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IMPACTS OF RAINFALL VARIABILITY IN GHARB PLAIN: MOROCCO

Abstract: The Mediterranean climate is characterized by irregular rainfall, leading to both severe droughts and occasional flooding. This research aims to examine the changes occurring in the rainfall regime of the Gharb plain over thirty-three years, with specific attention given to three sites: El Menasra, Bel Ksiri, and Sidi Slimane. A range of methods were employed to understand the dimensions and impacts of rainfall in the study area. These methods include trend detection, testing for breaks, analysis of reduced annual anomalies, utilization of the Hyrfan Plus software, calculation of the Martone aridity index, assessment of the standardized rainfall index, and mapping flood zones. The findings of this study revealed that the Gharb Plain experienced periods of rainfall deficits, resulting in drought conditions during years with below-average rainfall. Conversely, years with above-average rainfall exhibited severe flooding, indicating the occurrence of two extreme phenomena that necessitate effective hydraulic management strategies. The main results showed that the rainfall trend is regressing, as the Nicholson, Martone, Emberger, and standardized precipitation indexes justify this regression. In addition, the plain has received an immense quantity of water from the Rif and Atlas Mountains, with the result that the study area has from time to time experienced severe flooding, as shown by the return periods detected, The Gharb plain has therefore experienced a rainfall deficit (drought) in years with below-average rainfall, while years with above-average rainfall have seen severe flooding, putting the country under two extreme phenomena requiring hydraulic management.

Key words: Gharb Plaine, the trend of the rainfall series, break in the rainfall series, standardized rain index, flooding

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Introduction

Climate change is currently detected by two indicators: precipitation and temperature. Climate forecasts based on the Trewartha Climate Classification (TWCC) show an increase in global temperature in C° and a change in precipitation amount in mm (Valjarević et al., 2022). These changes have affected many countries around the world, such as Thailand, which will see an increase in maximum temperature, minimum temperature, and dune temperature (Phumkokrux, 2023).

Precipitation is the only source of replenishment of water resources that is influenced by global warming, a phenomenon that affects almost all of Africa (IPCC, 2007). In addition, current research and study results are sounding the alarm about the profound impact of climatic hazards and the negative repercussions linked to climate change, such as drought (Karouk, 2006). The Mediterranean basin has already been identified as an area particularly exposed to climate change at the global level (IPCC, 2014).

Morocco is one of the Mediterranean countries whose climate is characterized by frequent periods of drought, unusual flooding, shorter snow covers on the Rif and Atlas peaks, and changes in the spatiotemporal distribution of rainfall, etc. (Dmnati, 2006). Moreover, Morocco will experience a sharp drop in precipitation of around 20% by 2100 (Mokssit, 2016).

Plains are areas where wadis cause flooding, aggravated by direct runoff from the slopes of the surrounding hills. The often very gentle slopes of the watercourses within the plain do not facilitate runoff.

As far as the Gharb plain is concerned, the rainfall regime is influenced by several factors, namely the site, the Azores anticyclone, and the effect of the ocean. The rainfall history of the Gharb plain reveals serious floods, such as that of 1963 (Combe, 1975), as well as a succession of severe drought seasons that had a detrimental impact on Morocco's water resources in general, especially that of 1980-1984 (Maurer, 1996). More recently, the generating conditions of the Gharb Plain were characterized by a very deep and intense cold valley in a hot environment, which caused abundant and continuous rainfall for several days (Karrouk, 2017). As a result, this area sometimes experiences excess rainfall, leading to flooding on the one hand, and deficits, leading to drought on the other.

The Gharb Plain is one of Morocco's most important agricultural areas. In this sense, the plain plays an important role in the development of the area. As a result, the irregularity of this rainfall is detrimental to the Gharb's main activity, agriculture. This article analyzes rainfall data using several indices to characterize the local climate and assess its impact on the region.

Study area

The Gharb, or western country, offers a wide variety of landscapes. To the north, the High Gharb is a hilly region. To the east, it's dominated by the pre-meridian ripples of Jebel Boudaa and Jebel Oueteta. To the south, the plain is extended by the Mamora plateau. Finally, to the west, a string of consolidated Quaternary dunes isolates the plain from the Atlantic Ocean.

Gharb's climate is Mediterranean, mild and humid in winter and dry in summer. The topographical conditions of the plain give it much more nuanced characteristics. The coastal dune belt prevents oceanic influences from penetrating far into the plain, accentuating the continental nature of the coastline towards the interior.

The Gharb acts as an outlet for the Sebou basin, an extensive, heavily watered area (in the Rif and Middle Atlas) that discharges a significant quantity of billions of cubic meters of water into the lower Sebou which, due to the topographical characteristics already mentioned, cannot evacuate this large volume, causing the Sebou and its tributaries to overflow.

