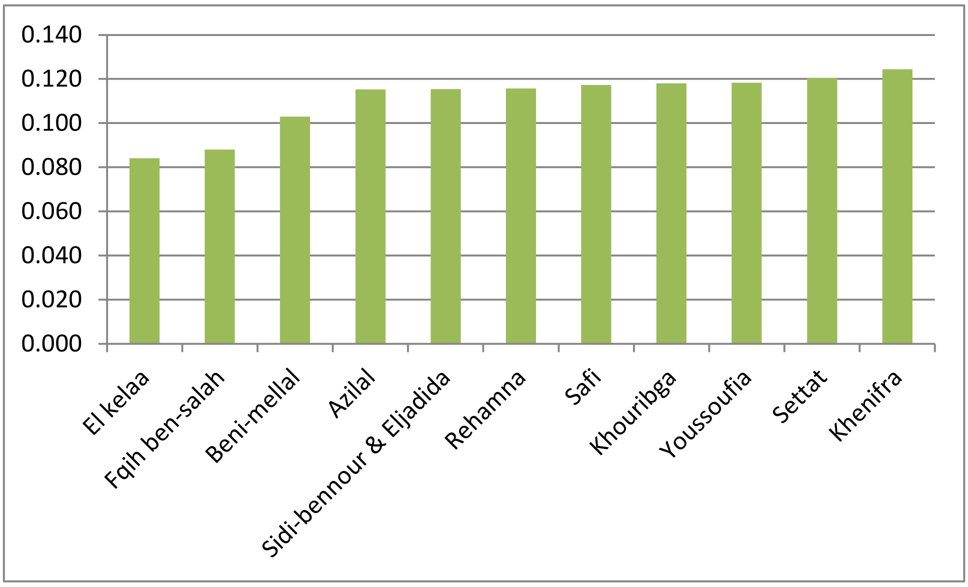

Figure 4-39: Drought Vulnerability of Human and Civic Resources in the provinces covered by the Oum er Rbia basin

Figure 4.39 presents the drought vulnerability of Human and civic resources at the basin level. All the provinces, excepted El Kelaa, Fquih ben Salah and Beni-Mellal present the same level of vulnerability. Those 3 last ones present a lower level of vulnerability explained by a better access to the public network of drinking water.

4.4.10 Vulnerability of Infrastructure and Technology to Droughts

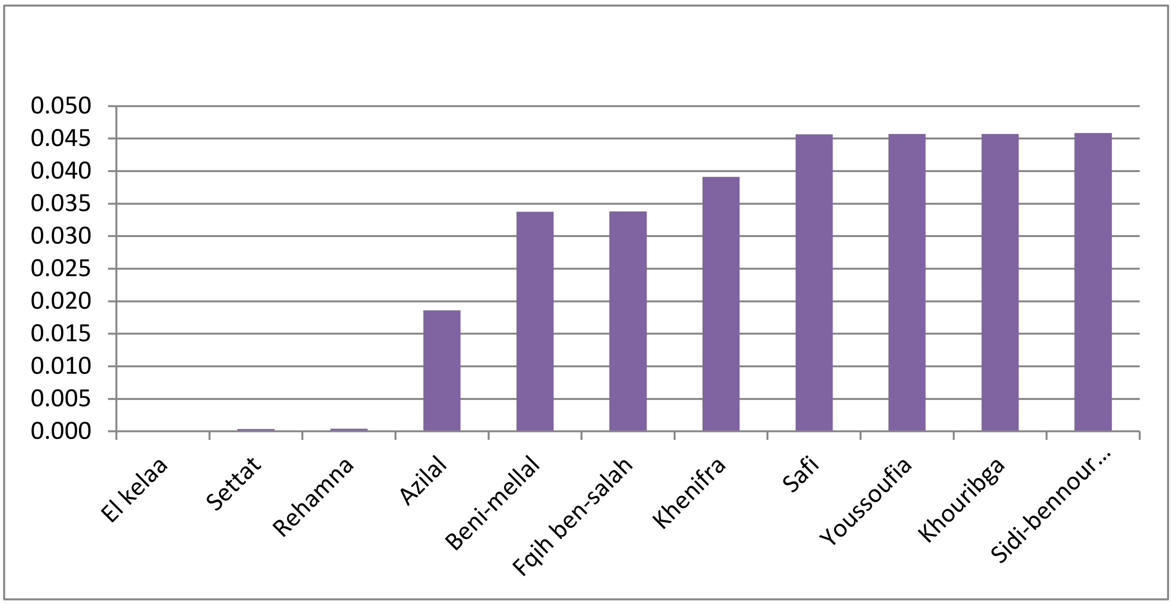

Figure 4-40: Drought Vulnerability of Infrastructure and Technology in the provinces covered by the Oum er Rbia basin

The vulnerability of infrastructure and technology to droughts is only presented at the basin level since this dimension counts only two sub-indicators and one of them (water infrastructures) is only available at provincial level. In addition, this dimension counts many missing data (El kelaa, Settat, Rehamna) and results should therefore be considered carefully. However, the provinces with the lowest drought vulnerability are mainly located in the eastern part of the basin (mountainous areas and foothills) whereas the most vulnerable ones are in the eastern part. Indeed, major dams (except the Al Massira dam) are located in those provinces. A popular proverb compares the Oum Er Rbia basin to: “a cow whose horns are held by the upperstream of the basin and which is milked by the downstream”.

4.5 VULNERABILITY MAPS AND VULNERABILITY ANALYSIS

4.5.1 Drought Vulnerability Index and Provincial maps of drought vulnerability

Figures 4.41 to 4.51 present the 4 dimensions of the Drought Vulnerability index for all the provinces covered by the Oum Er Rbia basin while figures 4.52 to 4.59 present the subsequent drought vulnerability maps.
Results show that for all the provinces, the two first components (Renewable Capital and Economic capacity) counts for nearly 3/4 of the global drought vulnerability index. The economic capacity has a higher impact but the number of sub-indicators considered in this dimension was also important, compared to the other dimensions. Above all, the major sub-indicators that explain the DVI are:

- The mean annual rainfall and the percentage of irrigated lands as well as the belonging to a big irrigated perimeter
- The Cereal / Fruit trees and cash cops ratio, the land status and the farm’s sizes
- The adult literacy rate and the access to improved drinking water

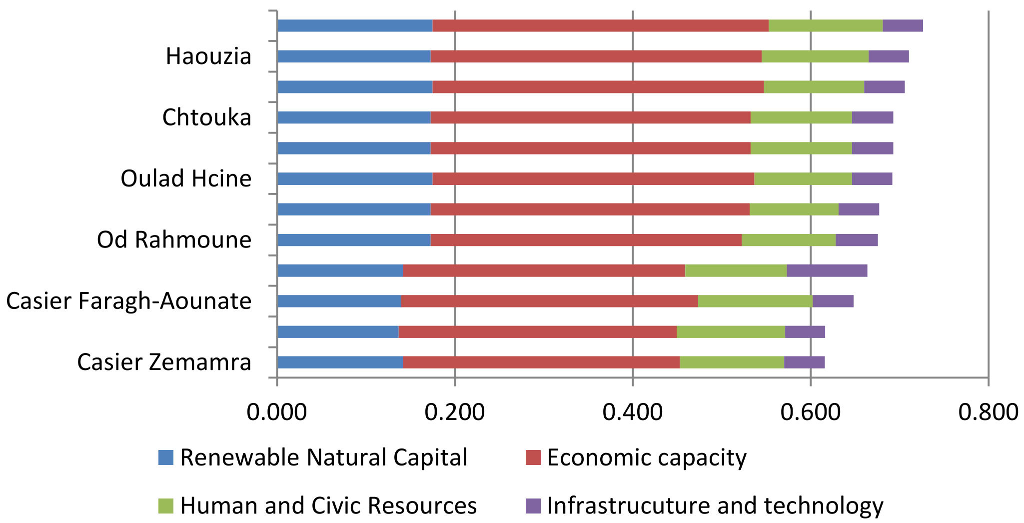

Figure 4-41: Four dimensions of Drought Vulnerability index in the provinces of El Jadida and Sidi Bennour

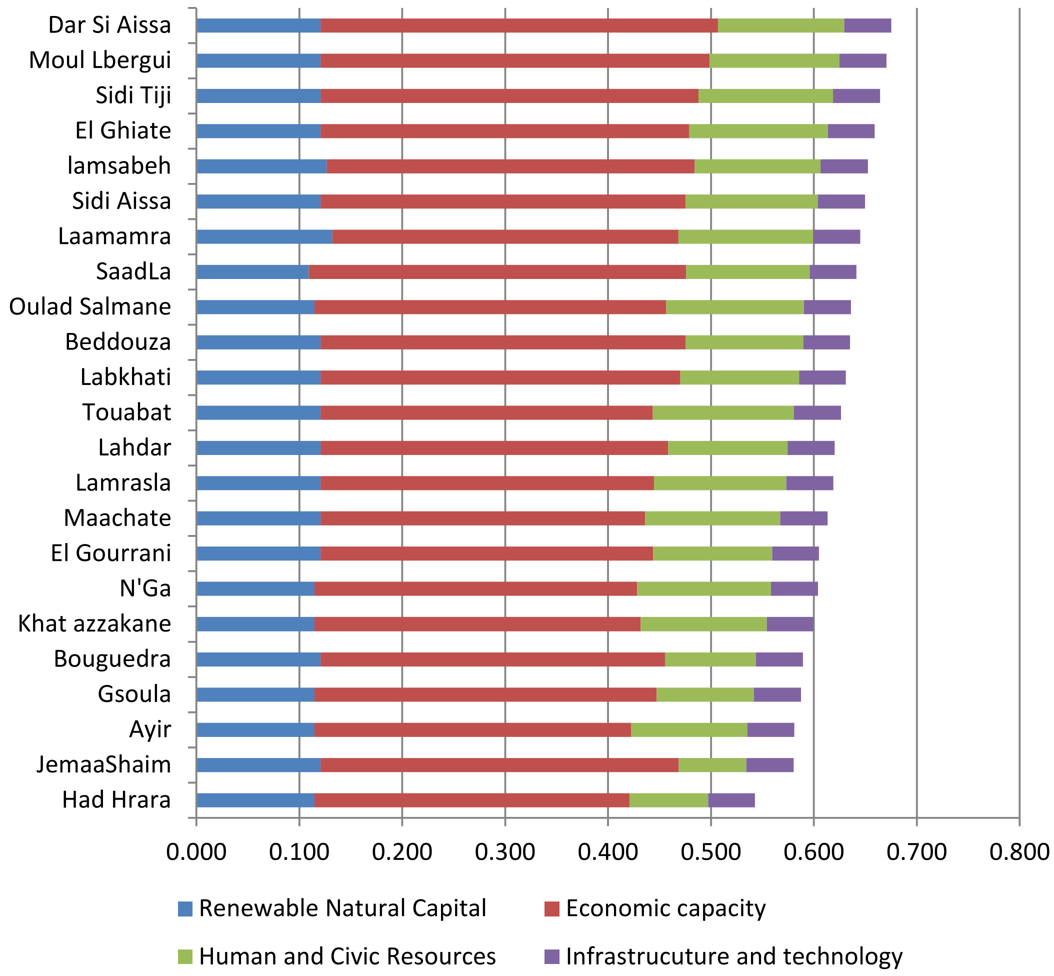

Figure 4-42: Four dimensions of Drought Vulnerability index in the province of Safi

