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Evolution of extreme climatic phenomena in the Central-West of Morocco: Case of the city of Agadir

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Abstract: This study aims to analyze the mechanisms of extreme climatic phenomena in the Central-West of Morocco. It examines trends in extreme climate indices in Agadir, Morocco, using meteorological data covering the period from 1982 to 2022. The analysis focuses on precipitation and temperature extremes to understand the region's vulnerability to climate change impacts. The study employs the Expert Team on Climate Change Detection and Indices (ETCCDI) methodology to calculate a range of climate indices. Results indicate a moderate statistical significance in the increase of very high temperature events, highlighting a trend towards warmer temperatures in the region. However, the statistical significance of precipitation trends varies, with some indices showing more consistent changes than others. Notable years with extreme weather conditions, such as heavy precipitation or prolonged periods of heat or cold, are identified. These findings underscore the importance of understanding local climate trends for effective climate change adaptation and mitigation strategies. Continued monitoring and analysis of climate data are crucial for informing decision-making and enhancing resilience to climate-related challenges in the region.

Keywords: Agadir, Variability, Precipitation, Temperature, Extremes climatic phenomena.

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1 Introduction

Morocco, like other countries in the southern Mediterranean basin, is currently experiencing the longest period of drought in its contemporary history, marked by a decrease in precipitation and a clear trend towards increasing temperatures, making its climate subject to numerous disturbances (El Hawari et al., 2023a). This situation places the country in a zone of climatic instability, with episodes alternating between conditions conducive to frost and cold phenomena, and periods favorable to extreme precipitation. As a transition zone between cold polar latitudes to the north and hot desert to the south, Morocco is influenced by several meteorological systems, notably the Azores high-pressure system, the desert cell, as well as dry and humid tropical air masses (El Hawari et al., 2023b).

In the context of current climate variations in Morocco, several regions of the country have been impacted by these changes. Central and southern Morocco remains particularly vulnerable to these modifications, whether in terms of increasing extreme temperatures or fluctuations in exceptional precipitation. Recent studies confirm that the climate in southern Morocco has begun to warm and dry significantly since the mid-1980s, thus highlighting an increasing trend towards warming and drought (Bahou et al., 2010). Abdullah Mokssit's work (2009) also supports this trend by noting that the beginning of winter is marked by significant precipitation, reaching its peak halfway through the season. Furthermore, the geographical distribution of extreme precipitation is influenced by a spatial gradient, with the northwest and the Agadir region (our study area) standing out as areas with a significant concentration of extreme precipitation and a positive statistical correlation.

In this context, given the impact and increasing intensity of these extreme meteorological phenomena on human populations and the environment, this study is undertaken. Its objective is to analyze extreme climatic phenomena, especially intense precipitation, and extreme temperatures, using appropriate statistical methods and based on calculated climate indices. This will help explain and measure the variability of precipitation in this region.

Before beginning this analysis, it was necessary to provide a precise definition of extreme precipitation and extreme temperatures phenomena. Although various definitions have been proposed in the field of climatology, there is no global consensus on these definitions, except for a few brief descriptions. This study will therefore address the size, temporal and spatial intensity of these phenomena, as well as the resulting outcomes.

In summary, the analysis of annual precipitation data will highlight exceptional years, while the examination of monthly data will reveal seasonal patterns. The study of maximum daily precipitation events will shed light on extreme weather conditions. This information will be crucial for further studies on climate change, its impact on ecosystems, as well as for the development of strategies to adapt to changing weather conditions. A holistic approach to this data will provide a comprehensive understanding of regional climate variations over several decades.

Agadir is considered one of the most vulnerable Moroccan cities to the impacts of climate change. Over the past decade, it has faced several major events, largely attributed to climatic conditions as well as to the topographic, geological, and geomorphological characteristics of the region. In this context, the objective of this essay is to analyze extreme autumnal precipitation and its correlation with urban flooding in Agadir (Karrouk, 2012).

This multidimensional study aims to provide a comprehensive understanding of local climate changes, with potential implications for decision-making in various sectors, ranging from urban planning to natural resource management.

2 Study Area Presentation

The Souss-Massa watershed is located in the southwest of Morocco, between coordinates 7.5°-9.9° W and 29.3°-31.1° N, covering an area of approximately 24,867 km², representing 3.49% of the total area of the Kingdom. From a hydrographic point of view, this basin can be divided into three distinct parts: an upstream part, extending from the highest point to the east, the Siroua massif (3000m), to Aoulouz where the river opens onto the plain through gorges that mark the end of its mountainous course; a middle part between Aoulouz and Taroudant, where the valley takes the form of a rectangle 60 km by 20; and a downstream part to the mouth. In this last part, the valley widens further to the west, with the edge of the Anti-Atlas turning straight south (El Hawari et al., 2023).

The city of Agadir is located in Central-West Morocco, in the Souss-Massa watershed, on the edge of the Atlantic coast, at a distance of 550 km south of Casablanca and 170 km from Essaouira. It is surrounded by the mountain ranges of the High Atlas to the north and east, by the Souss River to the south, and by the Atlantic Ocean to the west (Fig.1).

Agadir's climate is semi-arid, characterized by hot and very dry summers, as well as cool and very humid winters. Precipitation shows spatial and temporal variability, ranging from 45 to 530 mm per year. Annual average temperatures vary between 10 and 32°C.

