Trends in rainfall and temperature extremes in the Bouregreg and Tensift regions (Morocco)

K. Khomsi[1], G. Mahe[2], Y. Tramblay[2], M. Sinan[3], M. Snoussi[4]

[1]{Direction de la Météorologie Nationale, Casablanca, Morocco}

[2]{IRD-Hydrosciences Montpellier, Montpellier, France}

[3]{Ecole Hassania des Travaux Publics, Casablanca, Morocco}

[4]{Université Mohammed V, Faculté des Sciences, Rabat, Morocco}

Correspondence to: K. Khomsi (k.khomsi@gmail.com)

Abstract

In Morocco, socio-economic activities are vulnerable to extreme weather events. This work aims to analyze the frequency and the trends of temperature and rainfall extreme events in two contrasted Moroccan regions (the Tensift in the semi-arid South, and the Bouregreg in the sub-humid North), during the second half of the 20th century. This study considers long time series of daily extreme temperatures and rainfall, recorded in the stations of Marrakech and Safi for the Tensift region, and Kasba-Tadla and Rabat-Sale for the Bouregreg region, data from four other stations (Tanger, Fes, Agadir and Ouarzazate) from outside the regions were also considered. Extremes are defined by using as thresholds the 1st, 5th, 90th, 95th, and 99th percentiles. Results show upward tendencies in maximum and minimum temperatures for both regions, but no significant tendencies for rainfall amounts. Changes in cold events are larger than those observed for warm events, and the number of very cold events decrease significantly in the whole studied area. The southern region is the most affected with the changes of the temperature regime. Most of the trends found in heavy rainfall events are positive, with weak magnitudes even though no statistically significant tendencies could be identified in all the stations.

1 Introduction

Extreme events such as: heat waves, cold spells and heavy rains can damage agricultural production, increase energy and water consumption and also badly affect economy and human health and well being (Collins *et al.,* 2000; Nasrallah *et al.,* 2004; Beniston *et al.,* 2007; Deo *et al.,* 2007; Kuglitsch, 2010; Toreti *et al.,* 2010). Over Morocco, the general tendency towards increasing warm temperature extremes and decreasing cold ones has sharply been felt during the last decades, together with heavy rainfall episodes. For example, the heat wave over the country, between the 25th and 28th June 2012, has caused important losses for the agricultural field mainly the poultry farming (L'opinion, 2012). The deadly floods of the 22th November 2014 in the south of Morocco have caused the fate of at least 36 persons (Atlasinfo, 2014). The flood of the 29th and 30th November 2010 had caused enormous human and material losses in Casablanca (Yabiladi, 2010). In the province of Settat, the flood of the 23th and 24th December 2001 has caused the death of eight people and flooded several industrial units and villages in the region, adding to many other tragedies in the flood areas (Aujourd'hui le Maroc, 2002). Also in the Ourika valley, the floods of the 17th August 1995 had caused more than 230 deaths, 500 missing, 200 damaged cars and other property damages (Libération, 1995). Most of studies on climate variability in Morocco have focused on the inter-annual variability of recorded and forecasted climatic variables at the country-scale, as well as their connections with the large scale atmospheric circulation and have shown trends toward hotter and drier conditions (Knippertz *et al.,* 2003; Driouech *et al.,* 2009; Sinan *et al.,* 2009; Singla, 2009; Driouech *et al.,* 2010a; Sebbar *et al.,* 2011; Tramblay *et al.,* 2012; Schilling, 2012; Khomsi *et al.,* 2013; Khomsi, 2014). In the Kingdom, the study of extreme weather events, using climatic indices, has rarely been realized before. We count the studies of Driouech (2010b), Tramblay *et al.* (2012, 2013) and Donat *et al.* (2014) for observed extreme rain events while only the study of Donat *et al.* (2014) was interested in observed extreme temperature events.

This work aims to examine trends in rainfall and maximum and minimum temperature, during the second half of the 20th century, in two contrasted Moroccan areas: the region of the Bouregreg river basin in the North, where many agricultural activities are developed and where the whole river runoff is stored in a large dam for potable water consumption of the largest population basin of the country with about 7 million people (between Casablanca and Kenitra), and the region of the Tensift river basin in the South, the most touristic area of Morocco with more than one million inhabitants and a growing need of water for tourism and irrigation. The paper is organized as follows: first, the study area, data sets and the methods used are described in section 2, the results are given in section 3 and finally, these results are summarized and discussed in section 4 and main conclusions are drawn.

2 Study area, datasets and methodology

2.1. Study area

Morocco is the most Northwestern country of Africa. It is located in the Southern part of the Mediterranean region and is considered among the most vulnerable countries with respect to climate variability, especially the increasing frequency of extreme events (Agoumi, 2003; Sinan *et al.,* 2009b). The Bouregreg River basin (located between 5.4°-6.8°W and 32.8°-34°N), occupies a large area of the Moroccan central plateau (Fig. 1.). It is a combination of monotonous plateaus, deep gorges and basins partitioned by steep ridges over an area of 9656 km² (Marghich, 2004) thus 1.3% of the surface of the country. The elevation rises to 1627 m and 50% of the surface is located between 500 and 1000 m (SIGMED[1] project; Mahe *et al.,* 2013). The climate is sub-humid to semi-arid (Mahe *et al.,* 2012) and average annual rainfall is about 400 mm in coastal regions to 760 mm in the western part of the basin. The number of rainy days per year is 75-100 in the mountainous regions and 60-75 elsewhere. The Tensift River basin (7.2°-9.4°W and 30.8°-32.2°N) covers an area of 19400 km², thus 2.7% of the surface of the country (Fig. 1.). The relief of the High Atlas influences the rainfall distribution and the climate is semi-arid (Mahe *et al.,* 2012). Rainfall is low in the plains where the annual total does not exceed 350 mm, whereas in the mountains it can reach more than 600 mm. The number of rainy days is 25-50 per year for coastal areas and the Haouz central plain, and 45-70 in the mountains (CID, 2004).

Figure 1: Bouregreg and Tensift watersheds and daily measurement stations

2.2. Rainfall and temperature data

Each region (Bouregreg and Tensift) may be presented by only two meteorological stations that record daily data, these stations are not enough to reflect the real climate of the regions and this is probably one of the reasons why only a small number of studies have been focused on local extremes. This is why, in addition to the daily rainfall and maximum and minimum

[1] The SIGMED project stands for « spatial approach of the impact of agricultural activities in the Maghreb on sediment transport and water resources in large river basins »- http://armspark.msem.univ-montp2.fr/sigmed/

temperature series recorded by the four synoptic meteorological stations representative of the Bouregreg and the Tensift basins, data from four other points of measurement, from outside the regions, are used. Adding these new data may help in drawing general conclusions about variability of extremes.