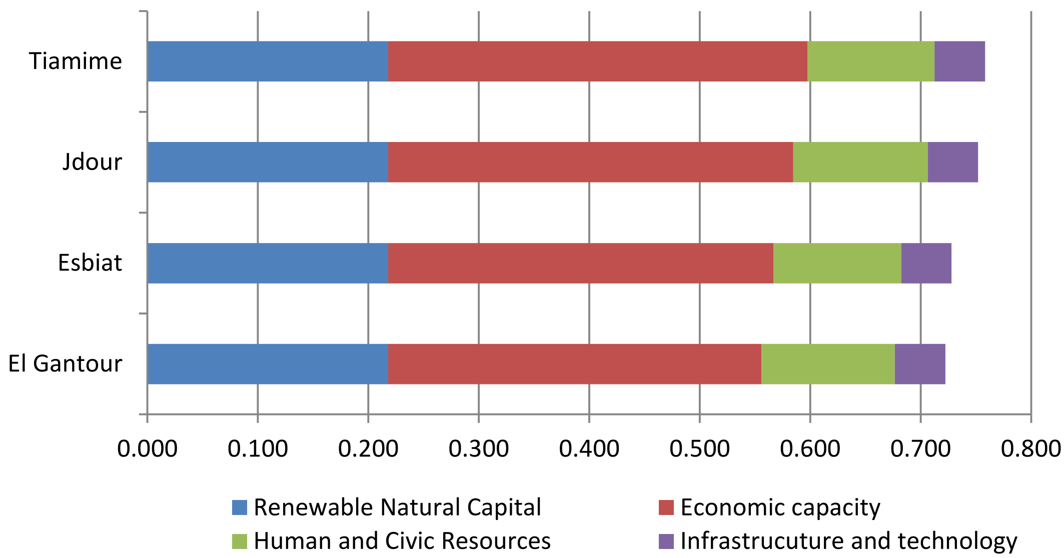

Figure 4-43: Four dimensions of Drought Vulnerability index in the province of Youssoufia

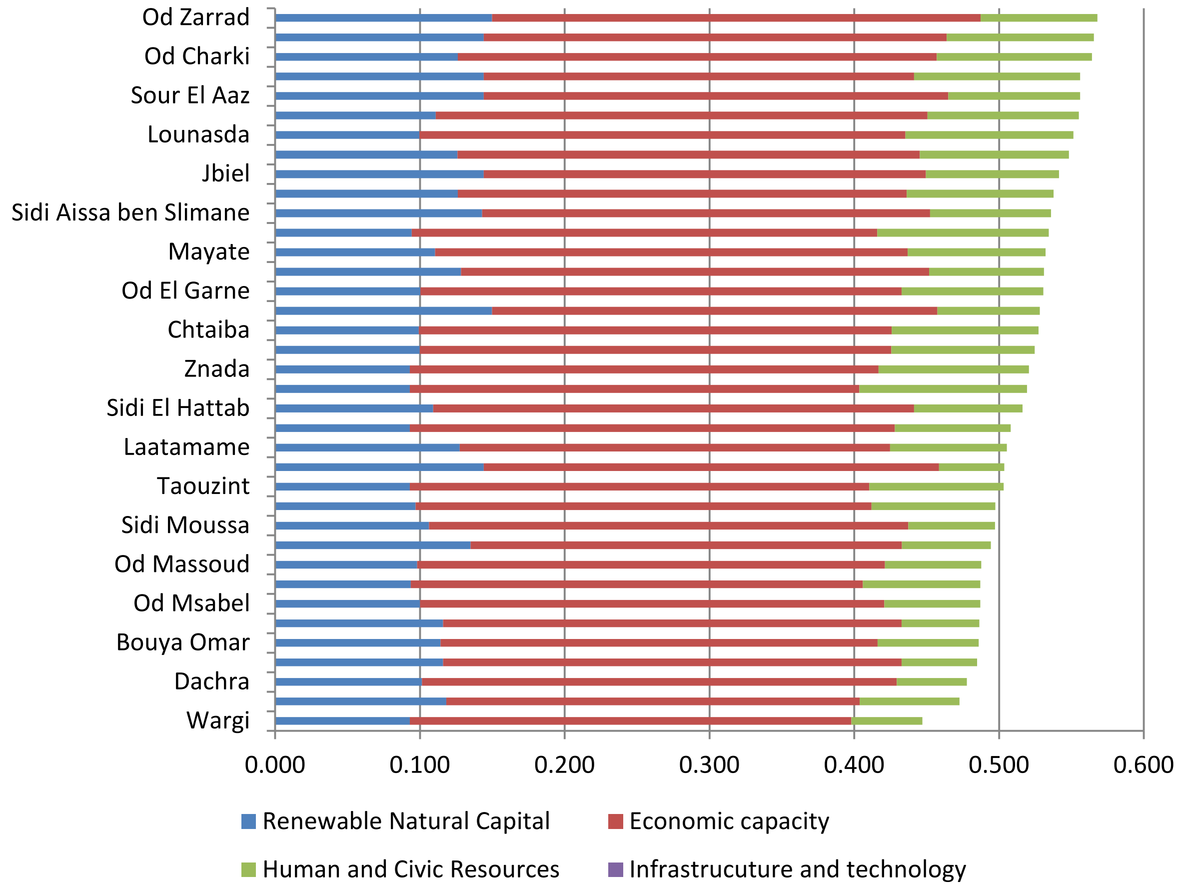

Figure 4-44: Four dimensions of Drought Vulnerability index in the province of El kelaa

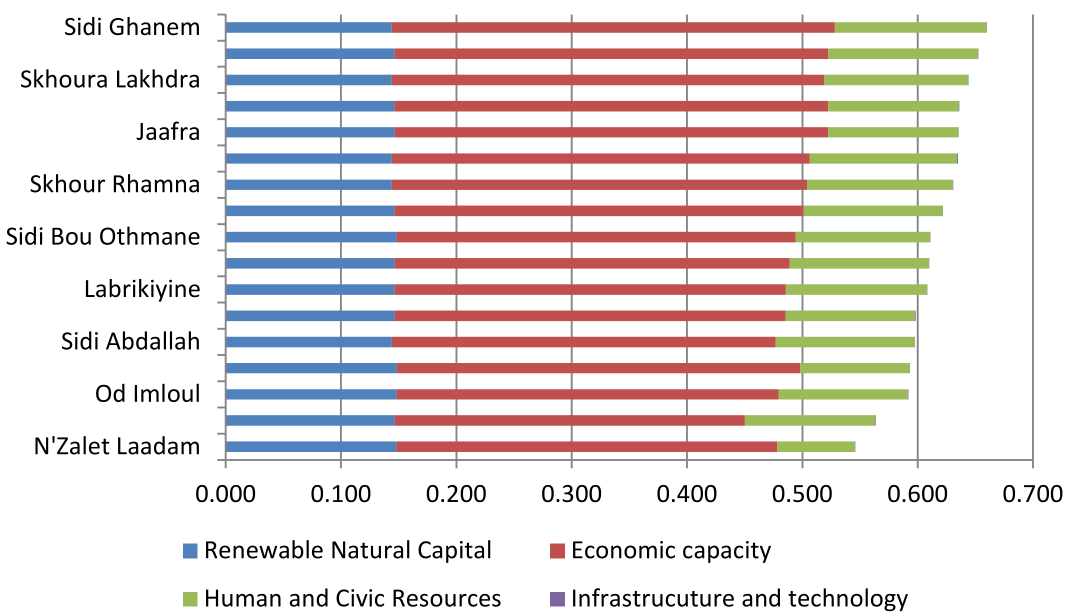

Figure 4-45: Four dimensions of Drought Vulnerability index in the province of Rehamna