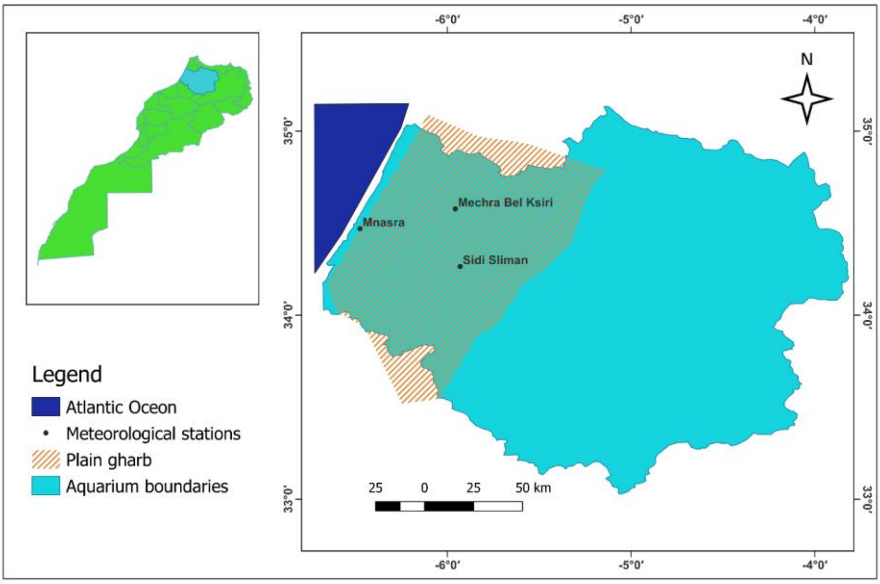

Fig. 1: Location of the study area (Source: Sebou Basin Agency, Fez)

Materials and Methods

Data

The study is based on the collection of annual rainfall data and temperature data from three stations (El Mnesra, Bel Ksiri, and Sidi Slimane), spanning 33 years. These stations are located in representative areas of the Gharb Plain (Fig. 1). The maximum daily data for the Bel Ksiri station, located in the central Ghab Plain, covers 45 years. These data were provided by the Office Regional de la Mise en Valeur Agricole du Gharb, one of the leading players in irrigation water management, and the Agence Hydraulique du Bassin de Sebou, which manages water resources in the Sebou basin in general and in the plain concerned in particular, to whom we would like to express our thanks on this occasion. On the other hand, we based this research on bibliographical work concerning the study area to better understand the terrain, then we consulted references linked to climate change to analyze rainfall variability in the Gharb basin in the general context.

Methods

The approach adopted in this article is based on the following:

The linear trends of the rainfall time series were evaluated by the Man-Kendell test.

A break in a time series is detected by a change in the probability distribution of the series at a given, usually unknown, point in time (Ardoin-Bardim, 2004). A possible break in an annual rainfall series, linked to non-stationarity, was detected using the KHRONOSTAT software (Boyer, 1998). This software includes several tests for detecting breaks: Petitt's Test; Buishand's Test; Lee and Heghinian's Test and Hubert's Segmentation La.

The Nicholson index is used to calculate interannual rainfall anomalies. Rainfall indices are calculated using the Nicholson formula (Nicholson, 1979) as follows:

$$Ii = \frac{(\bar{x})}{\partial(x)} \qquad (1)$$

where: Ii= centered reduced anomaly for a year i; xi(mm)= the value of the variable for a station in the year i; x moy (mm)= interannual mean of the series; ∂(x)= standard deviation of the series.

The Matronne annual aridity index (Beltarndo and Chémery, 1995). is used to calculate the annual aridity of any given station. De Martonne uses the mean annual temperature and total annual rainfall for a given station. It is written as follows:

$$IM = \frac{Pmm}{(T+10)} \qquad (2)$$

where: IM=annual precipitation index; P=average annual precipitation; T=average annual temperatures.

A value of 10 has been added to the thermometric averages to avoid negative index values. De Matrone proposes six major types of climates.

Tab. 1. Six major types of climates according to De Martonne annual index values

Value of IM	Signification
< 5	absolutely arid
5 < IM < 10	desert (arid)
10 < IM < 20	semi-arid
20 < IM < 30	semi-humid
30 < IM < 40	humid
IM > 40	humid

Emberger's rainfall quotient (1952), also known as EMBERGER's rainfall index, defines the climate's degree of humidity. It takes into account the annual precipitation P, the average maximum temperature of the warmest month (M), and the average minimum temperature of the coldest month (m). The quotient is expressed as follows:

$$QE=nP/(365(M+m)(M-m))\times100 \qquad (3)$$

If the number of days of precipitation is not known, Emberger proposes a simplified form:

$$QE=2000P/((M+m)(M-m)) \quad (4)$$

This index has the same result as that of Emberger (1952), who has been studying the distribution of rainfall in Morocco since the 1940s, thanks to his work as the first author to draw up a rainfall map of northern Morocco.