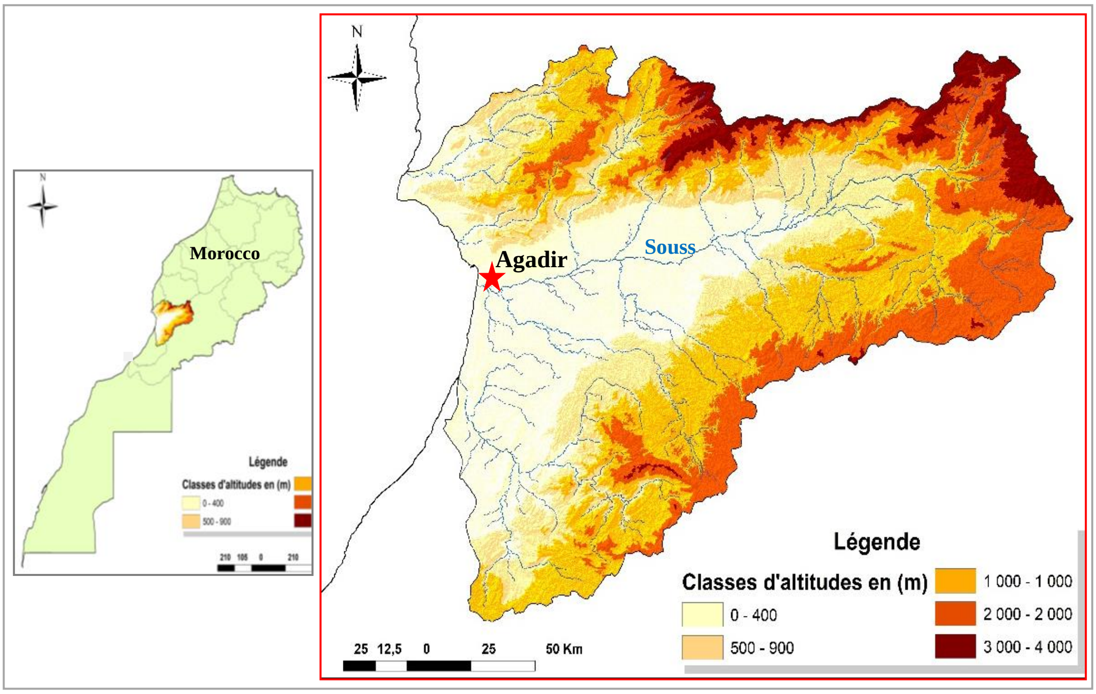


Figure 1. The geographical location of the study area

3 Data and Methods

3.1 Data Used

Firstly, this study is based on the use of climate data provided by the General Directorate of Meteorology (DGM). We have chosen the Agadir station for our research due to the often difficult natural and climatic conditions encountered in the Central-West of Morocco, our study area, as well as the long data recording period, covering the period from 1982 to 2022 (see Table 1).

The indices considered are part of a standard list of extreme indices. The use of these indices for detecting climate change has several advantages. Firstly, these indices can be applied to different parameters, allowing for the comparison of trends between different regions. Additionally, they are understandable and easily exploitable for studying the impacts of these extreme weather events on the population and the territory. These indices are listed in Table2.

Table 1. Geographic coordinates of the Agadir station

Basins	**Stations**	**Coordinates**			**Chronicles**	**Location**
		Longitude	Latitude	Altitude (m)		
Souss-Massa	Agadir	-9,57	30,38	23	1982-2022	Downstream of the watershed

3.2 Methodology of the Work

The methodology adopted in this study aims to examine extreme weather events that have occurred in Agadir over the past 40 years. Extreme events are defined as occurrences with a probability of less than 10%, making them unlikely and rare (Hanchan M, 2016). To study these extreme precipitation events, a statistical approach was used.

The indicators used are defined by the World Meteorological Organization (WMO) as part of the Expert Team on Climate Change Detection, Monitoring, and Indices (ETCCDMI). The Expert Team on Climate Change Detection and Indices (ETCCDI) facilitated the analysis by defining a set of climate indices and developing software (RClimDex) to calculate them (Filahi S et al, 2015). The period from 1982 to 2022 allowed us to

analyze trends over approximately four decades and to highlight recent climate developments in the study area. Climate indices were calculated using the RClimDex software, developed in several steps by Frich et al. (2002) and by Zhang and Yang (2004).
The RClimDex software, programmed in the R language, provides a user-friendly graphical interface for calculating a set of 27 meteorological indices. These indices are determined after a simple quality control of the input daily data and cover 16 temperature-related indices and 11 precipitation-related indices, based on maximum and minimum temperatures as well as precipitation data. The values calculated by these climate indices can be used to describe the state and changes of the climate system, thus facilitating the statistical study of variations in dependent climatological aspects. This includes the analysis and comparison of time series, averages, extremes, and trends. The indices are listed in the table below:

Table 2. Indices used for characterizing extreme weather events in the city of Agadir