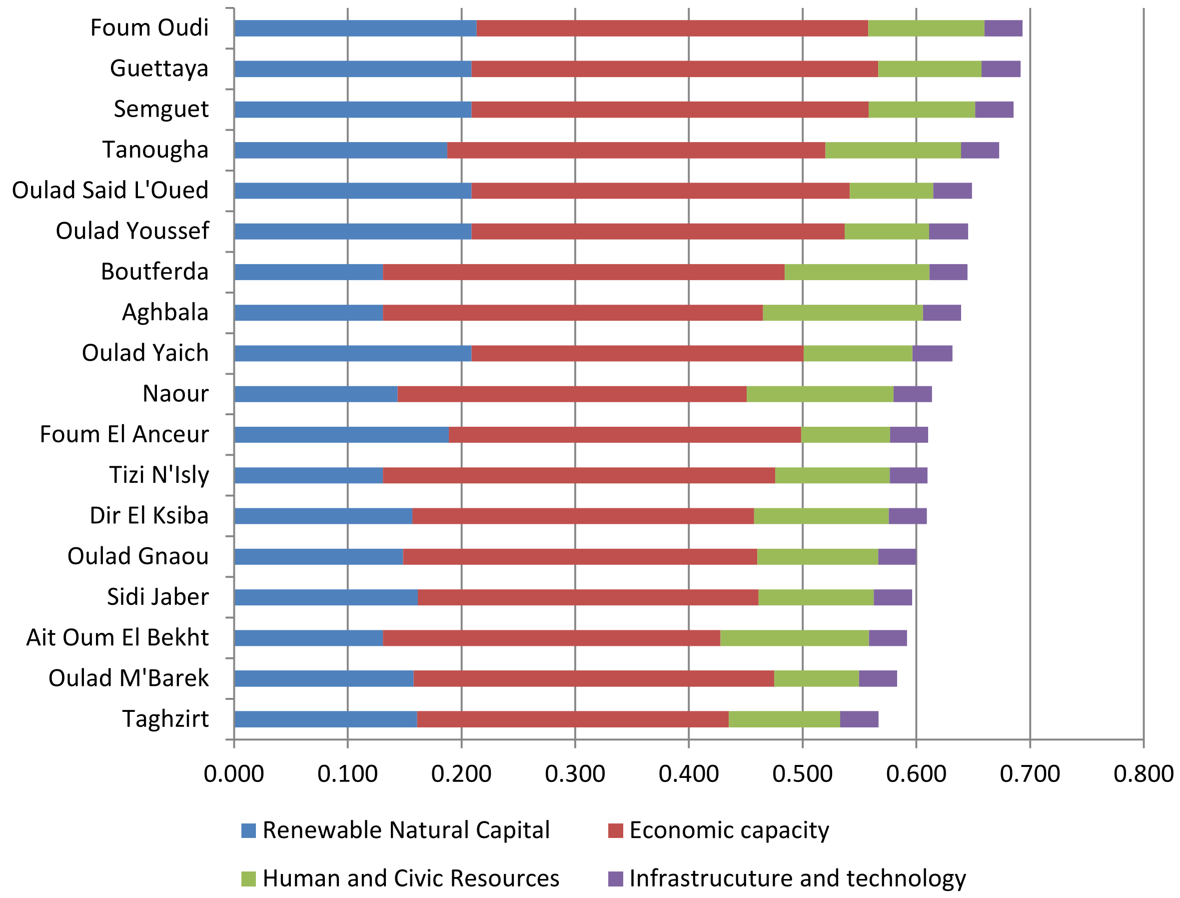

Figure 4-46: Four dimensions of Drought Vulnerability index in the province of Beni-Mellal

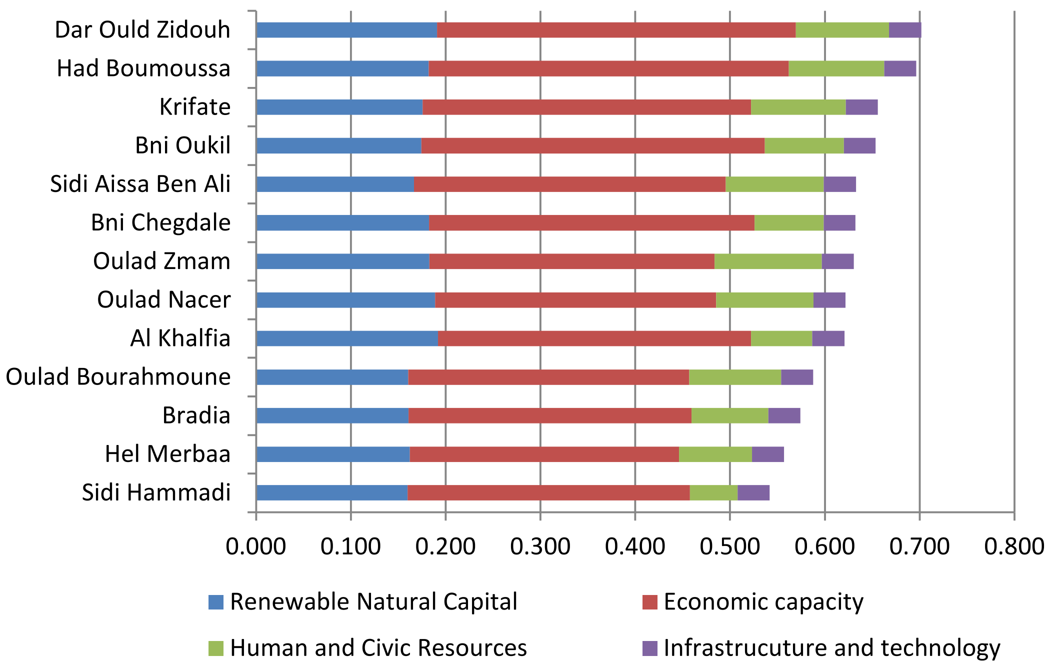

Figure 4-47: Four dimensions of Drought Vulnerability index in the province of Fquih Ben Salah

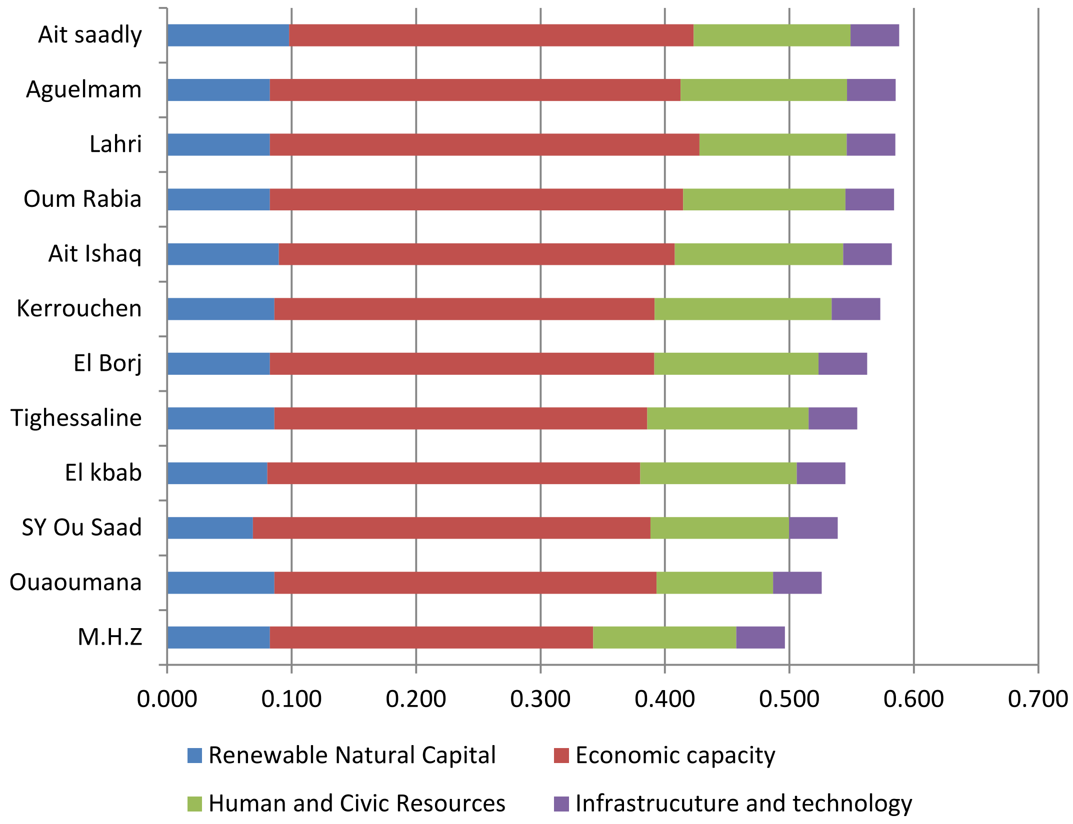

Figure 4-48: Four dimensions of Drought Vulnerability index in the province of Khénifra

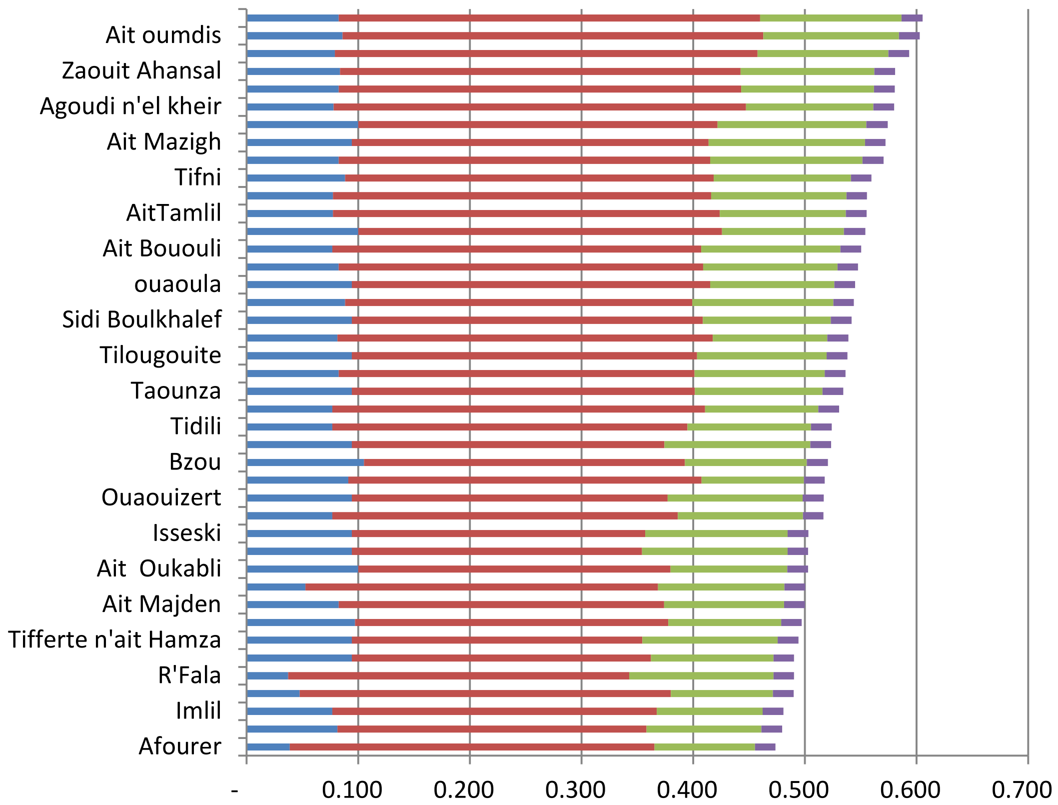

Figure 4-49: Four dimensions of Drought Vulnerability index in the province of Azilal