Hyrfan Plus software to determine return periods exclusively at the Bel Ksiri station, as it is located in the central plain where rainfall swells loads of small wadis, causing local flooding.

Calculation of the standardized rainfall index over the study period to classify drought severity (McKee et al., 1993). The SPI is calculated based on the following equation:

$$IPS=(pi-pm)/\partial(x) \quad (5)$$

where SPI = Standardized Precipitation Index; Pi = precipitation in the year i; Pm = mean precipitation of the study series; $\partial(x)$ = Standard deviation.

Results

Annual rainfall variability in the study area

Gharb is a low-lying region, which means it receives relatively large amounts of rainfall when humid air masses arrive. And here's a graph showing internal rainfall at three stations.

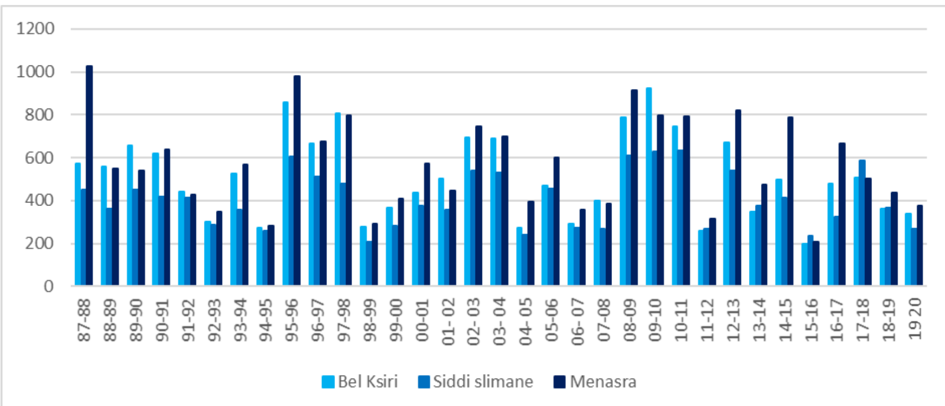

Fig. 2. Rainfall variability in the study area from 1987-1988 to 2019-2020 (Source: Gross data, Office régional de la mise en valeur agricole du Gharb, Kenitra, 2021)

The study stations show a single structure for annual rainfall in the Gharb plain, as shown in the graph. However, at the level of shape, some distinctions appear in the same year representing the rainfall of the study area, as the coefficient of variation does not exceed 37% of the average in the study stations which means that the rainfall in the Gharb plain is not of great importance. The site plays a key role in the zonal distribution of rainfall, despite the low altitudes that characterize most of the Gharb land, except the edges of the plain, since the topographical conditions of the plain give it a much more threatened character. The coastal dune belt prevents oceanic influences from penetrating far into the plain, accentuating the coast's continental character towards the interior (Fejjel, 1982).

Applying the trend and break test

Table 2 shows that the non-parametric Mann-Kendall (MK) test (Mann, 1945 and Kendall, 1975) was used to determine monotonic trends in non-normal weather series (Ouarda et al., 2014). The null hypothesis H0 is that of stationarity of the series (no trend). The alternative hypothesis H1 corresponds to the non-stationarity of the series.

Tab. 2. Mann Kendall test of precipitation from 1987-1988 to 2019-2020

Annual rainfall	Mann-Kendall test = 0.05	Trend
MNASRA station	0.935	Non-significative
BEL KSIRI station	0.258	Non-significative
SIDI SLIMANE station	0.987	Non-significative

Source: Gross data, Office régional de la mise en valeur agricole du Gharb, Kentra, 2021

The Mann-Kendell test (alpha=0.005) is non-significant for all stations proposed for study from the year 1987 onwards, showing a downward trend in precipitation at the 95% confidence level.

Table 3 shows the results of the Khronostat software application detecting the break in the rainfall study series.

Tab. 3. Applications of the 1987-1988 rainfall break to 2019-2020

Meteorological stations	Correlation test on the Rank	Petitt test	Buishand test	Test by Lee and Heghinian	Segmentation by Hubert
Mnasera station	Random	No break	No break	2013	No break
Machraa Bel ksiri station	Random	No break	No break	2013	No break
Sidi Slimane station	Random	No break	No break	2013	No break

Source: Gross data, Office régional de la mise en valeur agricole du Gharb, Kentra, 2021

Analysis of the character of the random series proposed for the rainfall study by the correlation test on rank indicates, at the 99% confidence level, significant independence between the successive terms of the rainfall series. In addition, the test for randomness of the rainfall series studied is confirmed by the variable U Pettit test, with the absence of a break at the 99% confidence level. Carrying the Lee and Heghinian test indicated a break in the study series in 2013. However, the latter is not significant compared with the Pettit test, which is a robust test. The results of the Mann-Kendell and Pettit tests are therefore homogeneous.