The eight stations (four of them are coastal) belong to the synoptic network of the Moroccan Meteorological Office (Direction de la Météorologie Nationale - DMN). All the data of the Met Office undergo a quality control before being publicly available; this control is performed according to the recommendations of the World Meteorological Organization (WMO, 1981; 1982; 1989; 1993; 1996; Zahumensky, 2004). We used the rainfall and temperature datasets of the meteorological stations of Rabat-Sale on the coastline of the Bouregreg basin, Kasba-Tadla from the inland, Safi near to the coastline of the Tensift basin and Marrakech from the inland. From outside the basins, we used Tanger in the extreme north coastline of Morocco, Fes in the North-East of the Bouregreg basin, Agadir from the south coastline of Morocco, South of Marrakech, and Ouarzazate in the East of the Tensift basin on the Saharian side of the Atlas Mountains (Fig.1.). The study was performed on a seasonal basis and the study periods are the whole periods of data availability after applying the criteria suggested by Kuglitsch *et al.* (2010) for reducing the amount of missing data in time series (Table 1):

1- A month is considered complete when it contains no more than three missing days;
2- A season is considered as available when all months are complete in respect to criterion 1;
3- A station dataset is considered as complete when no more than three consecutive seasons are missing.

As the common period to all the datasets is between 1983 and 2005, this work was performed on the overall periods of data availability and also on the common period of 23 years, the most significant results were obtained from the long periods. Here after we show the most significant results, those relative to the common period are not presented.

For this work, the homogenization of the data used was not performed due to the poor horizontal resolution of data and the differences in the periods of availability; this implies an additional uncertainty to the results. Nonetheless, the problem was addressed by researching change points and analyzing the discontinuities in the studied time series. The metadata of available stations was gathered and documented changes in the stations' location and instruments were compared to the found dates of breaks in the time series. Undocumented changes mainly in the observing practices and working procedures remain difficult to take into account.

2.3. Methods

This work was performed on a seasonal basis and seasons were identified using monthly normal temperatures and rainfall, recorded on the second half of the 20th century, to draw the climatograms of the measurement stations used (Figure 2). On the climatograms, the months when the curves are below the 0 constitute the warm season, the months when the curves are above constitute the cold season; and the months of intersection between the curves and the axis are the transition periods (Khomsi *et al.* 2012; Khomsi, 2014).

According to Figure 2, cold and warm seasons were defined for all the stations, as containing the following months respectively: November to February and June to September. For this paper needs, the cold season is named winter, while the hot season is named summer.

In order to rank the extreme events of rainfall and temperature, we used a percentile based sampling. The meaning of percentile can be captured by stating that the pth percentile of a distribution is a number such that approximately p percent (p%) of the values in the distribution are equal to or less than that number. So, if '30' is the 90th percentile of a larger batch of numbers, 90% of those numbers are less than or equal to 30. If n is the total number of observations, a percentile can be calculated by sorting the data from the smallest x_1 value to the largest x_n, x_i is the p_i^{th} percentile of the data set and :

$$p_i = 100\frac{i - 0.5}{n}$$

To study extreme events, the 1st , 5th, 90th and 95th percentiles are used as thresholds, as they are widely employed and recommended by the STARDEX (STAtistical and Regional dynamical Downscaling of EXtremes for European regions) (http://www.cru.uea.ac.uk/projects/stardex/) and the ETCCDI (Expert Team on Climate Change Detection and Indices) (http://cccma.seos.uvic.ca/ETCCDI/) projects. In addition, exceptional events were selected using the 99th percentile as threshold. This approach was applied to the winter and summer data of the whole periods of availability and the following definitions have been used:

- A heavy rainfall event is a day that recorded precipitations greater than or equal to the 90th percentile;

- An intense rainfall event is a day that recorded precipitations greater than or equal to the 95th percentile;
- An exceptional rainfall event is a day that recorded precipitations greater than or equal to the 99th percentile;
- A one day hot (cold) event is a day that recorded a maximum (minimum) temperature greater (lower) than or equal to the 95th (5th) percentile;
- A one day very hot (cold) event is a day that recorded a maximum (minimum) temperature greater (lower) or equal to 99th (1th) percentile;
- A hot (cold) spell is a succession of 3 or more hot (cold) events;
- A very hot (cold) spell is a succession of 3 or more very hot (cold) events.

The magnitude of trends in the time series of total rainfall and maximum and minimum temperatures has been analyzed using the non parametric method proposed by Theil (1950) and Sen (1968) for univariate time series. This approach involves computing slopes for all the pairs of ordinal time points and then using the median of these slopes as an estimate of the overall slope. Since the Sen's slope is insensitive to outliers or missing data, it is widely used for the estimation of trends' magnitudes of climate series (Deo et al. 2007; Guentchev et al. 2010; Hidalgo-Muñoz et al. 2011). The ordinary linear regression (OLS) was used for trend detection in the frequency of identified extreme events because the Sen's slope is affected by ties in the time series. The statistical significance of the obtained trends was investigated using the modified Mann-Kendall test proposed by Hamed and Rao (1998) for auto-correlated time series. The test is performed at significance level α of 5%.

Discontinuities in the datasets of total rainfall and mean maximum and minimum temperatures time series were analyzed using the rupture tests of Pettitt, Buishand, Lee & Heghinian and the segmentation procedure of Hubert (Lubès-Niel et al., 1998). The null hypothesis tested is that there is no rupture in the series and a rupture is considered as very likely when it is detected by, at least, two tests. These procedures are well defined by Maftei et al. (2011).

Figure 2: Cold and warm seasons of Kasba-Tadla, Marrakech, Rabat-Sale, Safi, Tanger, Fes, Agadir and Ouarzazate.

3 Trends in total precipitation and frequency of rainfall extreme events

3.1. Observed total rainfall

Table 2 shows tendencies in winter and summer annual rainfall recorded in the studied stations. Decreasing tendencies are noticed in the winter rainfall of the north (Rabat Sale, Tanger and Fes) and the inland south (Marrakech and Ouarzazate) while all the other tendencies are increasing. None of the found tendencies is significant.

Table 8 shows the changing points in the rainfall time series. During the winter no discontinuities are observed, while during the summer, a change appears around 2007 in the precipitation regime of Rabat Sale and Marrakech.

3.2. Observed rainfall extreme events

Table 3 shows the trend magnitudes for extreme rainfall events in the studied stations, during winter and summer. According to this table, no significant generalized tendencies could be identified during the both seasons; moreover, most of the tendencies are positive with weak magnitudes. Some isolated positive and significant tendencies are noticed in the winter exceptional events of Kasba Tadla and summer exceptional events of Rabat Sale; these tendencies remain difficult to explain as they may characterize the small areas related to the stations of measurement.