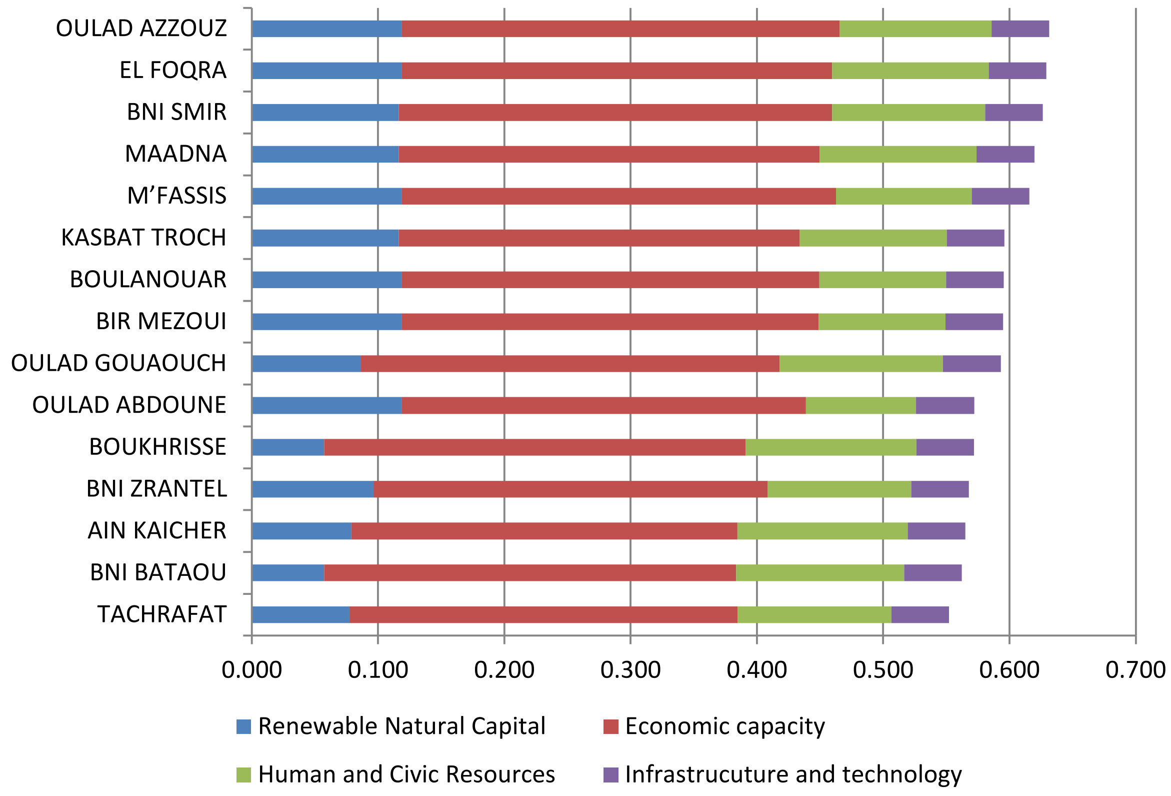

Figure 4-50: Four dimensions of Drought Vulnerability index in the province of Khouribga

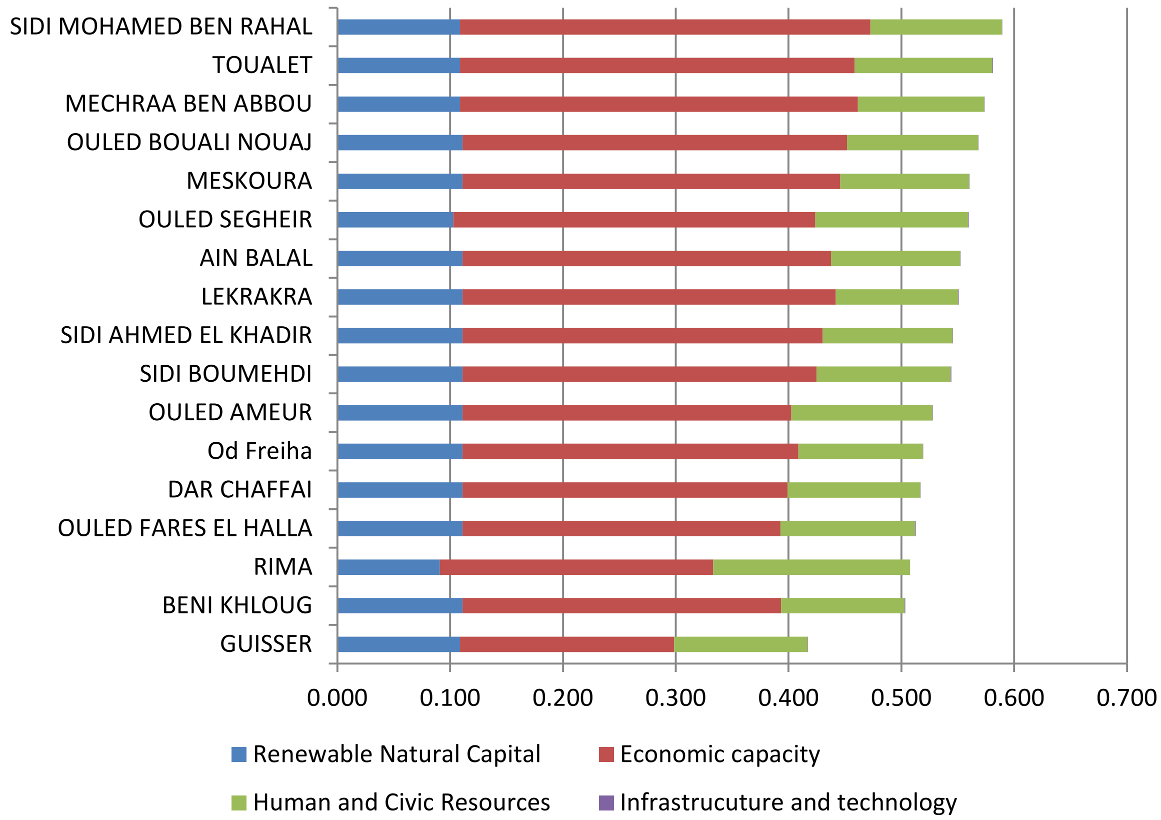

Figure 4-51: Four dimensions of Drought Vulnerability index in the province of Settat

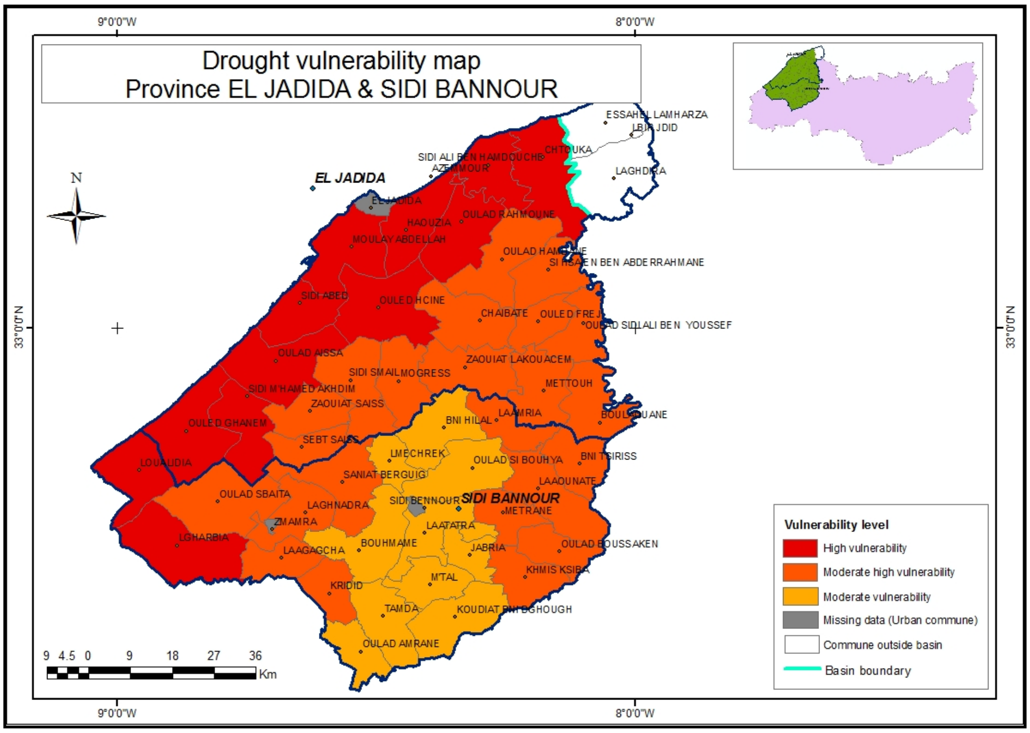

Figure 4-52: Drought Vulnerability map of the provinces of El Jadida and Sidi Bennour