The centered annual rainfall anomaly

Climate is a set of stable trends resulting from permanent conditions over a long period (30 years, at least, by definition). It is the climate that interests the geographer (Pédlaborde, 1982). this work is based on 33 years to obtain low results. We have used the 0 axes as the mean and the deviations above and below.

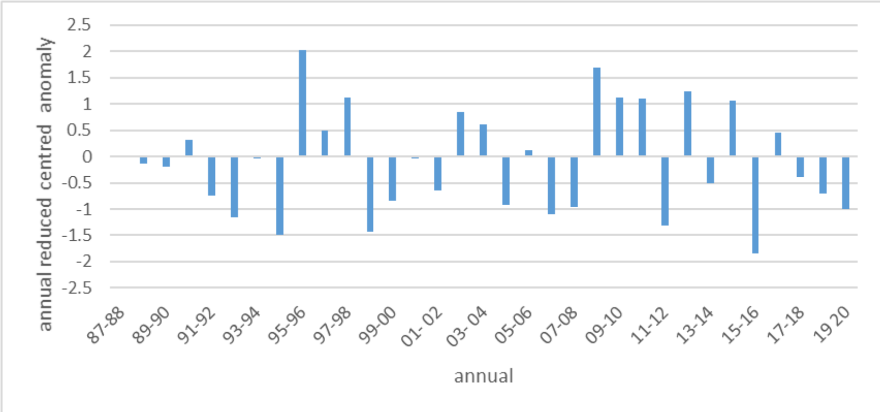

Fig. 3. Annual reduced centered anomaly of Mnasra station from 1987/1988 to 2019/2020 (Source: Gross data, Office régional de la mise en valeur agricole du Gharb, Kentra, 2021)

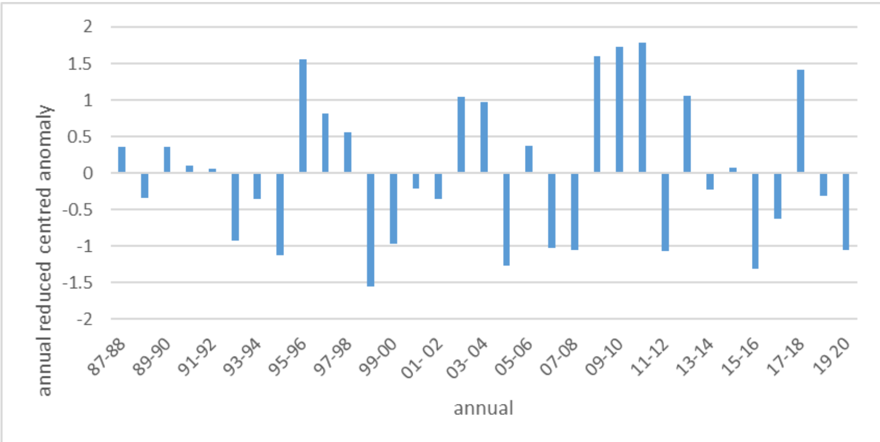

Fig. 4. Annual reduced centered anomaly of Sidi Slimane station from 1987/1988 to 2019/2020 (Source: Gross data, Office régional de la mise en valeur agricole du Gharb, Kentra, 2021)

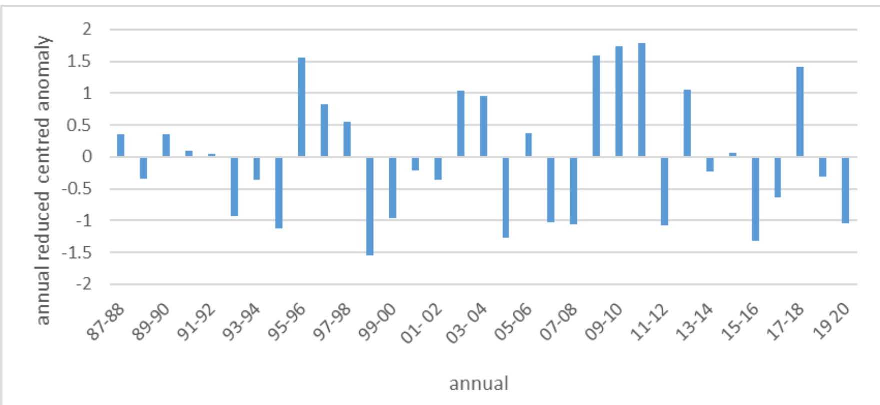

Fig. 5. Annual reduced centered anomaly of Sidi Slimane station from 1987/1988 to 2019/2020 (Source: Gross data, Office régional de la mise en valeur agricole du Gharb, Kentra, 2021)

The annual reduced centroid anomaly for each study series is an important indicator of surface hydrology, which is very closely linked to previous interannual rainfall trends (Figure 2). This situation shows that rainfall is irregular in the study area, and despite this the water reservoirs of the reservoirs formed by the dams are influenced by rainfall-hydrological variations, making it difficult to exploit them rationally (Konan et al., 2013).