Indices	Description	Categories	Source of the index
(TN10p)	Occurrence of cold nights	Indices based on percentiles	**ETCCDI :** Expert Team on Climate Change Detection
(TN90p)	Occurrence of warm nights		
(TX10p)	Occurrence of cold days		
(TX90p)	Occurrence of warm days		
(R95p)	Very wet days		
(R99p)	Extremely wet days		
(TXx)	Warmest days Absolute	indices representing the maximum or minimum values in a season or year	
(TNx)	Warmest nights		
(TXn)	Coldest days		
(TNn)	Coldest nights		
(RX1j)	Maximum one-day precipitation		
(RX5j)	Maximum five-day precipitation		
(R10)	Number of days with heavy precipitation >10 mm	Threshold indices correspond to the number of days where a temperature or precipitation value falls above or below a fixed threshold.	
(R20)	Number of days with very heavy precipitation >20 mm		
(CSDI)	Cold spell duration indices	Duration indices represent periods of heat, cold, humidity, excessive dryness, or the length of the rainy season and periods of mildness	
(WSDI)	Warm spell duration indices		
(CDD)	Consecutive dry days sequences	Other indices	
(CWD)	Consecutive wet days sequences		
(PRCPTOT)	Total precipitation		

The analysis of trends in extremes relies on determining indices of extreme climatic events in the data series, allowing for the characterization of their gradual variation in the properties of such a random variable. These indices are calculated for each chronological series of the station using the Sen's slope estimator (1968), widely used in other works describing extremes, such as those of Aguilar et al. (2005), and Zhang et al. (2005). Spatial averages of the indices or anomalies over the selected period are arithmetic averages of the indices, calculated at the level of the studied station.

3.3 Studied Climatic Indices

There is a variety of climatic indices documented in the literature. For this study, we chose to use those recommended by the World Meteorological Organization (WMO) in 2012 and by the international scientific community, within the framework of the ETCCDMI project, determined by RClimDex. We selected commonly used climatological indices to allow for comparisons with other similar studies on climatic extremes.

Our focus was on ten indices related to average precipitation, dry spells, the number of heavy precipitation events, as well as the number of rainy and dry days. These indices are as follows: PRCTOT, SDDI, CDD, CWD, R10, R20, R95p, R99p, RX1day, RX5day.

As for indices related to extreme temperatures, we selected 11 indices related to the hottest or coldest days or nights, the frequencies of the hottest or coldest days or nights, as well as hot or cold spells. These indices are as follows: TXx, TNx, TXn, TNn, DTR, TN10p, TX10p, TN90p, TX90p, WSDI, and CSDI.

4 Results and interpretation

4.1 Annual Rainfall in the City of Agadir

The analysis of annual and interannual rainfall patterns reveals a temporal evolution of precipitation, characterized by an alternation between wet and dry years over the study period. The highest rainfall was recorded in the year 2010, reaching 613 mm, as well as in the year 1996, with a total of 491 mm. In contrast, the driest years of the study period were recorded in the years 2008 and 2019 with totals of 77 mm and 79 mm respectively at the Agadir station.

From a statistical point of view, the total amount of precipitation varies considerably from year to year, ranging from 77 mm in 2008 to a peak of 613 mm in 2010. The years 1988, 1996, and 2015 stand out for their high PRCPTOT values, indicating extreme weather events. A temporal analysis reveals a general trend towards an increase in PRCPTOT over the years.

Years characterized by high PRCPTOT can lead to impacts such as flooding, while those with low PRCPTOT could cause drought problems. These observations highlight the importance of understanding climate variability and its consequences for local weather patterns. Further analysis could lead to a better understanding of the relationships between these meteorological parameters.

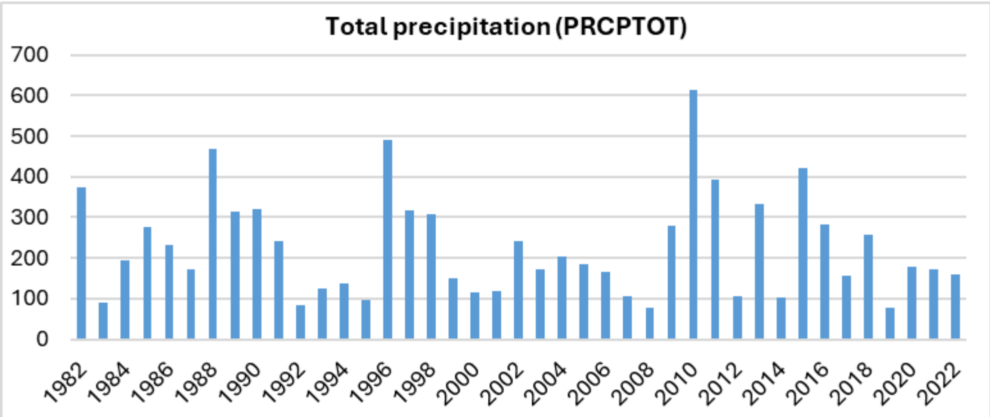


Figure 2. Evolution of total precipitation (1982-2022)

4.2 Extreme Precipitation Indices

4.2.1. Very Wet Days (R95p)

The data provided regarding the number of very wet days (R95p) reveal a significant annual variation, ranging from 0 days for several years to a maximum of 264.9 days in 1987. The year 1987 stands out for an exceptionally high number of very wet days, indicating a prolonged period of very humid weather conditions. In comparison with other years, the years 1996, 2009, 2010, 2014, and 2012 are also noteworthy, displaying 233.3, 139.4, 132.7, 223.2, and 143.9 very wet days respectively. This observation suggests both annual variability and a trend towards a higher number of very wet days in recent years.