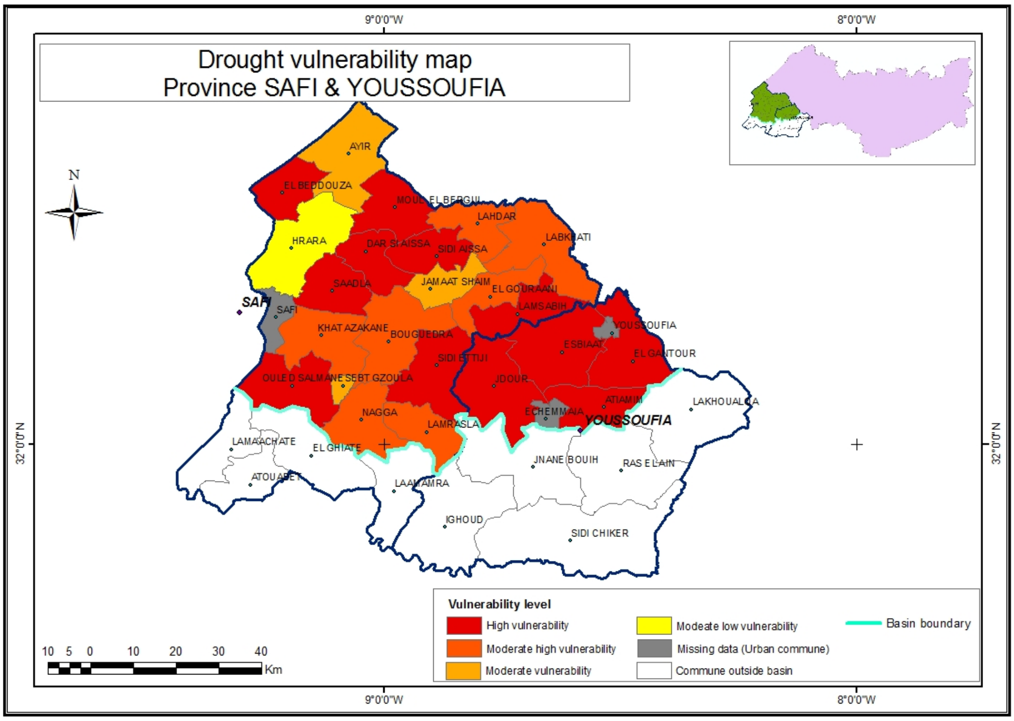

Figure 4-53: Drought Vulnerability map of the provinces of Safi and Youssoufia

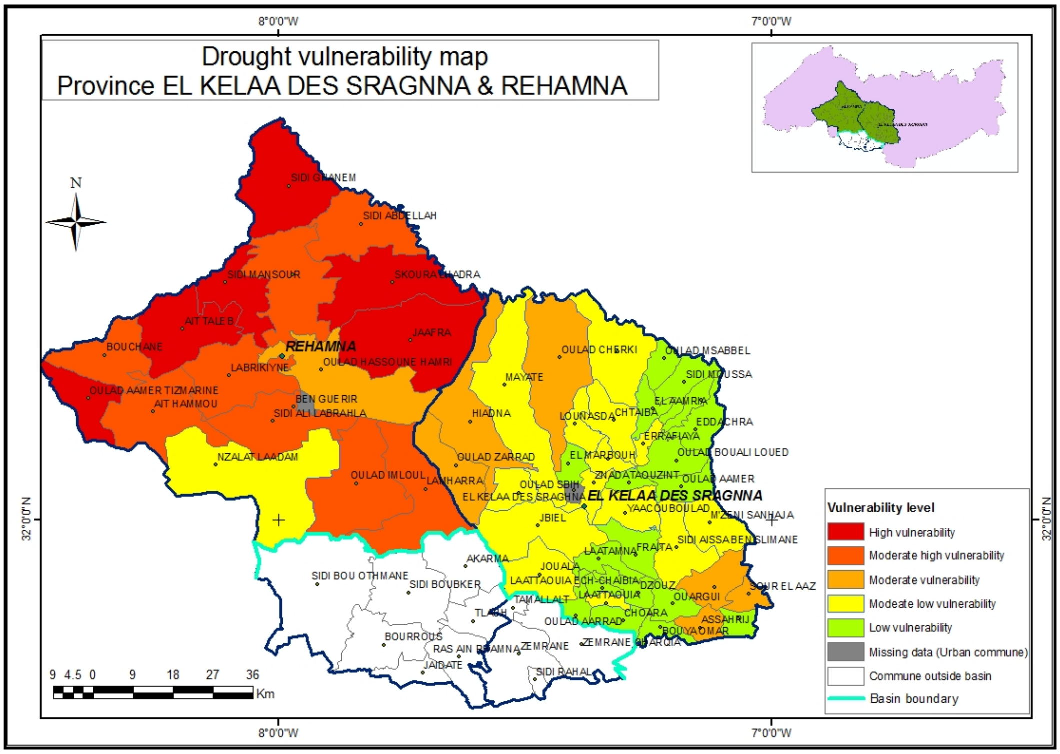

Figure 4-54: Drought Vulnerability map of the provinces of El kelaa and Rehamna

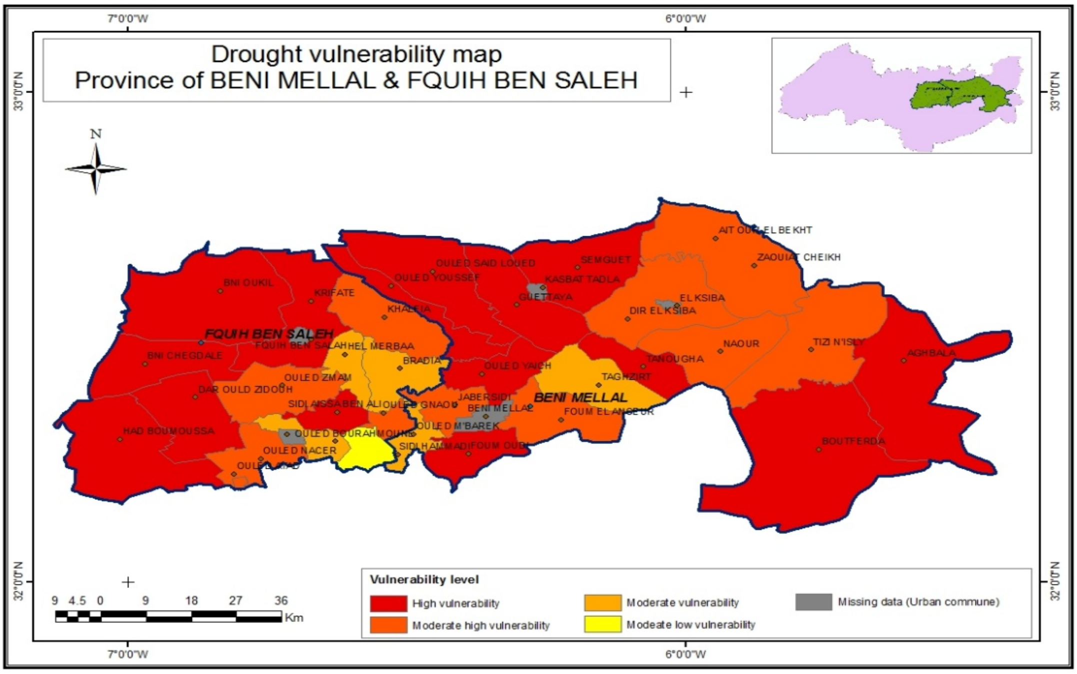

Figure 4-55: Drought Vulnerability map of the provinces of Beni-Mellal and Fquih Ben Salah