Analysis of maximum daily rainfall in the study area

Recent years have seen a change in the structure of daily rainfall in terms of frequencies and intensity in some parts (Minsk, 2011) as extreme rainfall has shown that almost two-thirds of the world's rainfall stations have experienced this trend (Westra et al., 2013). We chose the Machraa Bel Ksiri station to calculate return periods because it constitutes the Oued Sebou overflow benchmark and is located in the center of the Gharb plain, which is most at risk from flooding. Therefore, analysis of maximum daily rainfall is of great practical importance, particularly for certain flood protection studies on major rivers (Rémanéas, 1976). This is the case in the Gharb Plain, where flooding is frequent.

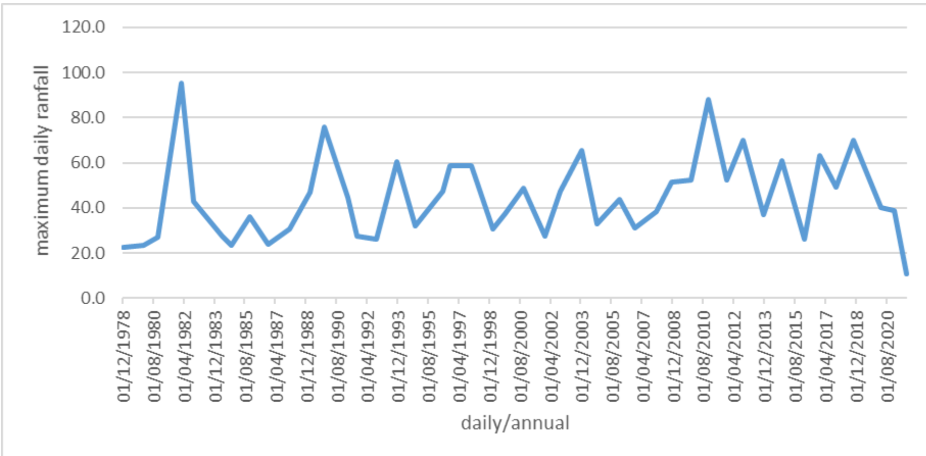

Fig. 6. Maximum daily rainfall at Belksiri from 1978 to 2021 (Source: Sebou Basin Agency, Fez, 2022)

The graph clearly shows that there is an interannual oscillation in maximum daily rainfall. We detected These maximum values with a return period using Gumbel's law. We used Hyrfan Plus software to adjust the maximum daily rainfall (Fig. 7).

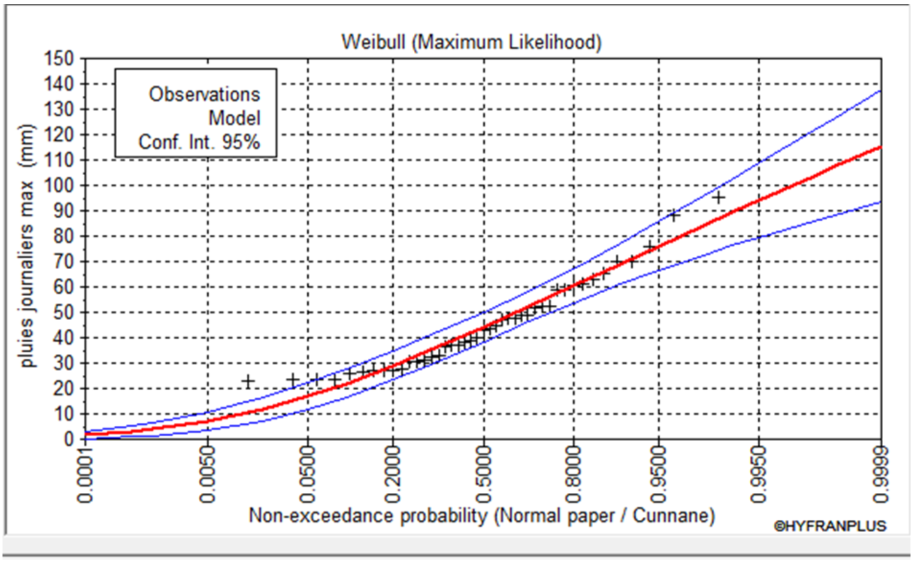

Fig. 7. Adjustment of maximum daily rainfall according to Gumbel's law

We then identified the return periods and classified them in the table 4 for easier reading.

