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Trends in rainfall and temperature extremes in Morocco

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Abstract

In Morocco, socioeconomic fields are vulnerable to weather extreme 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 added. Extremes are defined by using as thresholds the 1st, 5th, 90th, 95th, and 99th percentiles. Results show upward trends in maximum and minimum temperatures of both regions and no generalized trends in rainfall amounts. Changes in cold events are larger than those 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 rainfall heavy events are positive with weak magnitudes even though no statistically significant generalized trends could be identified during both seasons.

1 Introduction

Nowadays our planet is facing more extreme events such as: heat waves, cold spells and heavy rains. These events 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 25 and 28 June 2012, has caused important losses for the agricultural field mainly the poultry farming (L'opinion, 2012). The deadly floods of the 22 November 2014 in the south of Morocco have caused the fate of at least 36 persons. The flood of the 29 and 30 November 2010 had caused enormous human and material losses in Casablanca. In the province of Settat, the flood of the 23 and 24 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. Also in the Ourika valley, the floods of the 17 August 1995 had caused more than 230 deaths, 500 missing, 200 damaged cars and other property damages. 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., 2010; Sebbar et al., 2011; Tramblay et al., 2012; Schilling, 2012; Khomsi et al., 2013). The study of extreme weather events using indices computed from station data has rarely been realized in the Kingdom. We count the studies of Driouech (2010), 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 intrested in observed extreme temperature events.

This work aims to examine trends in rainfall and maximum and minimum temperature, during the second half of the 20 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 Sect. 2, the results are given in Sect. 3 and finally, these results are summarized and discussed in Sect. 4 and main conclusions are drawn.

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2 Study area, datasets and methodology

2.1 Study area

Morocco is the most Northwestern country of Africa; it is situated between 1.5 and 17° W longitudes and 20.5 and 36° N latitudes. 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 almost all of the central plateau of Morocco (Fig. 1). It is a combination of monotonous plateaus, deep gorges and basins partitioned by steep ridges over an area of 9656 km^2 (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 19 400 km^2, 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).

[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/.

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2.2 Rainfall and temperature data

In each region (Bouregreg and Tensift) there are only two meteorological stations that record daily data, these stations are not enough to represent the climate of the region 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 temperature series recorded by the four synoptic meteorological stations in 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 on 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 period was chosen after applying the criteria suggested by Kuglitsch (2010) for the elimination of datasets with several missing data (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;

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3. A station dataset is considered as complete when no more than three consecutive seasons are missing.

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 examining the metadata of available stations and considering the documented changes in the stations' location and environment, the instruments or also the observers. Undocumented changes mainly in the observing practices and working procedures remain difficult to take into account. Discontinuities in the used datasets were considered from the studies of Khomsi et al. (2013, 2014) and Singla et al. (2010) where the authors applied a statistical approach to detect the break points in temperature, rainfall and runoff time series.

2.3 Methods

This work was performed on a seasonal basis and seasons were indentified using monthly normal temperatures and rainfall to draw the climatograms of the measurement stations used (Fig. 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).

According to Fig. 2, cold and warm seasons were defined for all the stations, as containing the following months respectively: November to February and June to Septem-

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ber. 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, the 1st, 5th, 90th and 95th percentiles 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://www.wmo.int/pages/prog/wcp/ccl/opace/opace2/ETCCDI.php) projects. In addition, exceptional events were selected using the 99th percentile as threshold. This approach was applied to the winter and summer data separately 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 (1st) 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 magnitudes of trends in the total rainfall and the frequency of identified extreme events have been analyzed using the ordinary linear regression (OLS). The statistical

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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 %.

3 Trends in total precipitation and frequency of rainfall extreme events

3.1 Observed total rainfall

Table 2 shows trends in winter and summer annual rainfall recorded in the studied stations. Decreasing trends 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 trends are increasing. None of the found trends is significant.