3.3. Trends in maximum and minimum temperature

Trends in seasonal daily maxima and daily minima temperatures are shown in table 4 while the changing points in these time series are presented in table 8.

In winter, there are significant positive trends of maximum temperature in the coastal north stations: Rabat-Sale (0.17 ± 2.55°C/decade), Safi (0.21 ± 2.73 °C/decade) and Tanger (0.15 ± 3.18 °C/decade). The other upward tendencies are not statistically significant. For minimum temperature, significant positive tendency affects the series of Safi (0.22 ± 1.80°C/decade) and Marrakech (0.18 ± 2.46°C/decade) (uncertainties are ±1 s.e. (standard error) of the slope). Break points were observed in maximum temperature time series in Safi in 1978, Tanger in 1987 and Fes in 1973. Minimum temperatures have changed in Marrakech in 1945, Agadir in 1994 and Ouarzazate in 1975.

In summer, maximum temperatures have increased in most of the stations while they decreased, slightly, in the south (Marrakech, Agadir and Ouarzazate). However, according to the Mann-Kendall test, only the trends in the two northern coastal stations (Rabat-Sale and Tanger) are statistically significant with magnitudes equal to 0.15 ± 2.72 and 0.19 ± 2.14 °C/decade respectively (uncertainties are ±1 s.e. (standard error) of the slope). Minimum temperatures have increased in all the stations, except for the times series of Kasba-Tadla, all the trends computed are statistically significant. A break point was observed in the maximum temperature of Rabat Sale in 1986, Safi and Tanger in 2002, Marrakech in 1951, Agadir in 1955 and Ouarzzate in 1997. The series of minimum temperatures show a change in Rabat Sale in 1978, Safi in 1983, Tanger in 2002, Fes and Agadir in 1984 and Ouarzazate in 1977.

3.4. Frequency and occurrence of hot temperature events

Table 5 shows the trend magnitudes for hot and very hot events in the studied stations, in winter and summer.

In summer, the four stations in the north: Rabat-Sale, Kasba Tadla, Tanger and Fes recorded positive trends of hot events while trends in the other stations of the south were negative. Significant trends are recorded in Tanger (0.17 day/decade), Fes (1.45 day/decade) and Ouarzazate (-2 day/decade). For very hot events, i.e. when daily maximum temperature exceeds the 99 percentile, apart from the positive trends in the coastal stations of Rabat-Sale, Safi and Tanger, all the other trends are significant. Upward significant tendencies are noticed in the north (Kasba Tadla (0.67 day/decade) and Fes (0.69 day/decade)) while downward significant trends are shown in the south (Marrakech (-0.34 day/decade), Agadir (-0.15 day/decade) and Ouarzazate (-0.88 day/decade)).

In winter, all the hot events trends are positive except that of Agadir. Significant trends are found in Safi (0.67 day/decade), Marrakech (0.76 day/decade), Fes (0.72 day/decade) and Ouarzazate (0.64 day/decade). Regarding very hot events, most of the computed trends are positive, a slight downward trend appears in Marrakech. Only the trend of the very hot events observed in Fes is statically significant (0.44 day/decade).

3.5. Frequency and occurrence of cold temperature events

Table 6 shows the magnitude of the trends for cold and very cold events during summer and winter.

In summer, the cold events decreased significantly in almost all of the stations, these trends range between -0.64 day/decade and -2.21 day/decade. Very cold events decreased also significantly in many stations and trends range between -0.64 day/decade and -0.2 day/decade.

In winter, cold and very cold events decrease in Kasba Tadla, Safi, Marrakech, Agadir and Ouarzazate and increase in the other stations. Trends are significant in Safi (-0.9 day/decade), Marrakech (-1.01 day/decade), Agadir (-0.64 day/decade) and Ouarzazate (-1.33 day/decade) while those in very cold events are in Kasba Tadla (-0.74 day/decade), Safi (-0.23 day/decade) and Marrakech (-0.26 day/decade).

3.6. Frequency and occurrence of extreme temperature spells

Trend magnitudes for hot and very hot spells and cold and very cold spells lasting more than 3 days are shown in table 7.

In summer, significant trends are found in hot spells of Tanger (0.16 day/decade) and Fes (0.19 day/decade) and also in very hot spells of Ouarzazate (-0.14 day/decade) and Fes (0.1 day/decade). In winter, the station of Fes has also recorded an increasing trend in hot spells (0.16 day/decade).

Regarding cold and very cold spells (Table 7), in summer, all of the significant trends are decreasing. Trends are of -0.12 day/decade in Rabat-Sale, -0.28 day/decade in Safi, -0.11 day/decade in Fes, -0.16 day/decade in Agadir and -0.23 day/decade in Ouarzazate. During the cold season, frequency of cold spells decrease significantly in Safi (-0.14 day/decade), Marrakech (-0.11 day/decade) and Ouarzazate (-0.18 day/decade) and increase in Fes (0.27 day/decade).

During both seasons, no changes are noticed in long lasting very cold events, estimated trends are quite negligible.

Hot spells of more than 5 days increase significantly in Tanger and Fes and decrease in Ouarzazate in summer. Very hot spells decrease softly in Marrakech and increase in Tanger. In winter, a slight increase in hot spells of more than 5 days is noticed in Safi. Cold spells of more than 5 days decrease significantly in Kasba Tadla and Ouarzazate in summer and in Marrakech in winter. No significant trends are noticed in extreme events lasting more than 7 days.

4 Conclusions

This paper presents the study of the variability of rainfall amount, temperature extremes and extreme rainfall and temperature events in eight stations from the synoptic network of the Morocco MetOffice. Four of these stations can represent two different watersheds: Rabat Sale and Kasba Tadla for the Bouregreg basin and Marrakech and Safi from the Tensift basin.

For the aim of this study, all the stations were assigned same and unique warm and cold seasons. The results show that the climatic features and variability can be different between North and South Morocco; they depend on the geographical location relatively to the Atlantic and the Mediterranean coasts and to the Atlas Mountain.

During the second half of the 20^{th} century, no statistically significant generalized trends could be identified in the trends of summer and winter cumulative and extreme rainfall events of the studied areas. This finding agrees with the results found by Tramblay *et al.* (2012) and is in contradiction with the tendency toward drier conditions and decreasing amounts of precipitations already found by some authors in many regions of Morocco (Driouech, 2010b; Singla *et al.,* 2010). In fact, the seasonal approach chosen for this research may be the cause of this difference and the significant decreasing may be observed during the months of transition (Mars, April, May and October) not studied in this paper. The important increasing trend recorded in Kasba Tadla during the winter is mainly due to the short period of its data availability that may not capture the drier conditions of before the year 1983.