Tab. 4. Return periods of maximum daily rainfall according to Gumbel's law over the period 1978-2020 at the Machraa Belksiri station.

return period	2	3	5	10	20	25	50	100
probable rainfall	41.9	49.3	57.6	67.9	77.9	81	90.8	100

Source: raw data (Sebou Basin Agency, Fez, 2021)

Extreme rainfall causes flooding, human losses, and material damage (Bouaicha et al., 2018), so calculating return periods is of great importance to planners and decision-makers in considering flood-prone areas during project planting.

Climate synthesis

The classification of our study area's climate type is based on the Demartone index and the Emberger index, which takes into account precipitation and temperature. Table 5 and graph 8 classify the study stations according to the 'indices' adopted.

Tab. 5. Climate type according to Martone aridity index in the three study stations, Period 1987/1988 - 2019/2020

Stations	1987/1988-1996/1997	1997/1998-2007/2008	2008/2009-2019/2020	1987/1988 - 2019/2020
MNASRA	semi-humid	semi-humid	semi-humid	semi-humid
BEL KSIRI	semi-arid	semi-arid	semi-arid	semi-arid
SIDI SLIMANE	semi-arid	semi-arid	semi-arid	semi-arid

Source: Gross data, Office régional de la mise en valeur agricole du Gharb, Kentra, 2021

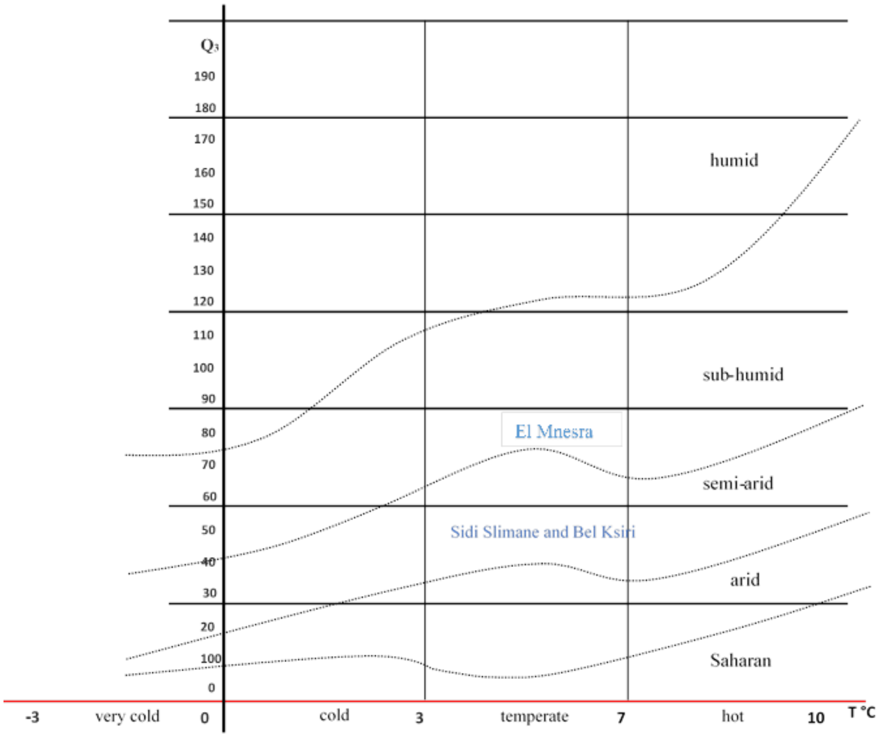

Fig. 8. Position of stations on the Emberger climagram

From the two Demartone and Emberger indices, we can deduce that the coastal zone is influenced by oceanic effects, while stations located within the plain are influenced by continental severity.

Calculating the standardized precipitation index

The use of SPI makes it possible to classify the years of a long rainfall series according to drought severity. The intensity of events is based on the SPI shown in Table 6.

Tab. 6. Drought types according to the standardized precipitation index

Parameters of the SPI index	Type of drought
2<SPI	Extreme humidity
1.5<SPI<1.99	Severe humidity
1<SPI<1.49	Moderate humidity
0<SPI<0.99	Light humidity
0<SPI<-0.99	Light dryness
-1<SPI<-1.49	Moderate dryness
-1.5<SPI<-1.99	Severe drought
SPI<-2	Wet drought

The SPI detects dry periods as well as wet periods because it compares precipitation from 1 to 24 months over a long data series of 33+ years at the same site.