- Province of Khénifra

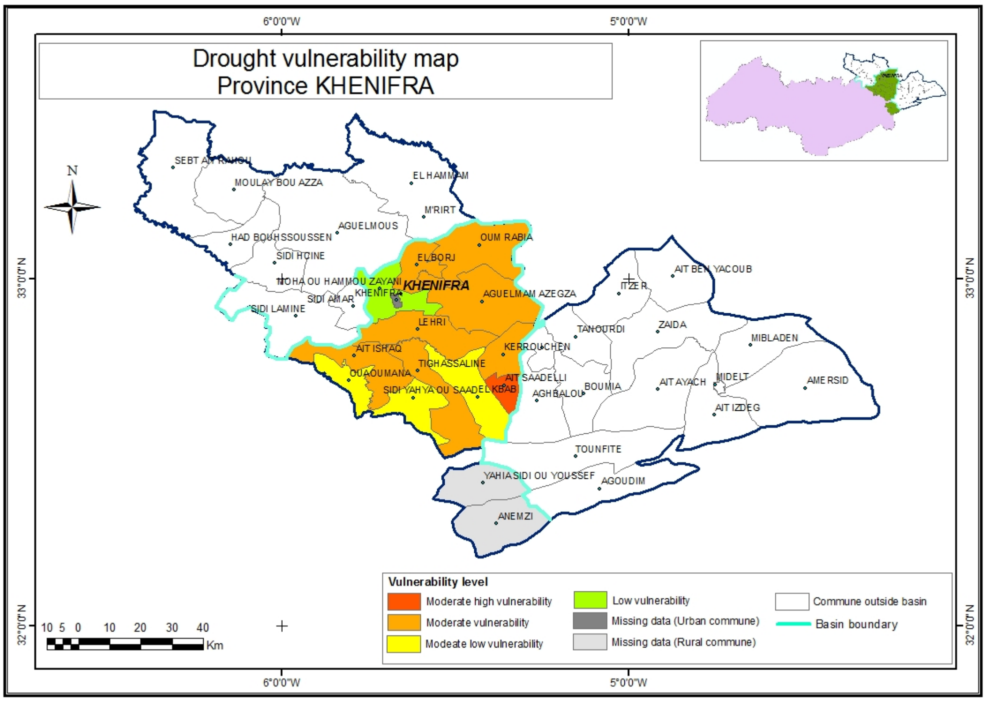

Figure 4-56: Drought Vulnerability map of the province of Khénifra

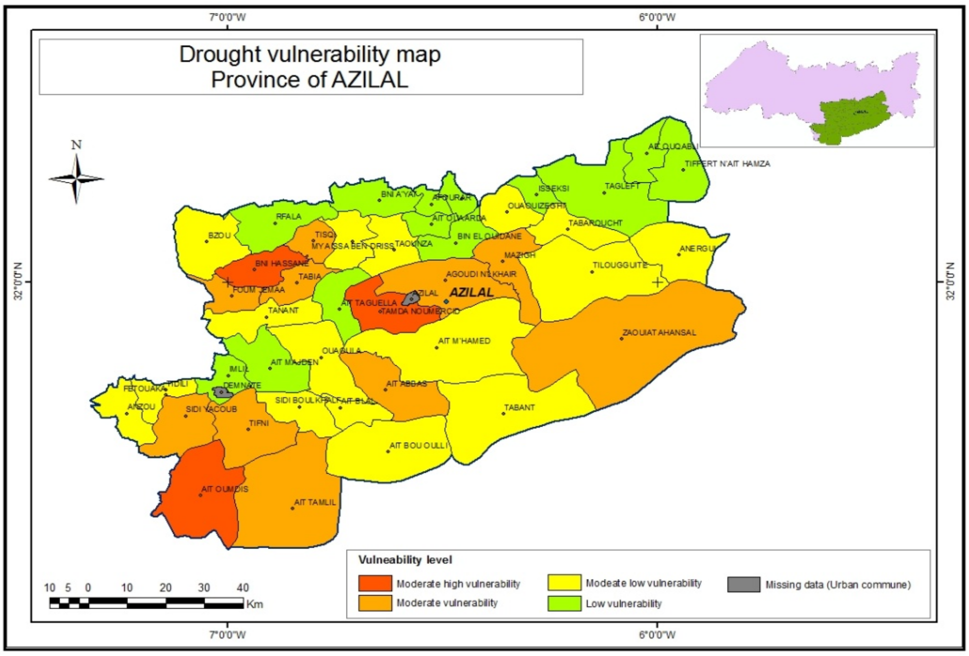

Figure 4-57: Drought Vulnerability map of the province of Azilal

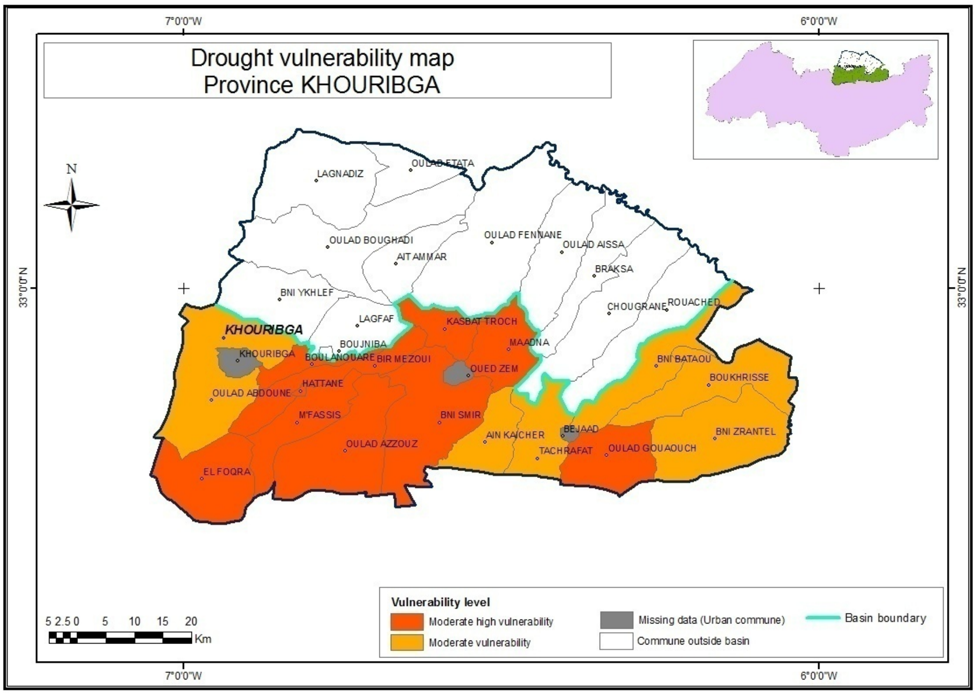

Figure 4-58: Drought Vulnerability map of the province of Khouribga

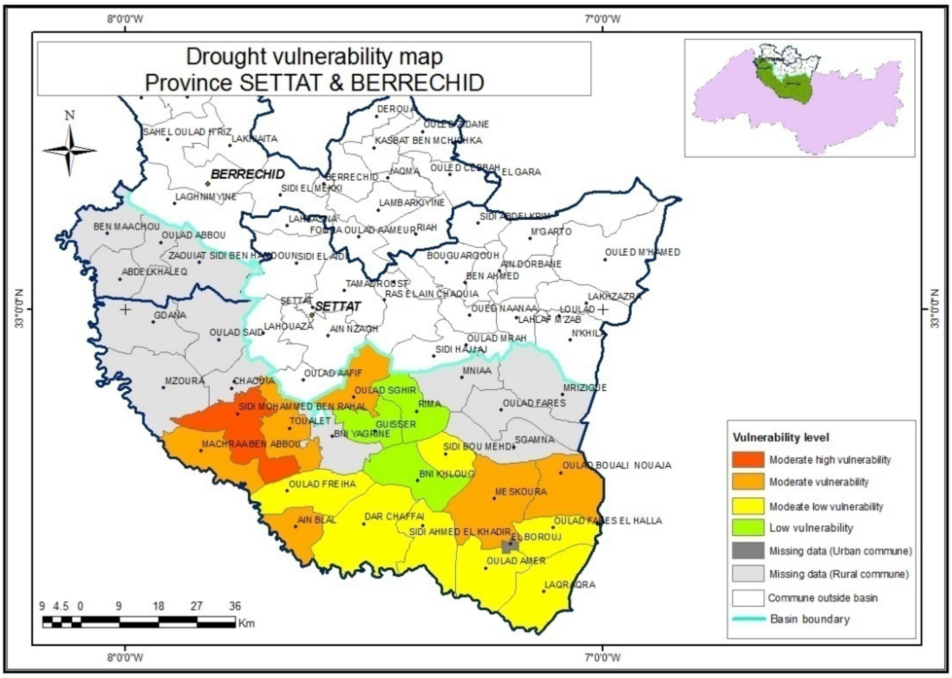

Figure 4-59: Drought Vulnerability map of the province of Settat

4.5.2 Drought Vulnerability map of the Oum er Rbia basin

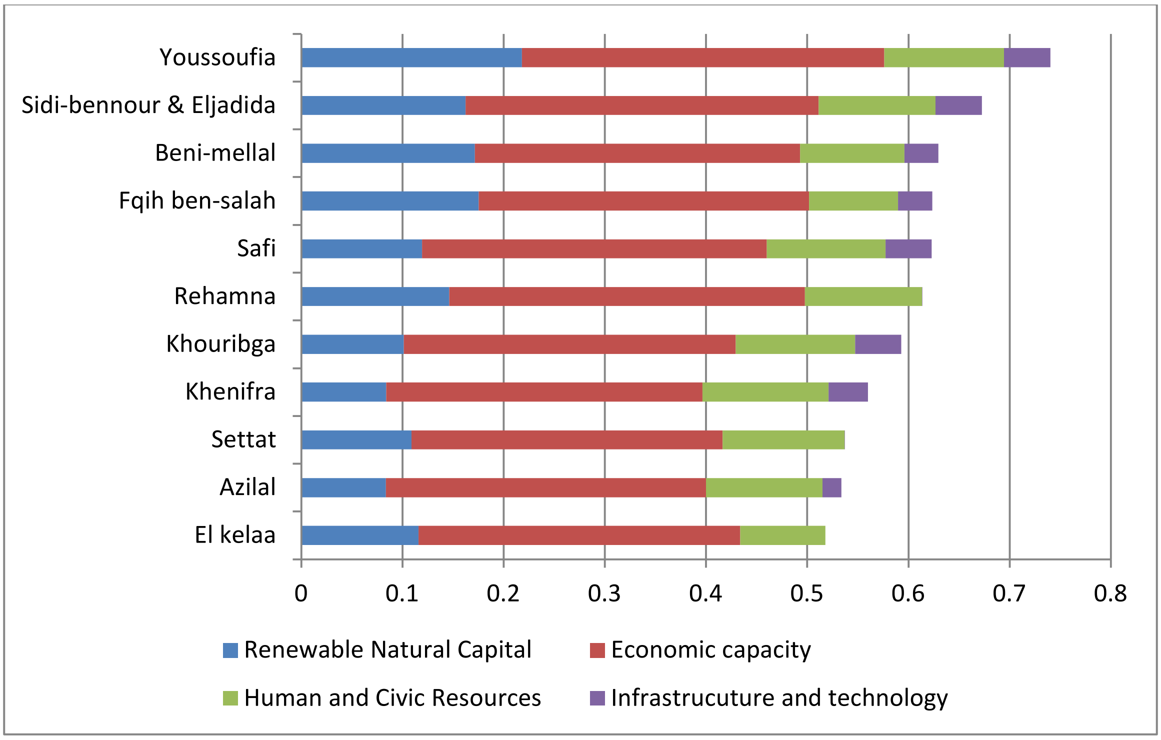

Figure 4-60: Four dimensions of the Drought Vulnerability index in the Oum er Rbia basin