The positive trends of seasonal mean maximum and minimum temperatures found in this paper are in good agreement with the results of Donat *et al.* (2014) and those obtained for other countries both in Europe and Asia (Jones, 1995; Brunetti *et al.,* 2004; Tabari *et al.,* 2011). For all these regions, the rise in minimum temperature is large when compared to the detected trends in maximum temperature. Although evaluated with different definitions and indicators, most of the studies in the literature found that extreme temperatures tend to increase. Inverse trends of mean maximum temperatures at the stations of Marrakech, Agadir and Ouarzazate (in summer) and mean minimum temperatures at the stations of Rabat-sale, Tanger and Fes (in winter) may be explained by natural factors such as microclimates and local physical geographic and vegetations conditions or also by inhomogeneities in the analyzed datasets. In addition, human-induced conditions like the differences in air quality and urbanization characteristics may have an influence here since most of the stations above are located in large cities with a sustained population increase since 30 years. The warming trend in average minimum temperature series found for all the studied stations is certainly coherent with the decreasing observed in the recorded frequency of cold events, this might confirm the effect of greenhouse gases and may refer to saturated and polluted air in the early morning (Turkes *et al.,* 1996; Bani-Domi, 2005). The insulating effect of clouds, which tends to warm surface temperatures by trapping infrared radiations, can give rise to a positive relationship between cloud cover and temperature changes.

Also, it can be related to a lower number of low-pressure events over the country, increasing in turn the average temperatures as there is more direct sun radiation on the ground. Following the same idea, a lesser extension to the South of the cold air tongues during the coldest spells of winter may have the same influence. Both cases are related to the global warming impact on the global air masses circulation. An other possible cause for the increase of the average temperatures can be related to the increase of the sea surface temperatures (Skliris *et al.,* 2010; Sykes *et al.,* 2010). For most of the stations studied, except Ouarzazate, rainfall come directly from the Atlantic Ocean, and as the average temperature of the air masses flowing into Morocco is likely to increase, it might be responsible for a part of the temperature increase over Morocco, especially during the winter rainfall season.

When analyzing the dates of breaks in the studied time series, it appears that the studied regions did not witness a generalized change in the regimes of rainfall and maximum and minimum temperatures. After comparing the found dates of ruptures to the available metadata, we can conclude that some of the found discontinuities may be due to changes in the station location or in the instruments of measurement. Some ruptures remain unexplained and may be due to undocumented changes, we especially mean the breaking point in the summer rainfall of Rabat Sale in 2007, the winter minimum temperature of Marrakech in 1945, Ouarzazate in 1975 and Agadir in 1994. Also, the summer maximum temperature of Rabat Sale in 1986, Marrakech in 1951 and Agadir in 1955 and the summer minimum temperature of Rabat Sale in 1978 and Ouarzazate in 1977.

Variations of hot extreme events and cold extreme events during both seasons are significant in the overall evolution of the temperature regime. The southern region is the most affected with the changes in the hot temperature regime while almost all the studied area is affected with the change in the cold temperature regime mainly during the summer. These variations are explained partly with the changes in the mean values of maximum and minimum temperatures. They also may be due, apart from the differences in the climate and the topography between both studied regions, to other factors such as the response to large scale atmospheric circulation. According to Khomsi *et al.* (2012), the North East disturbed weather is behind most of the cold temperature events on Morocco. This weather type appears during the cold season, than the country is subject to a direct air discharge coming from the North East after crossing the Mediterranean. During the warm season, hot events result when the axis of the zonal ridge is on the north of Morocco and the country is subject to an East or North-East regime called Chergui and dry and warm air masses invade it.

The results of this study highlight the fact that the northern and southern regions respond differently to the recent global warming. This response depends on the considered region characteristics and emphasizes the need for more regional to local studies. It would be worthwhile making such a study on other areas from Morocco if more long daily data are available. Obtained results could then be compared with those of the present study. As a surrogate for station data, regional climate models driven by reanalysis now available at a fine spatial resolution could be also analyzed mainly for temperature since they usually reproduce it with a good adequacy.

The data and metadata used in this project are not free of charge, so cannot be made publically available, nonetheless, resulting samples of extreme events will be available, to the scientific community, through the SIGMED project website (http://armspark.msem.univ-montp2.fr/sigmed/).

Acknowledgements

The authors thank the DMN (Direction de la Météorologie Nationale – Morocco) and the IRD (Institut pour la recherche et développement - France) for financing this work in the framework of the SIGMED/AUF project (http://armspark.msem.univ-montp2.fr/sigmed/).

References

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

Atlasinfo : Le sud du Maroc en "alerte maximale" face à de nouvelles inondations, available at : http://www.atlasinfo.fr/Le-sud-du-Maroc-en-alerte-maximale-face-a-de-nouvelles-inondations_a57380.html, 04 April 2014. (In Frensh)

Aujourd'hui le Maroc.: Bilan préliminaire des inondations de Settat, http://www.aujourdhui.ma/maroc/societe/bilan-preliminaire-des-inondations-de-settat-6483#.VR-9X_zz27Q, 04 April 2015. (In Frensh)

Bani-Domi, M.: Trend Analysis of Temperatures and Precipitation in Jordan, Ph.D. thesis, Dept. of Geography, Yarmouk University, Irbid–Jordan, 2005.

Beniston, M., Stephenson, D.B., Christensen, O.B., Ferro, C.A.T, Frei, C., Goyette, S., Halsnaes, K., Holt, T., Jylhä, K., Koffi, B., Palutikof, J., Schöll, R., Semmler, T. and Woth, K.:

Future extreme events in European climate: An exploration of regional climate model projections, Climatic. Change., 81, 71-95, 2007.

Brunetti, M., Buffoni, L., Mangianti, F., Maugeri, M. and Nanni, T.: Temperature, precipitation and extreme events during the last century in Italy, Global. Planet. Change., 40(1-2), 141-149, 2004.

CID.: Etude d'actualisation des ressources en eau de surface de la zone d'action de l'Agence du Bassin Hydraulique du Tensift, Rabat , 2004. (In Frensh)

Collins, D., Della-Marta, P., Plummer, N. and Trewin, B.: Trends in annual frequencies of extreme temperature events in Australia, Aust. Meteorol. Mag., 49, 277-292, 2000.