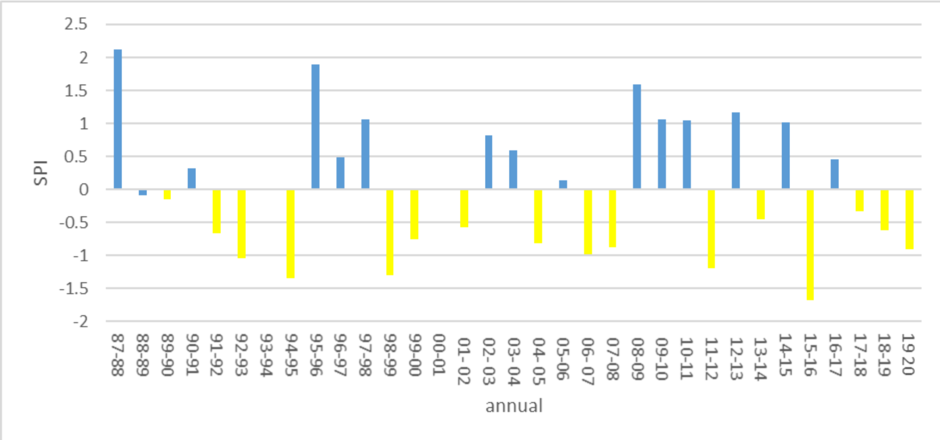

Fig. 9. SPI at El Menesra station, during the period from 1987-1988 to 2019-2020

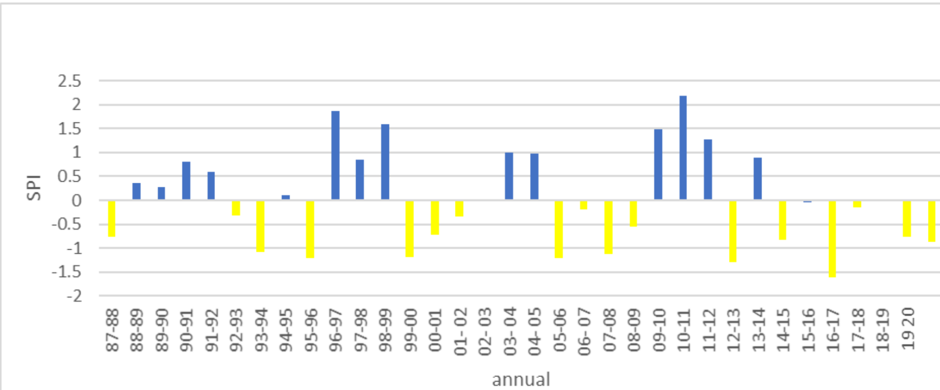

Fig. 10. SPI at Bel Ksiri station, during the period 1987-1988 to 2019-2020

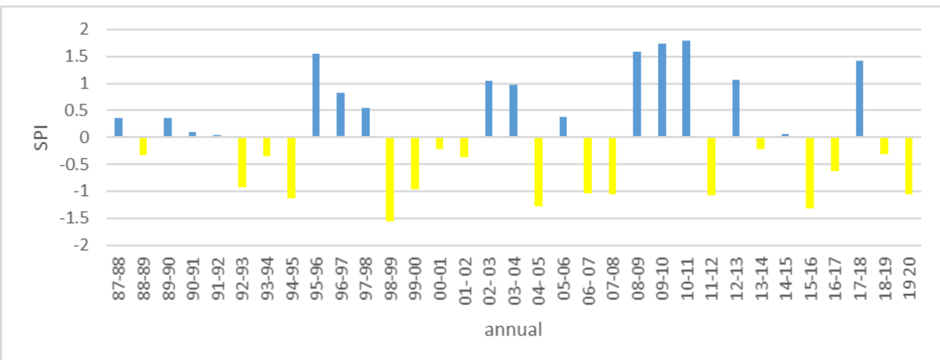

Fig. 11. SPI at Sidi Slimane station, during the period 1987-1988 to 2019-2020

Figures 9, 10, and 11 show that positive indices exceed the value 2, meaning that the Gharb plain has received significant amounts of rain in wet years. Negative indices, on the other hand, sometimes exceed -1.5 (2015-2016), heralding extreme droughts, with adverse consequences for water resources and the agricultural system in general, especially Bor agriculture.

Flooding

The Gharb, or low country, records floods caused by the Sebou wadi when the flood reaches 1900 m3/S at Sidi Allal Tazi (le Coz.1964) and 1600 m3/s at Machraa Belksiri (Combe, 1975). As shown (figures 3, 4, and 5), the plain has from time to time experienced severe flooding, such as during the 2009/2010 season, when atmospheric conditions marked by the intrusion of a cold air flow caused heavy, continuous rainfall for several days. Combined with releases from dams threatening to overflow, the Gharb was transformed into a closed lake, or global overflow and emersion (Karrouk, 2020). Figure 12 shows the emersion of the plain.