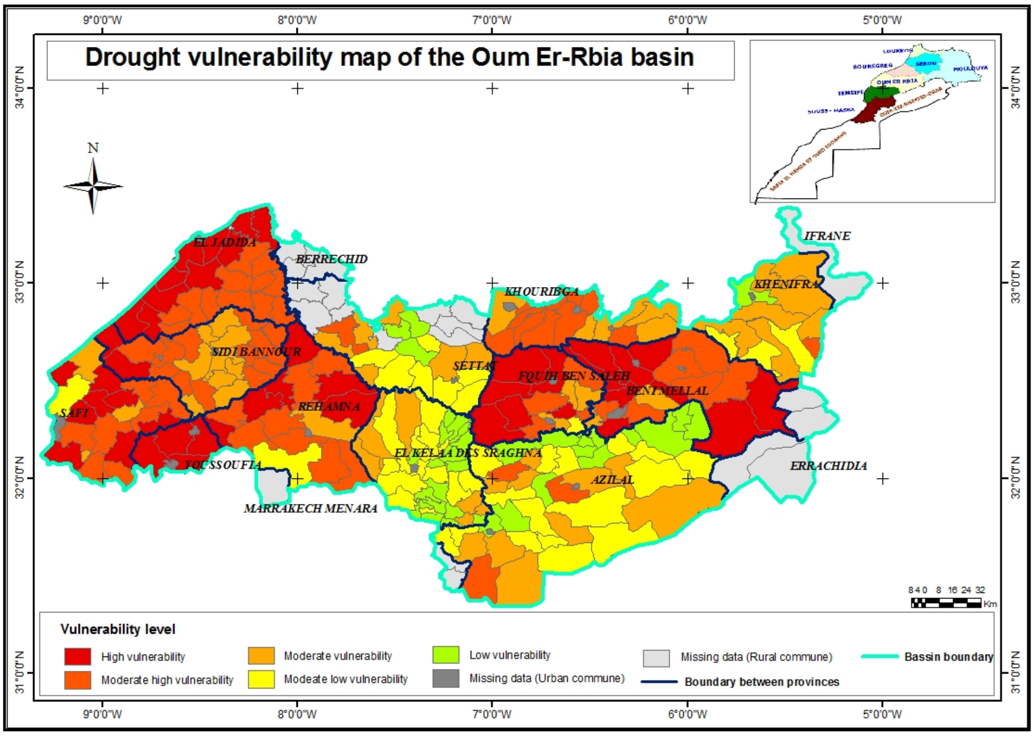

Figure 4-61: Drought Vulnerability map of the Oum er Rbia basin

In the framework of the MEDROPLAN project, an agricultural drought vulnerability map of the basin was developed. The key factors used for this assessment, included the probability of crop moisture deficiency, the soil root zone available water-holding capacity and land-use types. The output map contained four classes of vulnerability: `low', `low to-moderate', `moderate', and `high' (Figure 4.62). However, this map did not include the socio-economic dimension and this is why one of the initial objectives of the case study of the

Oum Er Rbia in the framework of the DEWFORA project was to further the assessment of drought vulnerability in the basin by the means of the newly developed drought vulnerability assessment methods that include socio-economic parameters.

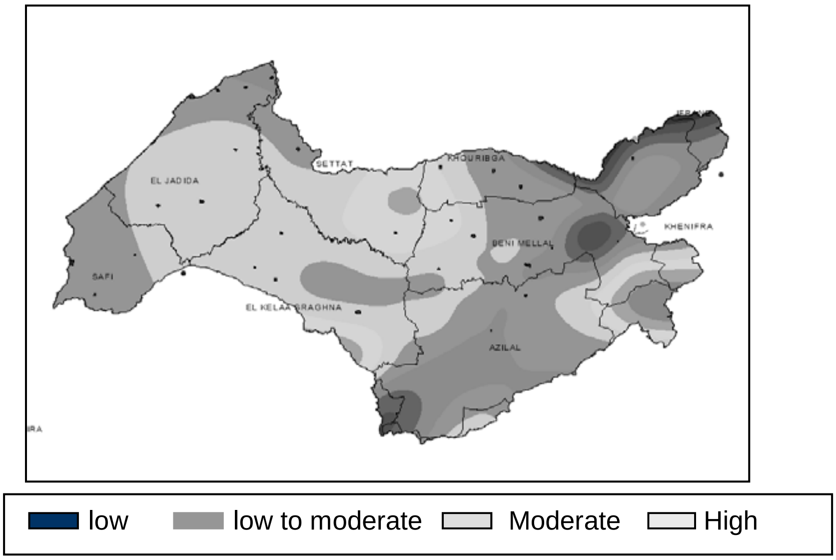

Figure 4-62: Drought Vulnerability map of the Oum er Rbia basin (MEDROPLAN project)

The new drought vulnerability map of the basin (Figure 4.61) shows that except the provinces of Azilal, Khenifra, Settat and El Kelaa, most of the other parts of the Oum er Rbia basin are highly vulnerable to drought. The comparison between the two maps shows that the eastern part of the basin presents the lowest level of drought vulnerability in both cases. The main differences are for the Provinces of Safi and Settat.

The provinces of Azilal and Khenifra are mountainous areas that present the most favorable annual rainfall (Figure 4.63). That contributes to explain their low DVI, especially, since as shown by figure 4.60, the vulnerability of the renewable capital to drought presents the largest variations among provinces and the vulnerability of the other dimensions present fewer variations. For these provinces, the drought vulnerability map is therefore closely linked to the map of the distribution of mean annual rainfall.

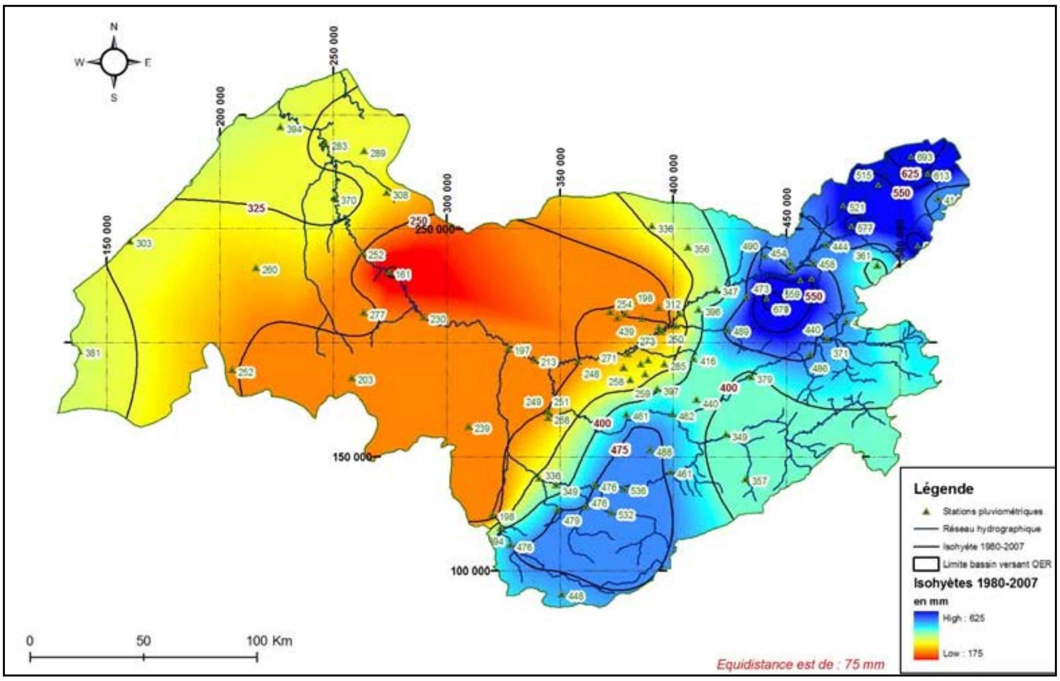

Figure 4-63: Distribution of mean annual rainfall in the Oum er Rbia basin

In addition, although in Morocco, mountainous rural communes may somehow be landlocked, they are of great importance at the national level. Indeed, they represent the water tower of the country and present many agricultural, forest and pastoral opportunities. They also offer an important cultural richness and “Amazighe” people legacies that are characterized by an important human force, socio-institutional organizations and ingenious practices of resources management. However, despite their potential and their spatial and demographic importance, mountainous areas have been so far relatively ignored by the rural development plans in comparison with plain areas. Therefore, their lower drought vulnerability, in a context of climate change and increasing drought frequency and severities, should be considered with more attention and priorities given to the development of those areas.

Although being more arid than coastal areas (Figure 4.63), the inner plains of Settat and El kelaa has lower DVI’s. This should be considered carefully and relativized somehow. Indeed, the province of Settat presents several missing data. It is also known to be a semi-arid area which, although having a long agricultural and pastoral tradition and being considered as the breadbasket of Morocco, is mainly rainfed and has suffered a lot from the past drought episods. On the other hand, the center of Dry Land Farming of Settat is promoting many drought agricultural adaptation practices in the region that contributes to reduce drought vulnerability.

The DVI of the province of El Kelaa should also be relativized by the lack of data regarding water infrastructure. However, despite the poorness of its natural water resources and its aridity (mean annual rainfall of 250 mm), this province is knowing an important development due to the development of the irrigated perimeters of the Upstream and Downstream Tassaout whose water comes from dams located in the provinces of Azilal and Beni-Melal. This allowed reducing the vulnerability of its natural capital to drought. The low DVI of the province is also explained by the importance of olive trees culture in the region and especially the trend towards the replacement of cereals by drought resistant fruit trees species such as olive, fig, carob and pomegranate trees. The development of this province is also translated by the access of rural population to an improved source of drinking water that knew a very important improvement during the last decade and reaches now more than 95% of the population.

In the provinces of Sidi-Bennour, Fquih Ben Salah and Beni-Mellal which are, according to these results mostly highly vulnerable to drought, spots presenting a lower vulnerability corresponds to the irrigated perimeters of Tadla and Doukkala. However, although presenting a lower level of aridity (figure 4.63), these provinces presents a high vulnerability of their renewable capacity to drought. It may be due to the fact, that they present a high population density and exert consequently a higher pressure on the limited water resources.
It is also the case of the province of El Jadida that presents one of the highest demographic density of the country. Nevertheless, regarding this province in particular, the high drought vulnerability should be relativized in the coastal fringe that knows an important development of intensive market crops production thanks to private wells.

According to these results, the provinces of Youssoufia and Rehamna are also highly vulnerable to drought , mainly because of their aridity and their low irrigation potential. However, they are actually, as a drought adaptation strategy, and a way of alleviating their drought vulnerability, developing the cactus crop acreages. Indeed, in Morocco, the Cactus plant was until very recently only used to delimit cultivated parcels, farms's borders. However with the increased frequency of drought episods, the economic value of this specie and its potential use for drought adaptation led to the development in the provinces of Youssoufia and Rehamna but also in the province of El Kelaa of cactus plantations.