Deo, R.C., McAlpine, C.A., Syktus, J., McGowan, H.A. and Phinn, S.: On Australian heat waves: time series analysis of extreme events in Australia, 1950-2005, In: Les Oxley and Don Kulasiri, International Congress on Modelling and Simulation, The University of Canterbury, New Zealand, 10 -13 December 2007, 626-635, 2007.

Donat, M.G., Peterson, T.C., Brunet, M., King, A.D., Almazroui, M., Kolli, R.K., Boucherf, D., Al-Mulla, A.Y., Youssouf Nour, A., Aly, A.A., Nada, T.A.A., Al Dashti, H.A., Salhab, T.G., El Fadli, K.I., Muftah, M.K., Eida, S.D., Badi, W., Driouech, F., El Rhaz, K., Abubaker, M.J.Y., Ghulam, A.S., Sanhouri Erayah, A., Mansour, M.B., Alabdouli, W.O. and Al Shekaili, M.N. : Changes in extreme temperature and precipitation in the Arab region: long-term trends and variability related to ENSO and NAO, Int. J. Climatol., 34, 581-592, 2014.

Driouech, F., Déqué, M. and Mokssit, A.: Numerical simulation of the probability distribution function of precipitation over Morocco, Clim. Dynam., 32, 1055–1063, 2009.

Driouech, F., Déqué, M. and Sánchez-Gómez, E.: Weather regimes - Moroccan precipitation link in a regional climate change simulation, Global. Planet. Change., 72, 1-10, 2010a.

Driouech, F.: Distribution des précipitations hivernales sur le Maroc dans le cadre d'un changement climatique : descente d'échelle et incertitudes. PhD thesis, Toulouse University France, 2010b.

Guentchev, G.S., Winkler, J.A.: A two-tier atmospheric circulation classification scheme for the European-North Atlantic region, Phys. Chem. Earth.. 35, 341-351, 2010.

Hamed, K.H.A. and Rao, R.: A modified Mann-Kendall trend test for autocorrelated data. J. Hydrol., 204(1-4), 182-196, 1998.

Hidalgo-Muñoz, J.M., Argüeso, D., Gámiz-Fortis, S.R., Esteban-Parra, M.J., Castro-Díez, Y.: Trends of extreme precipitation and associated synoptic patterns over the southern Iberian Peninsula, J. Hydrol.. 409, 497-511, 2011.

Jones, P.D.: Maximum and minimum temperature trends in Ireland, Italy, Thailand, Turkey and Bangladesh, Atmos. Res., 37, 67-78, 1995.

Khomsi, K., Mahe, G., Sinan, M., Snoussi, M., Cherifi, R., Nait Said, Z.: Evolution des évènements chauds rares et très rares dans les bassins versants du Tensift et du Bouregreg (Maroc) et identification des types de temps synoptiques associés. In: From prediction to prevention of hydrological risk in Mediterranean countries (E. Ferrari & P. Versace, Sci. Eds), 4th international Workshop on Hydrological extremes MEDFRIEND group, University of Calabria; EdiBios, Cosenza, Italia; 169-182, 2012.

Khomsi, K., Mahe, G., Sinan, M. and Snoussi, M.: Hydro-climatic variability in two Moroccan watersheds: A comparative analysis of temperature, rain and flow regimes, In: Climate and land surface changes in hydrology (E Boegh, E Blyth, DM Hannah, H Hisdal, H Kunstmann, B Su, KK Yilmaz, Eds.), IAHS-AISH. P., 359, 183-190, 2013.

Khomsi, K.: Variabilité hydroclimatique dans les bassins versants de Bouregreg et Tensift : étude des moyennes, extrêmes et projection futures, Ph.D. thesis., Université de Rabat Agdal, Rabat, Maroc, 2014 (In Frensh).

Knippertz, P., Christoph, M. and Speth, P.: Long-term precipitation variability in Morocco and the link to the large-scale circulation in recent and future climates, Meteorol. Atmos. Phys., 83, 67–88, 2003.

Kuglitsch, F.G.: Extreme Temperature Events in the Mediterranean Region, Ph.D. thesis, University of Bern, Switzerland, 2010.

Liberation.: Des inondations meurtrières ravagent le sud de Marrakech, available at : http://www.liberation.fr/monde/1995/08/21/des-inondations-meurtrieres-ravagent-le-sud-de-marrakech_140264, 04 April 2015. (In Frensh)

L'opinion. : La dernière vague de chaleur a occasionné des pertes de 131 millions de Dhs pour le secteur avicole, available at : www.lopinion.ma/def.asp?codelangue=23&id_info=26369 , 01 July 2012. (In Frensh)

Lubès-Niel, H., Masson, J.M., Paturel, J.E. and Servat, E. : Variabilité climatique et statistiques. Etude par simulation de la puissance et de la robustesse de quelques tests utilisés pour vérifier l'homogénéité de chroniques, Rev. Sci. Eau., 3, 383–408, 1998.

Mahe, G., Aderghal, M., AlKarkouri, J., Benabdelfadel, H., Bensafia, D., Brou, T., Chaker, M., Chikhaoui, M., Coupleux, S., Crouzevialle, R., Dieulin, C., Emran, A., Ezzaouini, M., Goussot, E., Hallouz, F., Khomsi, K., Laouina, A., Machouri, N., Maleval, V., Meddi, M., Nging, M., Planchon, O., Remini, B., Rouche, N., Saadi, H., Sfa, M., Sinan, M., Snoussi, M., Taibi, S., Toumi, S., Tra Bi, A., Yahiaoui, S. and Zerouali, A. : Etude de l'évolution de l'occupation du sol sur deux grands bassins d'Algérie et du Maroc, et relation avec la sédimentation dans les barrages, In: Considering hydrological change in reservoir planning and management. (A. Schumann. V.B. Belyaev. E. Gargouri. G. Kucera. G. Mahe. Eds), IAHS-AISH. P., 362, 115-124, 2013.

Mahé, G., Rouché, N., Dieulin, C., Boyer, J. F., Ibrahim, B., Cres, A., Servat, E., Valton, C. and Paturel, J. E. : Carte des pluies annuelles en Afrique. IRD Ed.. Bondy. France. 2012. (In French)

Maftei, C., Bărbulescu, A., Buta, C. and Şerban, C.: Change points detection on variability analysis of some precipitation series, MAMECTIS/NOLASC/CONTROL/WAMUS'11. In: Proc. the 13th WSEAS International Conference on Mathematical Methods, Computational Techniques and Intelligent Systems, 232–237, 2011.

Marghich, A. : Le bassin versant de Bouregreg (Maroc Central) : Etudes hydrologique, hydrogéologique et hydrochimie des eaux, Ph.D. thesis, Université Sidi Mohammed Ben Abdellah-Faculté des sciences Dhar Lmahraz, Fes, 2004. (In French)

Nasrallah, H.A., Nieplova, E. and Ramadan, E.: Warm season extreme temperature events in Kuwait, J. Arid. Environ., 56, 357–371, 2004.