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 trends could be identified during the both seasons; moreover most of the trends are positive with weak magnitudes. Some isolated positive and significant trends are noticed in the winter exceptional events of Kasba Tadla and summer exceptional events of Rabat Sale; these trends 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

Trend in seasonal daily maxima and daily minima temperatures are shown in Table 4.

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 and

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0.19 °C $decade^{-1}$ respectively. Minimum temperatures have increased in all the stations, except for the times series of Kasba-Tadla, all the trends computed are statistically significant.

In winter, there are significant positive trends of maximum temperature in the coastal north stations: Rabat-Sale (0.17 °C $decade^{-1}$), Safi (0.21 °C $decade^{-1}$) and Tanger (0.15 °C $decade^{-1}$). The other upward trends are not statistically significant. For minimum temperature, significant positive trend affects the series of Safi (0.22 °C $decade^{-1}$) and Marrakech (0.18 °C $decade^{-1}$).

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 $decade^{-1}$), Fes (1.45 day $decade^{-1}$) and Ouarzazate (–2 day $decade^{-1}$). 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 $decade^{-1}$) and Fes (0.69 day $decade^{-1}$)) while downward significant trends are shown in the south (Marrakech (–0.34 day $decade^{-1}$), Agadir (–0.15 day $decade^{-1}$) and Ouarzazate (–0.88 day $decade^{-1}$)).

In winter, all the hot events trends are positive except that of Agadir. Significant trends are found in Safi (0.67 day $decade^{-1}$), Marrakech (0.76 day $decade^{-1}$), Fes (0.72 day $decade^{-1}$) and Ouarzazate (0.64 day $decade^{-1}$). 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 $decade^{-1}$).

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 and −2.21 day decade^{-1}. Very cold events decreased also significantly in many stations and trends range between −0.64 and −0.2 day decade^{-1}. 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^{-1}), Marrakech (−1.01 day decade^{-1}), Agadir (−0.64 day decade^{-1}) and Ouarzazate (−1.33 day decade^{-1}) while those in very cold events are in Kasba Tadla (−0.74 day decade^{-1}), Safi (−0.23 day decade^{-1}) and Marrakech (−0.26 day decade^{-1}).

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^{-1}) and Fes (0.19 day decade^{-1}) and also in very hot spells of Ouarzazate (−0.14 day decade^{-1}) and Fes (0.1 day decade^{-1}). In winter, the station of Fes has also recorded an increasing trend in hot spells (0.16 day decade^{-1}).

Regarding cold and very cold spells (Table 7), in summer, all of the significant trends are decreasing. Trends are of −0.12 day decade^{-1} in Rabat-Sale, −0.28 day decade^{-1} in Safi, −0.11 day decade^{-1} in Fes, −0.16 day decade^{-1} in Agadir and −0.23 day decade^{-1} in Ouarzazate. During the cold season, frequency of cold spells decrease significantly in Safi (−0.14 day decade^{-1}), Marrakech (−0.11 day decade^{-1}) and Ouarzazate (−0.18 day decade^{-1}) and increase in Fes (0.27 day decade^{-1}).

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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 belong to two different watersheds: Rabat Sale and Kasba Tadla from 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 20th 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, 2010; 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

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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. According to Khomsi et al. (2013, 2014), the temperature regime has changed in all the studied stations (Marrakech in 1982, 1993 and 1999, Agadir in 1986 and 1993, Ouarzazate in 1976 and 1993, Rabat-sale in 1979 and 1986, Tanger in 1994 and Fes in 1993). When compared to the metadata, documented changes related to the station location and environment, the observer and the instruments don't match the break dates found. 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). Also, 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. This can be also related to the sharp decreasing of rainfall annual amounts since 1979/80 over the whole Moroccan country (Singla et al., 2010), this tendency

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was also confirmed by Khomsi et al. (2013) for the rainfall of Rabat Sale and Fes. This 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.

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 stud-

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ies. 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 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/).

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Table 1. Length of daily datasets of rainfall and maximum and minimum temperature (T_{max} and T_{min}).