Overall, although the drought vulnerability seems to be under or over-estimated in some parts of the basin, the main outputs of this study were the test and implementation of the newly developed drought vulnerability assessment methods. Nevertheless, it can and should be improved by:

- **Drought Vulnerability validation:**

In a first step, comparisons between results of vulnerability assessment and past data about drought impacts in the basin should be conducted to check the reliability of the results and the accuracy of the assessment.

- **The choice of more pertinent and appropriate indicators**:

Indeed, for example, in this study, we have considered the percentage of cereal crops while the Cereal index that includes yields would have given an idea on how technical inputs may buffer the climate variability. Another example is related to farms' incomes: the indicator chosen in this study (because of its availability at the rural commune level) is the number of emigrating households. A quantification of the additional incomes from emigration (even at the provincial level) may have given a better idea on the impact of this indicator on drought vulnerability. This is particularly true in the cases of Provinces like Beni-Mellal or Fquih Ben Salah where the number of emigrating households do not reflect the reality of the immigration that often concerns individuals and not entire households.

- **The integration of other indicators:**

In order to have a more complete idea on the drought vulnerability in the basin, other indicators such as the area under insurance should be integrated. The improved techniques for soil preparation and management and improved crop planting, planning and production methods, the use of more resistant strains of seeds available and animals selected for increased production of eggs, meat and honey should also be considered.

- **Qualitative studies:**

In order to have a better and more complete assessment of drought vulnerability in the basin, the quantitative analysis should be completed by qualitative studies that can reveal through the participative approach of individual and communities certain particular aspects that may affect drought vulnerability. Indeed, for example, in the Oum er rbia basin, it is somehow simple to consider the irrigated agriculture on one side and the rainfed on the other side. They often overlap and some farmers may have parcels in both types of agricultural systems. In that case, under drought situations, they may move their livestock from the rainfed area to the irrigated one and are therefore less vulnerable to drought. The gender approach should also be considered since in many parts of the basin, women's cooperatives represent a major source of income. In addition, since the basin is a very contrasted area, the particular customs and traditions of each community should also be considered. Women's points of views regarding vulnerability are also of great importance since they may reveal particular and unusual perspectives.

5. CONCLUSIONS

In Morocco, 50% of the population lives in rural areas. They are mostly small subsistent farmers whose production relies almost entirely on rainfall. They are therefore very sensitive to drought episodes that may dramatically affect their incomes.

However, at the time being, although Moroccan government decided in the late 90's, as a consequence to the increasing frequency, length and severity of drought episodes, to move on from a crisis management to a risk management approach, drought management remains in practice mainly reactive and often ineffective and drought mitigation strategies and actions stay scarce. The lack of effectiveness of public policy for drought mitigation is in part a consequence of:

- Lack of reliable forecasts and early warning
- poor understanding of drought vulnerability

Therefore, in the framework of the DEWFORA project, different approaches were tested in the case study of the Oum Er Rbia basin in order to improve drought mitigation strategies and drought preparedness. These are:

- The use of medium range and seasonal forecasts.
- The Drought Vulnerability assessment at the rural commune level.

Our main and first objective in the first part of the study was therefore to assess the skill of medium range weather forecasts in the Oum er-Rbia basin. The analysis focused on rainfed areas and cereal crops given their predominance and socio-economic importance around the basin and throughout all the country.

Both, daily and medium-range forecasts appeared not able to predict rain, but seemed to show better skills in forecasting dry periods.

The second objective was to investigate whether medium range forecasts can be used for a better drought mitigation and/or early warning, in the context of what they are meant to offer to the agricultural sector towards user needs. Emphasis was placed on farmers of rainfed areas.

Indeed, under North African conditions where drought is the worst threat, a reliable drought forecast system would provide farmers with a more comprehensive decision tool system for their decision-making.

We developed in this chapter some examples of medium-range forecasting used in the context of our case study. As discussed, some significant potential exist both for early warning and mitigation operations, especially for herders which are in financial inability to cope with major food purchases to save all of their herds account, but also for imports, subsidies and some agricultural practices.

However, knowing that in rainfed agriculture, there is little room for adjusting decisions once the crops are planted, some of the measures, such as pre-season agronomic corrections, control operations against pests and diseases, supplementary irrigation, and the scheduling of harvests, will be high-cost decisions. That's why improved forecasting of drought onset, frequency and intensity would allow farmers to make better choices.

Moreover, for an actual increasing of rainfed farming resilience, the integration of seasonal forecast appears to be essential. Such scale of forecast may allow governments and relief agencies to position themselves for more effective and cost-efficient drought interventions. Producers could more accurately evaluate their production options and insurance companies prepare their payment rate. Herders could better sell their livestock.

In that sense, a statistical-dynamical approach to estimate crop yields over the Oum er-Rbia basin was outlined in DEWFORA deliverables D4.10 and 4.11. The low level circulation fields were used as predictors using a principal component regression to test the predictability of seasonal crop yields in the region. A potential for making yield predictions over the mountains and over the coastal areas were detected using both deterministic and stochastic approaches. Particularly, with a two months lead-time, high and low yield are well discriminated for both areas. On the other hand a very low predictability was identified over the plains of the basin. Forecasts with lead-times of up to four months (but mainly up to two months) using ECMWF S4 hindcasts were analysed showing that low-level circulation data can be successfully downscaled for predicting durum wheat yield for the mountain and coastal areas.

The experiences of forecasts in many countries where there are fundamental difficulties in understanding and applying probabilistic information for decision-making showed that even if forecasts have little observable value, good communication provides farmers with valuable collateral benefits.

The Drought Vulnerability study aimed to assess and map agricultural drought vulnerability at the rural commune level in the Oum er-Rbia basin in order to assist and guide drought management authorities in the development of efficient mitigation actions, tailored to the needs and specificities of each rural community.
This has been achieved through the implementation of the improved methodology developed in Work Package 3. It consists in computing a Drought Vulnerability Index (DVI) that integrates several variables falling under four dimensions:

- Renewable Natural Capital
- Economic capacity
- Human and Civic Resources
- Infrastructure and Technology

The drought vulnerability map derived from the computation of the DVI shows that except for the provinces of Azilal, Khenifra, Settat and El Kelaa, most of the other parts of the Oum er Rbia basin are highly vulnerable to drought. The provinces of Azilal and Khenifra are mountainous areas that present the most favorable annual rainfall. That contributes to explain their low DVI. Although being more arid than coastal areas, the inner plains of Settat and El kelaa have lower DVI's. This should be considered carefully and deserves further investigation.

In the provinces of Sidi-Bennour, Fquih Ben Salah and Beni-Mellal which are, according to these results mostly highly vulnerable to drought, spots presenting a lower vulnerability correspond to the irrigated perimeters of Tadla and Doukkala. Regarding El Jadida province, the high drought vulnerability should be relativized in the coastal fringe that knows an important development of intensive market crops production thanks to private wells.

Overall, although the drought vulnerability seems to be under or over-estimated in some parts of the basin, the main outputs of this study were the test and implementation of the newly developed drought vulnerability assessment methods. In that sense, the methodology used represents a good approach for drought vulnerability assessment. Nevertheless, it can and should be improved by:

- Drought Vulnerability validation;
- The choice of more pertinent and appropriate indicators;
- The integration of other indicators;
- Qualitative studies.

The analysis of the 4 dimensions (Renewable Capital, Economic Capacity, Human and Civic Resources, Infrastructure and Technology) of the drought vulnerability index showed that at the river basin level, the following sub-indicators represent the major drivers of vulnerability that may therefore be targeted in prioritizing mitigation and adaptation actions:

- The mean annual rainfall and the percentage of irrigated lands as well as the belonging to a big irrigated perimeter
- The Cereal / Fruit trees and market crops ratio, the land status and the farm's sizes
- The adult literacy rate and the access to improved drinking water.

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7. APPENDICES

7.1 MAIN OUTCOMES OF THE OUM ER-RBIA CASE STUDY END-USERS WORKSHOP

The DEWFORA end-user workshop of the case study of Oum Er-Rbia Basin (Morocco) was held in Rabat on 7-8 November 2012,

The Objectives were:
- To present and discuss the advances on the case study;
- To receive the feedback from the potential users of the results of the study;
- To refine the proposed activities according to the stakeholders comments and suggestions.

The workshop were co-organised by:
- IAV, partner 17 of the project
- IAMZ-CIHEAM, partner 9 of the project

It was organised in plenary sessions and working groups and knew the participation of 38 participants:
- Members of the project
- Stakeholders from Moroccan institutions representing the water, agriculture and Meteorological administration,
- Farmer organisations
- Academic community
- Experts from other countries: Algerians and Tunisians

Three working groups assisted by guiding questionnaires were organised,
- Group I: Drought Early warning
- Group II: Drought forecasting
- Group III: Drought Mitigation and Adaptation

The relevant points that came out from the discussions can be summarised as following:
- In the Oum er- Rbia basin, the hydraulic development began in 1929 and most available water resources are already mobilised
- Regarding the Needs for medium range and seasonal weather forecasts:
  - ✓ In Rainfed areas (mainly cereals) : i) forecasts are important on a medium range ii) distribution pattern of the rainfall (on a more seasonal approach) is also crucial.
  - ✓ In Irrigated areas: there are two key periods for decisions regarding water allocations for agriculture: June-July & February-March. Thus for water allocation, seasonal forecast are more appropriated. Otherwise, weekly or decadal frequency and medium range forecasts may be helpful for the day to day decisions on irrigation scheduling
- The participants pointed out the important contrasts in the basin between: rainfed (up-stream and downstream) and irrigated areas, between coastal, plain, and mountainous areas. Studies and evaluations of agriculture vulnerability to drought have therefore to be adapted to the variability of the basin and need to take into account this variability. Several sources of variability should be tackled, agro-ecological variability and typology of production systems (irrigated/non

irrigated, intensive/extensive, field crops/fruit crops, livestock systems, forests…). The identification of vulnerability factors and the assessment of drought impacts have to be adapted to variability. Traditions and customs, the know-how, the objectives and practices, of farmers, should also be taken into account.

- They also put the emphasis the lack of data sharing & institutional cooperation that hinders effective drought monitoring and the implementation of early warning systems and relevant drought mitigation strategies.