A long-term analysis could provide a better understanding of larger climatic trends regarding very wet periods. Years characterized by a high number of very wet days can lead to impacts such as flooding, river flow, and other aspects of the local environment.

4.2.2. Extremely Wet Days (R99p)

In the same analysis framework, the number of extremely wet days (R99p) shows a variation from year to year, with most years showing 0 days, but some years revealing significant values. The years 1984, 1987, 1990, 1996, 2007, 2008, 2011, 2012, 2013, 2014, 2017, and 2020 stand out for non-zero values of R99p, indicating periods when extremely wet days were recorded.

Notably, the year 2014 stands out with 161.3 extremely wet days, closely followed by 1996 (138.7 days) and 1987 (107.4 days). While most years record 0 extremely wet days, some years show these events significantly, suggesting significant interannual variability.

4.2.3. Maximum One-Day Precipitation (RX1day)

The maximum one-day precipitation (RX1day) varies from month to month and from year to year, highlighting the importance of examining the months with the highest values for each year. For example, in 1982, April recorded the highest RX1day with 39.54 mm, while in 2014, July set the record with 161.26 mm.

Some years stand out for significant RX1day values:

- In 1984, November had an RX1day of 58.9 mm.
- In 1996, June impressed with an RX1day of 12.14 mm.
- In 2010, June reached 32.09 mm.

The variability of annual RX1day values highlights fluctuations from year to year. For example, in 1996, an RX1day of 53 mm was recorded, indicating an exceptionally rainy day. High RX1day events can also have significant impacts on drainage, flooding, and other aspects of the local environment. Additionally, some months may have very low RX1day values, indicating dry and less rainy periods.

4.2.4. Maximum Five-Day Precipitation (RX5day)

The data provided concern the maximum five-day precipitation (RX5day) for each year, allowing for several conclusions. Precipitation levels vary from year to year, with notable observations such as the year 2014 recording an exceptionally high maximum precipitation (244.48 mm), while the year 2019 has the minimum five-day precipitation with only 24.46 mm. The average annual value over the entire period is approximately 77.15 mm.

Years where maximum precipitation exceeds significantly the average may indicate extreme weather events or climatic anomalies. For example, the years 2014, 2013, and 1987 stand out for particularly high maximum precipitation, while the years 1992, 2019, and 1994 are notable for particularly low maximum precipitation. The year 2014, with 244.48 mm, could have been influenced by an extreme weather event, while 1992, with only 27.31 mm, could represent a relatively dry year. These data highlight significant year-to-year variability, with trends and extreme events that can be further explored to better understand the specific meteorological conditions of each year.

4.2.5. Number of Heavy Precipitation Days (>10 mm) (R10)

The data provided concerns the number of heavy precipitation days (>10 mm) (R10) for each year. There is a significant annual variability, with the number of these days varying from year to year. For example, in 2019, only 2 days were recorded, while in 1996, a maximum of 17 days was observed. The year 1996 stands out for a particularly high number of heavy precipitation days, indicating a prolonged period of rainy weather conditions. Additionally, the years 2009, 2010, and 2011 are also noteworthy with 15, 15, and 16 days respectively, indicating periods of heavy precipitation.

A general observation reveals annual variability, but a trend towards higher numbers of heavy precipitation days seems to be emerging over the last decade. A longer-term analysis could help identify climate trends on a larger scale, especially regarding heavy precipitation events. Therefore, years with a high number of heavy precipitation days can have significant consequences on flooding, agricultural lands, and other aspects of the local environment.

4.2.6. Number of Very Heavy Precipitation Days (>20 mm) (R20)

The number of very heavy precipitation days (>20 mm) varies considerably from year to year, ranging from 0 days in 1983, 1994, 1997, 2000, 2004, and 2019 to a maximum of 9 days in 2010. Notably, the year 2010 stands out with a particularly high number of very heavy precipitation days, totaling 9 days, indicating a prolonged period of very rainy weather conditions. The years 2009, 2014, and 2010 are also remarkable, with 8, 5, and 9 days respectively, suggesting periods of heavy precipitation during these years. Although annual variability is observed, there seems to be a trend towards an increase in the number of very heavy precipitation days in recent years. Years with a high number of very heavy precipitation days can lead to more serious consequences such as flooding, increased soil erosion, and other impacts on the local environment. This observation emphasizes the importance of understanding and monitoring these extreme weather events to better manage associated risks.