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
		T_{max}	1950–2009	0	1950–2009	0
		T_{min}	1950–2009	0	1950–2009	0
Kasba Tadla	Bouregreg	Rainfall	1983–2010	0	1983–2010	0
		T_{max}	1983–2010	0	1983–2010	0
		T_{min}	1983–2010	0	1983–2010	0
Safi	Tensift	Rainfall	1955–2010	0.12	1955–2010	0.54
		T_{max}	1955–2010	2	1973–2010	0
		T_{min}	1955–2010	2	1955–2010	2
Marrakech	Tensift	Rainfall	1937–2010	0	1936–2010	0
		T_{max}	1941–2010	0	1941–2010	0
		T_{min}	1941–2010	0	1941–2010	0
Tanger	North Bouregreg	Rainfall	1950–2005	0	1950–2005	0.17
		T_{max}	1953–2005	0	1953–2005	0.3
		T_{min}	1953–2005	0	1953–2005	0.3
Fes	East Bouregreg	Rainfall	1961–2005	0	1961–2005	0
		T_{max}	1961–2005	0	1961–2005	0
		T_{min}	1961–2005	0	1961–2005	0
Agadir	South Tensift	Rainfall	1945–2005	0.05	1945–2005	0
		T_{max}	1945–2005	0.04	1945–2005	0.12
		T_{min}	1945–2005	0.04	1945–2005	0.13
Ouarzazate	East Tensift	Rainfall	1950–2005	0	1950–2005	0
		T_{max}	1949–2005	0	1950–2005	0.09
		T_{min}	1949–2005	0	1950–2005	0.12

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Table 2. Linear trends in total rainfall (mm decade^{-1}), bold character: trend is statistically significant, significance level = 0.05.

Site	Winter	Summer	Site	Winter	Summer
Rabat-Sale	−3.31	0.81	Tanger	−23.7	0.54
Kasba-Tadla	24.63	3.25	Fes	−12.7	−5.14
Safi	4.31	0.17	Agadir	1.37	0
Marrakech	−2.79	0.06	Ouarzazate	−2.32	0.36

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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^{-1})		Intense events (day decade^{-1})		Exceptional events (day decade^{-1})	
	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

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Table 4. Linear trends in seasonal mean maximum and minimum temperature, Bold character: trend is statistically significant, significance level = 0.05.

Site	Maximum Temperature		Minimum Temperature	
	Summer	Winter	Summer	Winter
Rabat-Sale	**0.15**	**0.17**	**0.17**	−0.09
Kasba-Tadla	0.22	0.15	0.35	0.22
Safi	0.18	**0.21**	**0.43**	**0.22**
Marrakech	−0.04	0.15	**0.15**	**0.18**
Tanger	**0.19**	**0.15**	**0.15**	−0.1
Fes	0.31	0.24	**0.35**	−0.06
Agadir	−0.01	0.08	**0.27**	0.13
Ouarzazate	−0.03	0.17	**0.49**	0.14

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Table 5. Linear trends in hot and very hot events. 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**	0.2
Safi	−0.99	**0.67**	0.12	0.16
Marrakech	−0.3	**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**	**0.64**	**−0.88**	0.03

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Table 6. Linear trends in cold and very cold events. 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	**−0.2**	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**	**−0.2**	**−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

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Table 7. Linear trend in hot, very hot, cold, and very cold events of 3 days or more. 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**	0.1	−0.01	0.04	−0.04	−0.01	−0.03	0.02
Fes	**0.19**	**0.5**	**0.16**	0.22	**−0.11**	**0.27**	0	0.02
Agadir	−0.05	0.1	−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