Schilling, J., Freier, K., Hertig, E. and Scheffran, J.: Climate change, vulnerability and adaptation in North Africa with focus on Morocco, Agr. Ecosyst. Environ., 156, 12-26, 2012.

Sebbar, A., Badri, W., Fougrach, H., Hsaine, M. and Saloui, A. : Étude de variabilité du régime pluviométrique au Maroc septentrional (1935-2004), Sécheresse., 3, 139-148, 2011. (In French)

Sen, P.K.: Estimates of the regression coefficient based on Kendall's tau, J. Amer. Statistical Assoc.. 63, 1379–1389, 1986.

Sinan, M., Boussetta, M. and El Rherari A.: Changements climatiques : causes et conséquences sur le climat et les ressources en eau, Revue HTE., 142, 2009. (In Frensh)

Singla, S. : Impact du changement climatique global sur les régimes hydroclimatiques au Maroc : tendances, ruptures et effets anthropiques sur les écoulements, Master thesis, M2R2E, France, 2009. (In French)

Singla, S., Mahé, G., Dieulin, C., Driouech, F., Milano, M., El Guelai, F.Z., Ardoin-Bardin, S.: Evolution des relations pluie-débit sur des basins versants du Maroc. In: Global Change: Facing Risks and Threats to Water Resources (Proc. of the Sixth World FRIEND Conference, Fez, Morocco, October 2010), IAHS-AISH. P., 340, 679-687, 2010.

Skliris, N., Sofianos, S., Gkanasos, A., Mantziafou, A., Vervatis, V., Axaopoulos, P. and Alex, L.: Decadal scale variability of sea surface temperature in the Mediterranean Sea in relation to atmospheric variability, Ocean. Dynam., 62, 13-30, 2010.

Sykes, P., While, J., Sellar, A., Martin, M.: Diurnal Variability in Sea Surface Temperature: Observation and model assessment (Forecasting Research Technical Report 556), available at: http://www.metoffice.gov.uk/media/pdf/b/s/FRTR556.pdf, 2010.

Tabari, H. and Talee, P. H.: Analysis of trends in temperature data in arid and semi-arid regions of Iran, Global. Planet. Change., 79(1-2), 1-10, 2011.

Theil, H.: A rank-invariant method of linear and polynomial regression analysis, I, II, III, Nederl. Akad. Wetensch Proc.. 53, 386–392, 512–525, 1397–1412, 1950.

Toreti, A.: Extreme Events in the Mediterranean: Analysis and Dynamics, Ph.D. thesis, University of Bern, Switzerland, 2010.

Tramblay, Y., Badi, W., Driouech, F., El Adlouni, S., Neppel, L. and Servat, E.: Climate change impacts on extreme precipitation in Morocco, Global. Planet. Change., 82-83, 104-114, 2012.

Turkes, M., Sumer, U.M., Kilic, G.: Observed changes in maximum and minimum temperatures in Turkey, Int. J. Climatol., 16, 436–477, 1996.

WMO: Manual on the Global Observing System. World Meteorological Organization, WMO (Series); no. 544; 1981 edition, 1981.

WMO: Guide on the global data-processing system. World Meteorological Organization, WMO (Series); no. 305; 1982 edition, 1982.

WMO: Guide on the global observing system. World Meteorological Organization, WMO (Series); no. 488; 1989 edition, 1989.

WMO: Guide on the global data-processing system. World Meteorological Organization, WMO (Series); no. 305; 1993 edition, 1993.

WMO: Guide to Meteorological Instruments and Methods of Observation. World Meteorological Organization, WMO-No.8 edition, 1996.

Yabiladi.: Inondations-Maroc : L'euphémisme des autorités... et de la MAP, available at http://www.yabiladi.com/articles/details/3817/inondations-maroc-l-euphemisme-autorites.html, 04 April 2015. (In Frensh)

Zahumensky, I.: World Guidelines on Quality Control Procedures for Data from Automatic Weather Stations. World Meteorological Organization, 2004.