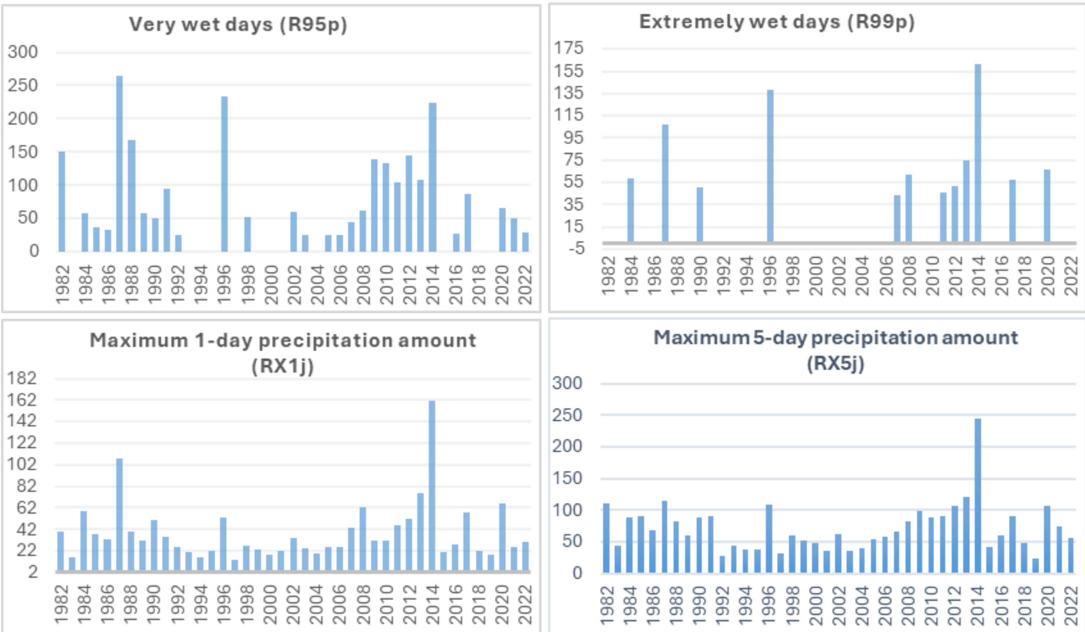
4.2.7. Consecutive Dry Days (CDD)

There is a significant variation in the duration of consecutive dry days (CDD) from year to year, ranging from 53 days in 2010 to a maximum of 230 days in 1998. The year 1998 stands out for a prolonged period of dry weather, characterized by a high CDD of 230 days.

In contrast, the years 2010 and 2006 show relatively low CDD values, with 53 and 56 days respectively. An interesting comparison can be made between 2006 and 2010, as despite relatively similar total precipitation levels (PRCPTOT), the duration of consecutive dry days varies significantly, highlighting variability in the temporal distribution of precipitation. By examining the data, a trend of decreasing CDD in the early 2000s seems to be followed by a slight increase over the last decade. It is important to note that prolonged periods of dry days can have significant implications for agriculture, water resources, and local ecosystems, emphasizing the importance of monitoring and understanding these variations as part of climate risk management.

4.2.8. Consecutive Wet Days (CWD)

In terms of annual variability of CWD, it is notable that the duration of consecutive wet days (CWD) varies considerably from year to year, ranging from 3 days in 1992 and 2019 to a maximum of 10 days in 1996, 2010, and 2011. The years 1996, 2010, and 2011 stand out for high CWD values, suggesting prolonged periods of consecutive rainy days. The 2010-2011 period is particularly interesting as it presents high CWD for two consecutive years (10 days each), indicating a prolonged period of moisture conducive to continuous sequences of rainy days. An observation of the data reveals a trend towards relatively high CWD values in the first half of the 2010s, followed by a decrease in the following years. High CWD can have significant implications for local ecology, agriculture, and water reserves, emphasizing the importance of monitoring and understanding these variations as part of water resource management and adaptation to climate change.



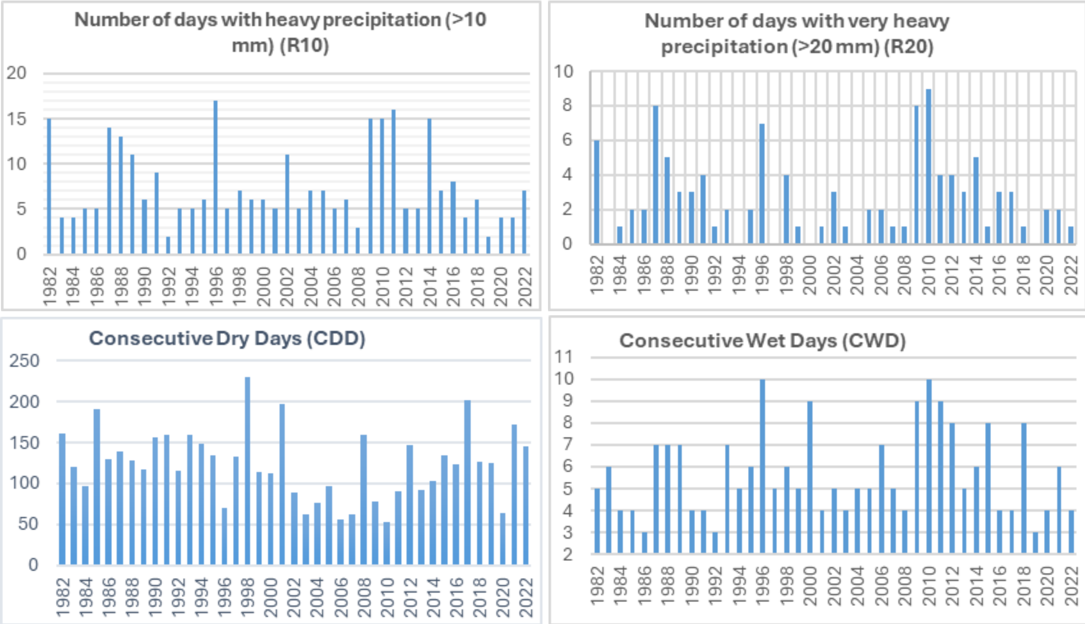


Figure 3-10. Evolution of the extreme precipitation indices used in this study.