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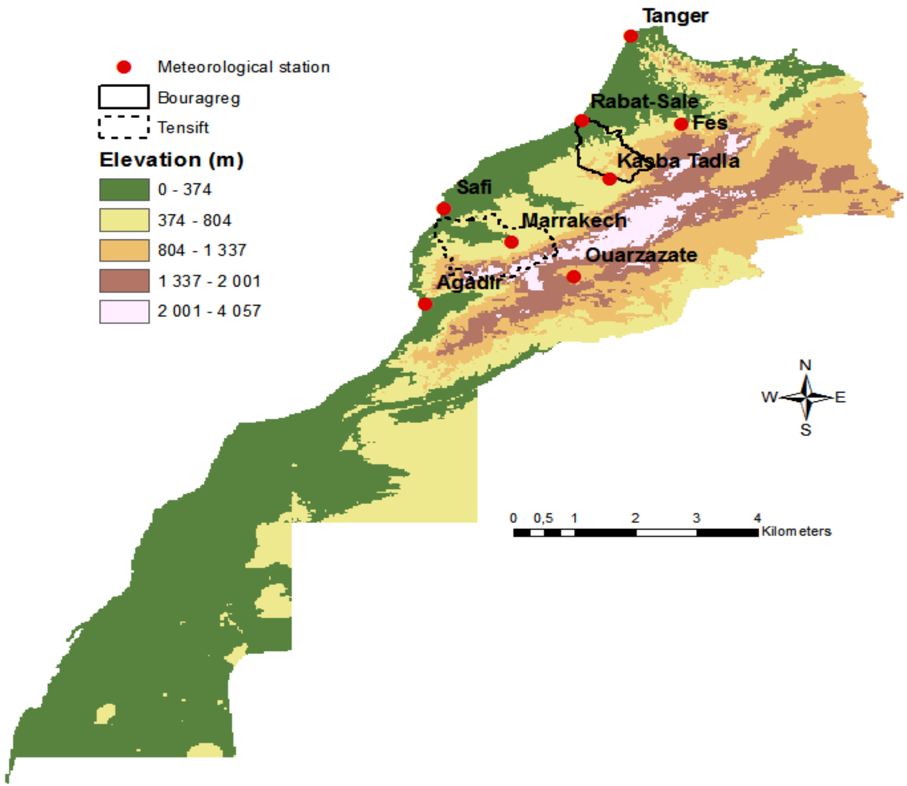

Figure 1. The study area and location of daily measurement stations in Bouregreg and Tensift catchments.

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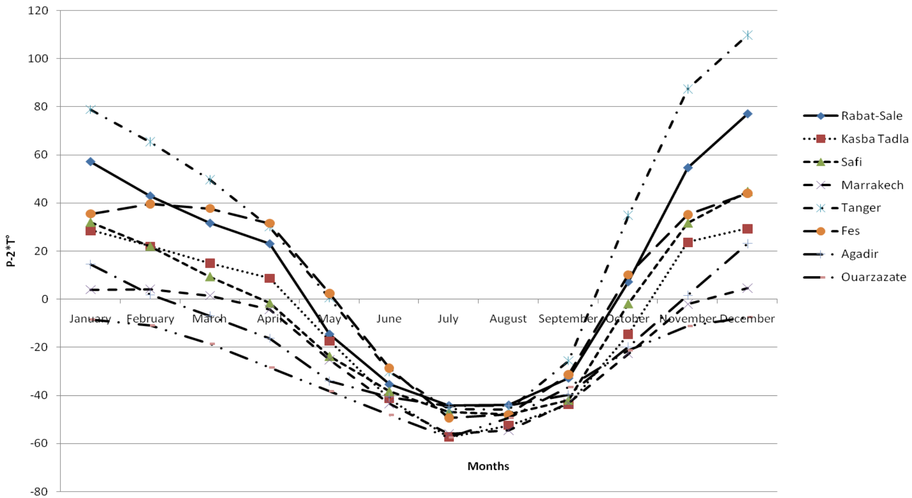

Figure 2. Cold and warm seasons of Kasba-Tadla, Marrakech, Rabat-Sale, Safi, Tanger, Fes, Agadir and Ouarzazate.

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