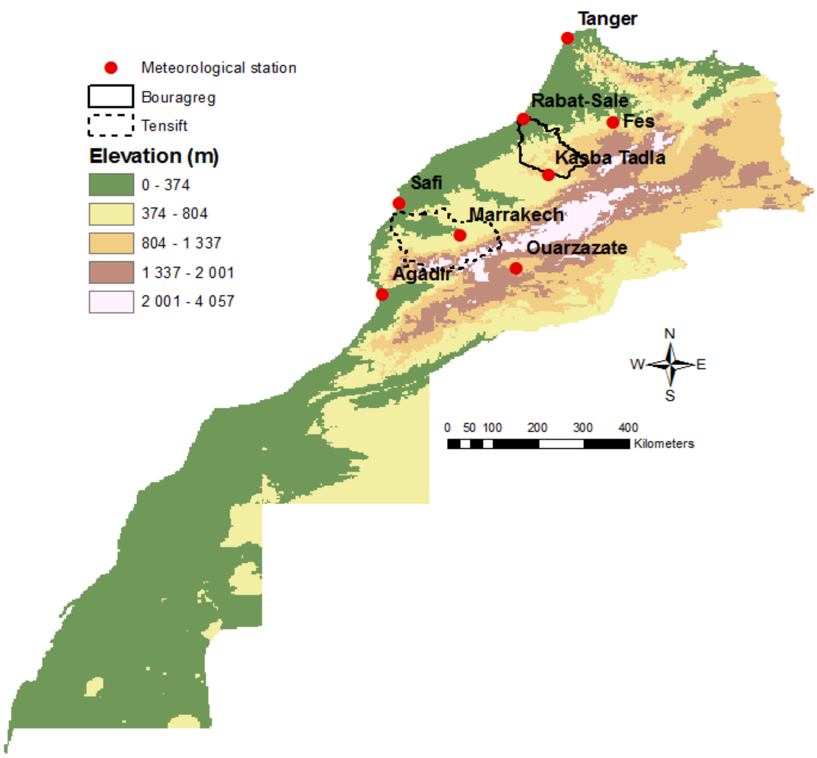

Figure 1. : Bouregreg and Tensift watersheds and daily measurement stations

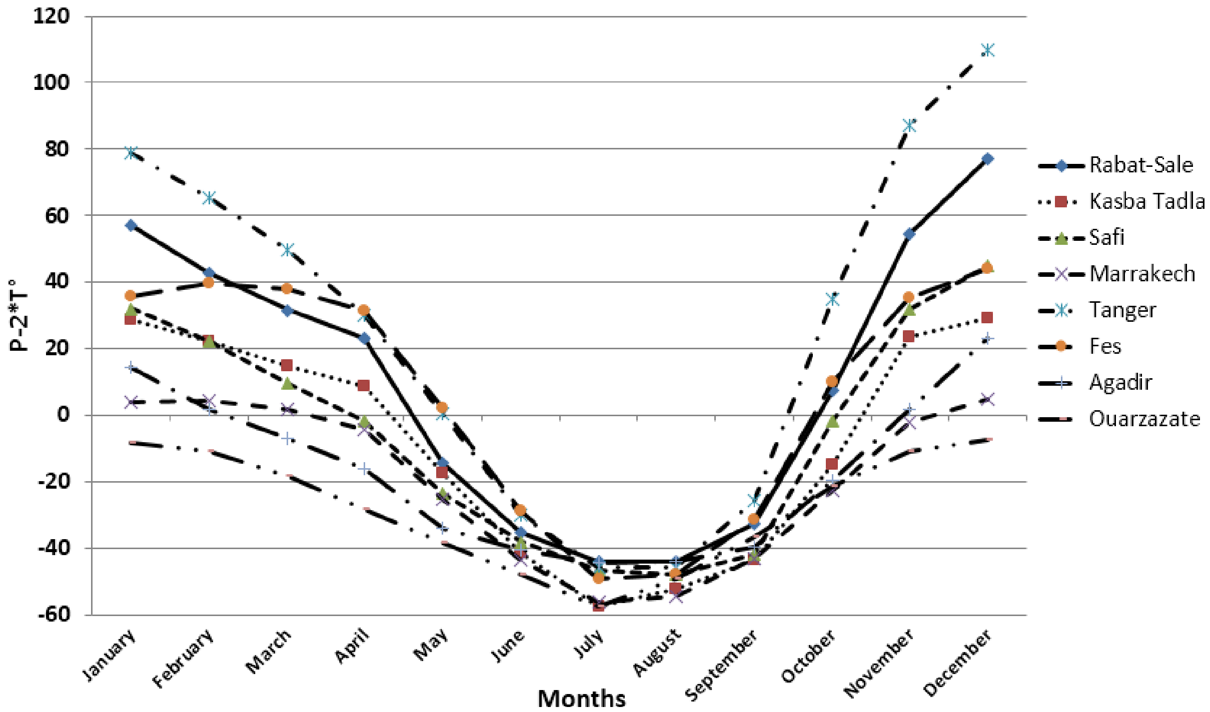

Figure 2. : Cold and warm seasons of Kasba-Tadla, Marrakech, Rabat-Sale, Safi, Tanger, Fes, Agadir and Ouarzazate.

Table 1. Length of daily datasets of rainfall and maximum and minimum temperature (Tmax and Tmin)

Weather Station	Region	Variable	Winter		Summer	
			Lengths of time series	**Missing data (%)**	**Lengths of time series**	**Missing data (%)**
Rabat-Sale	Bouregreg	Rainfall	1951-2009	0.01	1951-2009	0
		Tmax	1950-2009	0	1950-2009	0
		Tmin	1950-2009	0	1950-2009	0
Kasba Tadla	Bouregreg	Rainfall	1983-2010	0	1983-2010	0
		Tmax	1983-2010	0	1983-2010	0
		Tmin	1983-2010	0	1983-2010	0
Safi	Tensift	Rainfall	1955-2010	0.12	1955-2010	0.54
		Tmax	1955-2010	2	1973-2010	0
		Tmin	1955-2010	2	1955-2010	2
Marrakech	Tensift	Rainfall	1937-2010	0	1936-2010	0
		Tmax	1941-2010	0	1941-2010	0
		Tmin	1941-2010	0	1941-2010	0
Tanger	North Bouregreg	Rainfall	1950-2005	0	1950-2005	0.17
		Tmax	1953-2005	0	1953-2005	0.30
		Tmin	1953-2005	0	1953-2005	0.30
Fes	East Bouregreg	Rainfall	1961-2005	0	1961-2005	0
		Tmax	1961-2005	0	1961-2005	0
		Tmin	1961-2005	0	1961-2005	0
Agadir	South Tensift	Rainfall	1945-2005	0.05	1945-2005	0
		Tmax	1945-2005	0.04	1945-2005	0.12
		Tmin	1945-2005	0.04	1945-2005	0.13
Ouarzazate	East Tensift	Rainfall	1950-2005	0	1950-2005	0

	Tmax	1949-2005	0	1950-2005	0.09
	Tmin	1949-2005	0	1950-2005	0.12

Table 2: Linear trends in total rainfall (mm/decade), Bold Character: trend is statistically significant, Significance level = 0.05, Uncertainties are ±1 the standard error of the slope.

Site	Winter	Summer	Site	Winter	Summer
Rabat-Sale	-3.12 ± 0.02	-0.19 ± 0.12	**Tanger**	-23.70 ± 0.01	0.54 ± 0.09
Kasba-Tadla	21.82 ± 0.02	0.87 ± 0.07	**Fes**	-12.70 ± 0.02	-5.14 ± 0.07
Safi	1.41 ± 0.02	-0.17 ± 0.25	**Agadir**	1.37 ± 0.02	0 ± 0.32
Marrakech	-2.57 ± 0.05	-0.35 ± 0.12	**Ouarzazate**	-2.32 ± 0.05	0.36 ± 0.08

Table 3: Linear trends in heavy, intense and exceptional rainfall events. Bold Character: trend is statistically significant. Significance level = 0.05.

Site	Heavy events (day/decade)		Intense events (day/decade)		Exceptional events (day/decade)	
	Winter	Summer	Winter	Summer	Winter	Summer
Rabat-Sale	0.12	0.05	0.11	0.03	-0.02	**0.02**
Kasba-Tadla	0.09	0.01	0.02	-0.01	**0.23**	0.01
Safi	0.21	0	0.06	0.02	0.05	-0.01
Marrakech	-0.01	-0.01	-0.04	0.02	0.01	0.01
Tanger	-0.07	0.09	0.07	0.04	0.06	0.02
Fès	-0.06	0	0.07	-0.03	-0.02	-0.03
Agadir	0.08	0	0.05	0	0.01	0.01
Ouarzazate	-0.08	-0.06	-0.06	-0.07	0	-0.02

Table 4: Linear trends in seasonal mean maximum and minimum temperature (°C/decade), Bold Character: trend is statistically significant, Significance level = 0.05, Uncertainties are ±1 the standard error of the slope.