4.3 Extreme Temperature Indices

4.3.1. Cold Nights Frequency (TN10p)

The annual average occurrence of cold nights (TN10p) over the study period is 10.36 nights, suggesting some stability in the average number of cold nights despite observed individual variations. The standard deviation of the data, at 4.07 nights, highlights considerable variability around this average. The minimum and maximum values, 2 nights in 2022 and 20 nights in 1993, respectively, illustrate the amplitude of fluctuations. The year 1993 stands out with an exceptionally high occurrence of cold nights, with 20 nights, likely related to extreme weather conditions. In contrast, in 2020, the occurrence was very low, at only 3 nights, which could be attributed to milder weather conditions.

Examining the time series of years, periods of variations are identifiable. For example, an increasing trend is observed between 1982 and 1993, while a decreasing trend is noted between 1993 and 2000. The years 1993 and 2020 stand out, with the former recording the highest value and the latter the lowest.

The significant decrease recorded in 2020, with only 3 nights, could be attributed to exceptional climatic conditions such as milder winters or specific weather phenomena. Similarly, the extremely low value in 2022, with only 2 nights, also appears to be a notable exception.

An increased occurrence of cold nights can have repercussions on agriculture, particularly on crops sensitive to low temperatures. Conversely, lower values may indicate milder climatic conditions, underscoring the importance of monitoring these variations to understand their impact on agricultural activities and other sectors sensitive to temperature fluctuations.

4.3.2. Warm Nights Frequency (TN90p)

The provided data represents the occurrence of warm nights (TN90p), expressed as a percentage of the total number of nights in the year where the minimum temperature exceeded the 90th percentile threshold. This percentage varies considerably from year to year, reflecting normal seasonal and climatic fluctuations. In 2022, the percentage of warm nights is remarkably high (25.86%), suggesting an exceptionally warm period during the night. It would be prudent to analyze if this event is part of a long-term trend or if it is attributable to specific weather phenomena.

The years 1982, 1983, 1993, 2018, and 2015 show relatively low percentages of warm nights. This could indicate cooler nighttime conditions during these years. The observed variability can be influenced by various local factors such as topography, proximity to oceans, and other geographical features. These elements can play a significant role in modulating local climatic conditions and thus the frequency of warm nights.

By examining the annual variations of TN90p, it is possible to better understand the long-term trends and interannual fluctuations related to local weather conditions. This in-depth analysis could help determine the underlying factors responsible for the observed variations in the occurrence of warm nights and anticipate potential impacts on various aspects of daily life and the environment.

4.3.3. Cold Days Frequency (TX10p)

The provided data represents the occurrence of cold days (TX10p), expressed as a percentage of the total number of days in the year where the maximum temperature was below the 10th percentile threshold. This percentage varies from year to year, reflecting normal seasonal and climatic fluctuations.

The years 1996, 2003, 2018, and 2014 stand out with relatively high percentages of cold days. These years may have been characterized by particularly cold winters or specific weather conditions. In contrast, the years 1983, 1990, 1999, and 2022 show relatively low percentages of cold days. The years 2017, 2019, 2020, and 2021 stand out with particularly low percentages of cold days, suggesting milder winters or different weather conditions during those years.

This observed variation in the occurrence of cold days can be influenced by various climatic and meteorological factors, as well as larger-scale atmospheric phenomena. A more thorough analysis of this data could help better understand the long-term trends and interannual fluctuations related to local weather conditions, contributing to better anticipation of potential impacts on various aspects of daily life and the environment.

4.3.4. Hot Days Frequency (TX90p)

The provided data represents the occurrence of hot days (TX90p), expressed as a percentage of the total number of days in the year where the maximum temperature exceeded the 90th percentile threshold. This percentage varies considerably from year to year, reflecting normal seasonal and climatic fluctuations. The year 2022 stands out with a very high percentage of hot days (23.31%), indicating an exceptionally hot period during that year. The years 2017, 2020, and 2013 also show high percentages of hot days, suggesting periods of heat during those years. In contrast, the years 1982, 1993, 2011, and 2018 show relatively low percentages of hot days, which could indicate cooler summers or different weather conditions during those years.

These observed variations in the occurrence of hot days can be influenced by a range of climatic factors, including phenomena such as El Niño or La Niña, solar cycles, as well as local geographical conditions such as latitude, altitude, and proximity to warm air masses. A more thorough analysis of this data could help better understand the long-term trends and interannual fluctuations related to local weather conditions, which could be valuable for planning and adapting to climate change.

4.3.5. Hottest Days (TXx)

The provided data represents the hottest days (TXx), characterized by the highest annual maximum temperatures. These maximum temperatures vary from year to year, reflecting normal seasonal and climatic fluctuations.

The years 2010, 2012, and 2020 stand out with particularly high maximum temperatures during the hottest days, reaching 45.54°C, 46.13°C, and 46.04°C, respectively. These values indicate exceptionally hot periods during those years. In contrast, the years 2018, 2014, and 1997 show relatively low maximum temperatures during the hottest days, which could be associated with specific weather conditions. This could indicate cooler summers or different weather patterns during those years.

Observing this data on maximum temperatures of the hottest days can provide valuable information on climatic extremes and interannual variations that can have significant implications for various sectors, including agriculture, public health, and natural resource management.

4.3.6. Hottest Nights (TNx)

The provided data represents the hottest nights (TNx), characterized by the highest annual minimum temperatures. These minimum temperatures vary from year to year, reflecting normal seasonal and climatic fluctuations. The years 2010, 2012, and 2020 stand out with particularly high minimum temperatures during the hottest nights, reaching 45.54°C, 46.13°C, and 46.04°C, respectively. These values indicate exceptionally hot periods during those years. In contrast, the years 2018, 2014, and 1997 show relatively low minimum

temperatures during the hottest nights, which could be associated with specific weather conditions. This could indicate cooler summers or different weather patterns during those years.
Observing this data on minimum temperatures of the hottest nights can provide valuable information on climatic extremes and interannual variations that can have significant implications for various sectors, including agriculture, public health, and natural resource management.

4.3.7. Coldest Days (TXn)

The provided data represents the coldest days (TXn), characterized by the lowest annual maximum temperatures. These maximum temperatures vary from year to year, reflecting normal seasonal and climatic fluctuations. The year 2019 stands out with a relatively high maximum temperature of the coldest days (15.9°C), which could indicate an exceptionally mild period for the coldest days that year. The years 1984, 2002, 2003, 2004, and 2019 also have relatively high maximum temperatures during the coldest days, which could be associated with specific weather conditions. In contrast, the years 1988, 1991, 2006, and 2018 have relatively low maximum temperatures during the coldest days, which could indicate colder winters or different weather conditions during those years.
Observing these data on maximum temperatures of the coldest days can provide useful information on interannual variations and climatic extremes, which is important for understanding the impact of climate change and for planning across various sectors.

4.3.8. Coldest Nights (TNn)

The annual minimum temperatures of the coldest nights (TNn) do indeed vary from year to year, which can be attributed to different meteorological factors. The year 2022 stands out with a very low minimum temperature during the coldest nights (7.71°C), suggesting an exceptionally cold period that year. Similarly, the years 2001, 2014, and 2007 also show relatively low minimum temperatures during the coldest nights, which could be related to specific weather events occurring in those years. In contrast, the years 2005, 2017, and 2013 have less low minimum temperatures during the coldest nights, indicating perhaps milder winters or different weather conditions during those years.
Observing these variations in minimum temperatures of the coldest nights can provide valuable information on long-term climate trends and meteorological extremes, which is important for climate risk management and adaptation to climate change.

4.3.9. Cold Spell Duration Index (CSDI)

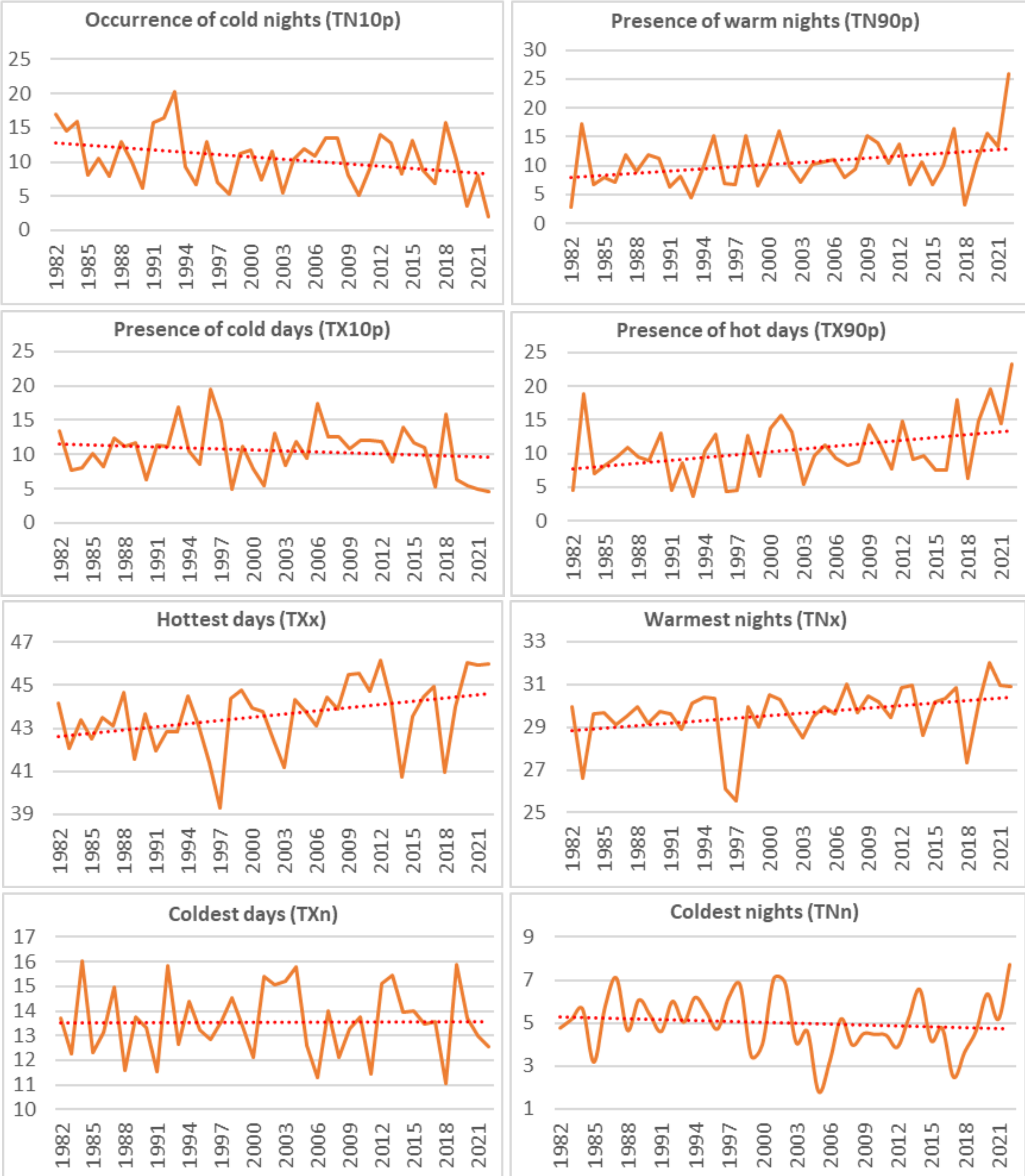
The provided data represents cold spell duration index (CSDI), measured in number of days, for each year. These cold spell durations are important as they assess the frequency of prolonged cold periods during a given year.
Some years, such as 1984, 1996, 2005, 2008, 2012, and 2013, recorded relatively high numbers of days of cold spell durations. This suggests that they experienced prolonged periods of cold weather. In contrast, the years 1982, 1985, 1986, 1987, 1989, 1990, 1994, 1997, 1998, 2000, 2002, 2003, 2004, 2006, 2009, 2010, 2015, 2016, 2020, 2021, and 2022 did not record any days of cold spell durations. More specifically, the years 2005, 2008, and 2012 stand out with a high number of days of cold spell durations, indicating prolonged cold periods. In contrast, the years 2011, 2017, and 2018 have a moderate number of days of cold spell durations.
In summary, this data allows for the assessment of the frequency of cold and prolonged periods from year to year, identifying trends and pinpointing years with extreme weather conditions in terms of cold spell durations. This information is crucial for understanding climate variability and its potential impacts on various sectors such as agriculture, energy, and public health.