Site	Maximum Temperature		Minimum Temperature	
	Summer	Winter	Summer	Winter
Rabat-Sale	**0.15 ± 2.72**	**0.17 ± 2.55**	**0.17 ± 2.95**	-0.09 ± 2.07
Kasba-Tadla	0.22 ± 1.45	0.15 ± 1.28	0.35 ± 1.95	0.22 ± 1.55
Safi	0.18 ± 1.91	**0.21 ± 2.63**	**0.43 ± 1.60**	**0.22 ± 1.80**
Marrakech	-0.04 ± 2.14	0.15 ± 2.09	**0.15 ± 2.61**	**0.18 ± 2.46**
Tanger	**0.19 ± 2.14**	**0.15 ± 3.18**	**0.15 ± 3.06**	-0.10 ± 2.11
Fes	0.31 ± 1.50	0.24 ± 1.97	**0.35 ± 1.87**	-0.06 ± 1.76
Agadir	-0.01 ± 2.54	0.08 ± 2.77	**0.27 ± 2.44**	0.13 ± 2.10
Ouarzazate	-0.03 ± 2.75	0.17 ± 1.72	**0.49 ± 1.30**	0.14 ± 2.21

Table 5: Linear trends in hot and very hot events (day/decade). Bold Character: trend is statistically significant. Significance level = 0.05.

Site	Hot events		Very hot events	
	Summer	Winter	Summer	Winter
Rabat-Sale	0.05	0.43	0.05	0.08
Kasba-Tadla	0.97	0.45	**0.67**	0.20
Safi	-0.99	**0.67**	0.12	0.16
Marrakech	-0.30	**0.76**	**-0.34**	-0.06
Tanger	**0.17**	0.38	0.25	0.19
Fes	**1.45**	**0.72**	**0.69**	**0.44**
Agadir	-0.41	-0.24	**-0.15**	0
Ouarzazate	**-2.00**	**0.64**	**-0.88**	0.03

Table 6: Linear trends in cold and very cold events (day/decade). Bold Character: trend is statistically significant. Significance level = 0.05.

Site	Cold events		Very cold events	
	Summer	Winter	Summer	Winter
Rabat-Sale	-0.58	0.65	**-0.20**	0.14
Kasba-Tadla	**-1.65**	-1.87	**-0.64**	**-0.74**
Safi	**-2.21**	**-0.9**	**-0.59**	**-0.23**
Marrakech	**-0.64**	**-1.01**	**-0.20**	**-0.26**
Tanger	-0.48	0.13	-0.18	0.18
Fes	**-0.86**	1.36	-0.16	0.22
Agadir	**-1.56**	**-0.64**	**-0.41**	-0.16
Ouarzazate	**-1.85**	**-1.33**	**-0.53**	-0.28

Table 7: Linear trend in hot, very hot, cold, and very cold events of 3 days or more (event/decade). Bold Character: trend is statistically significant. Significance level = 0.05.

Site	Hot events		Very hot events		Cold events		Very cold events	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Rabat-Sale	-0.01	0.07	0.01	0.02	**-0.12**	0.06	0	0.01
Kasba-Tadla	0.04	0	0.07	0.02	-0.19	-0.19	-0.04	0.03
Safi	-0.26	0.13	0.02	0	**-0.28**	**-0.14**	**-0.05**	-0.02
Marrakech	-0.09	0.05	-0.06	0.03	-0.05	**-0.11**	0	-0.03
Tanger	**0.16**	0.10	-0.01	0.04	-0.04	-0.01	-0.03	0.02
Fes	**0.19**	**0.50**	**0.16**	0.22	**-0.11**	**0.27**	0	0.02
Agadir	-0.05	0.10	-0.01	-0.16	**-0.16**	-0.09	-0.03	0.02
Ouarzazate	-0.16	0.13	0.18	-0.28	**-0.23**	**-0.18**	**-0.07**	0

Table 8: Dates of discontinuities in rainfall, maximum and minimum temperature time series. R: rupture found, NR: no rupture found, Bold Character: a very likely rupture, NP: not performed because of data non-normality. Significance level = 0.05.

Weather Station	Region	Statistical method	Winter			Summer		
			Rainfall	Tmax	Tmin	Rainfall	Tmax	Tmin
Rabat-Sale	Bouregreg	Buishand	NR	R	NR	NR	R	R
		Pettit	NR	1976	NR	NR	**1986**	**1978**
		Lee & Heghinian	2007	1993	2009	**2007**	**1986**	**1978**
		Hubert	NR	1980	NR	**2007**	**1986**	1964, **1978**
Kasba Tadla	Bouregreg	Buishand	NR	NR	NR	NR	NR	NR
		Pettit	NR	NR	NR	NR	NR	NR
		Lee & Heghinian	2007	1983	2008	1985	1999	1999
		Hubert	NR	NR	NR	NR	NR	NR
Safi	Tensift	Buishand	NR	R	R	NR	NR	R
		Pettit	NR	**1978**	1981	NR	NR	**1983**
		Lee & Heghinian	2008	**1978**	2009	2006	**2002**	**1983**
		Hubert	NR	**1978**	1995	2007	**2002**	1982, 2002
Marrakech	Tensift	Buishand	NR	R	R	NR	R	R
		Pettit	NR	1977	1976	NR	1954	1983
		Lee & Heghinian	1938	1978	**1945**	**2007**	**1951**	1997

		Hubert	NR	NR	**1945**	1949, 1950, **2007**	**1951**, 2002	1984
Tanger	North Bouregreg	Buishand	NR	R	NR	NR	R	R
		Pettit	NR	1985	NR	NR	1984	1986
		Lee & Heghinian	1997	**1987**	2003	2003	**2002**	**2002**
		Hubert	NR	**1987**	NR	NR	1964, 1977, **2002**	**2002**
Fes	East Bouregreg	Buishand	NR	R	NR	NR	NR	R
		Pettit	NR	NR	NR	NR	NR	**1984**
		Lee & Heghinian	1978	**1973**	1963	1998	2002	**1984**
		Hubert	NR	**1973**	NR	1990, 1992	NR	**1984**
Agadir	South Tensift	Buishand	NR	NN	NR	NR	NR	R
		Pettit	NR	NR	NR	NR	NR	**1984**
		Lee & Heghinian	1951	NN	**1994**	2003	**1955**	**1984**
		Hubert	NR	1990	**1994**	NR	**1955**	**1984**, 2002
Ouarzazate	East Tensift	Buishand	NR	NR	R	NR	NP	NP
		Pettit	NR	NR	**1975**	NR	**1997**	**1977**
		Lee & Heghinian	1993	1993	**1975**	1952	NP	NP
		Hubert	NR	NR	**1975**	1950	1955, **1997**	**1977**, 1997