4.3.10. Warm Spell Duration Index (WSDI)

The provided data represents warm spell duration index (WSDI), measured in number of days, for each year. These warm spell durations are important as they assess the frequency of prolonged warm periods during a given year.
According to the provided data, some years, such as 1983, 1995, 2000, 2019, and 2020, recorded relatively high numbers of days of warm spell durations. This suggests that they experienced prolonged periods of heat. In contrast, some years, such as 1984, 1988, 1989, 1990, 1991, 1993, 1996, 1997, 1998, 1999, 2003, 2005, 2006,

2010, 2017, and 2018, did not record any days of warm spell durations, according to the provided data. The years 2020, 2019, and 1995 stand out with a high number of days of warm spell durations, indicating prolonged periods of heat. In contrast, the years 2013, 2014, and 2016 have a moderate number of days of warm spell durations.

This data is crucial for assessing the impact of heatwaves on public health, agriculture, ecosystems, and other sectors sensitive to extreme weather conditions. It also helps understand climate variability and its potential consequences for the regions studied.



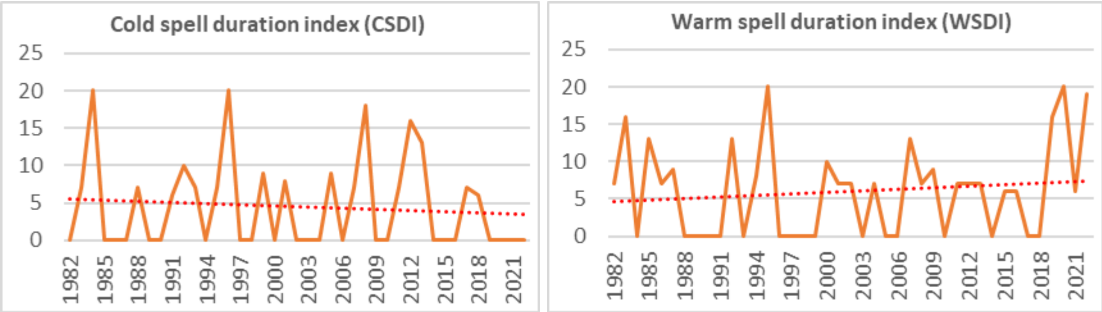


Figure 11-20. Evolution of Extreme Temperature Indices Used

5 Conclusion

The region of Agadir, Morocco, has experienced significant trends in extreme temperatures over the past decades, with a notable increase in very high temperature events. This trend highlights the impact of climate change on the region, with potential implications for agriculture, public health, and water resource management.

Regarding precipitation, the trends are more mixed, with variations in the statistical significance of extreme precipitation indices. This suggests complexity in precipitation patterns, which could be influenced by local and regional factors.

Years marked by extreme weather conditions, such as heavy rainfall or periods of intense heat, underscore the need for ongoing climate monitoring and effective adaptation to climate change. It is crucial to develop robust adaptation and mitigation strategies to address the potential impacts of climate change in the region.

In conclusion, this study highlights the importance of understanding local climate trends for effective planning and informed decision-making. Collaboration among scientists, policymakers, and stakeholders is essential to develop sustainable and resilient solutions to the climate challenges facing the region.

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