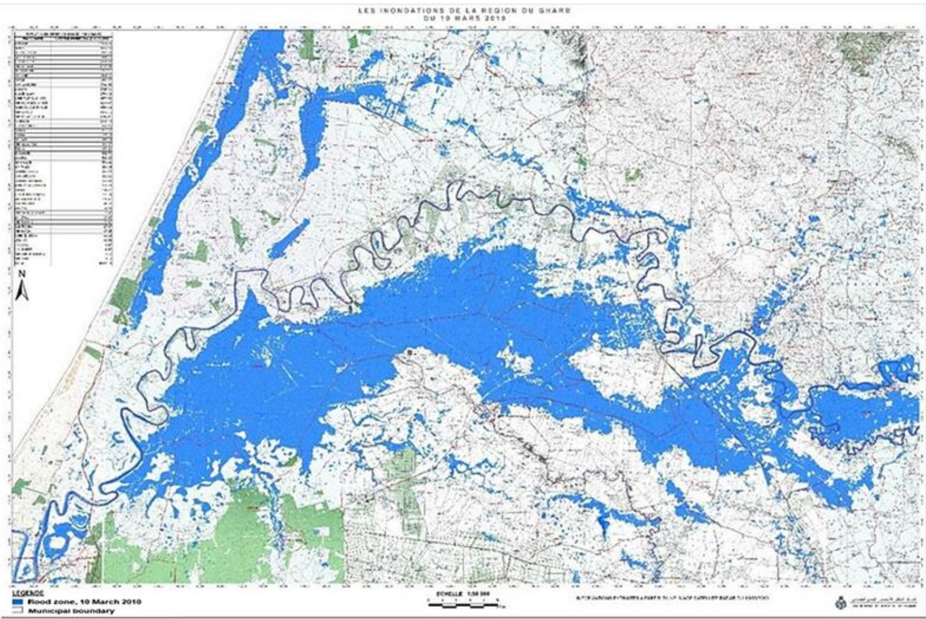

Fig. 12. Map of flooded areas obtained from Radar satellite images dated March 10, 2010 (Source: CRTS, 2010)

The 1:50,000 flood map produced by the Royal Center for Spatial Remote Sensing shows that the territorial communes of the central plain are the most threatened by flooding, despite the commissioning of the El Wahda dam in 1997, which was built on the Oued Ouargha in the Rif to protect the plain from flooding. In addition, the soils in flood-prone areas are hydromorphic, posing drainage problems, which means that the daily rainfall has caused local flooding, as the central plain is characterized by its low elevations. Thus, the plain experienced flooding without having seen the overflow of the main river such as on the day of 17/10/2018 (Figure 12) which recorded 70mm, this rainfall quantity has a return period of 10 years (Table 4). Based on a study of rainfall variability and its impact on the area concerned, we have concluded that rainfall is declining, as shown by the tests applied, due to climate change affecting the whole world. Despite this, the basin is threatened by flooding, as a result, the area is currently experiencing socio-economic damage requiring immediate action by the local authorities.

Discussion

Rainfall is an essential input for the renewal of water resources in general, whether surface or groundwater. Regarding the impact of rainfall variability in the Gharb Plain, we used several methods giving homogeneous results on rainfall variability in the study area. This homogeneity can be seen in the split between wet and dry years, which is justified by the Nicholson index. In addition, the linear stewardship of rainfall quantities is decreasing, which means that water resources in the semi-humid and semi-arid bioclimatic stages will experience a deficit, as the spatiotemporal evolution of precipitation is decreasing in terms of the total number of wet days (Driouech, 2010).

The tests we carried out on the Khronostat software identified, according to the Lee and Heghinian test, that there was a downward break in 2013 at the three study stations. The plain received immense amounts of daily rainfall from time to time, which led to severe local flooding in the central plain or elevations of between 4 and 8 meters (Le Coz, 1964), without overflowing the main Sebou River, by taking into account the nature of the impermeable clay soil, which means that the study of the return periods of extreme rainfall values in the study station (Bel Ksiri) which has the same topographical characteristics as those at low altitudes exposed to local flooding when the small wadis overflow locally. This rainfall variability has several impacts in the Gharb basin, the first of which is the drought that set in during the study period, disrupting irrigation water supply in the first instance and increasing pressure on groundwater, in addition, the plains are home to Boor crops which rely on rainfall, resulting in a loss of investment in these crops, which are of great importance to small farmers who have no access to state or private irrigation water.

The second impact concerns flooding in the basin during surplus rainy years, when maximum daily rainfall values are high. This situation generally affects the agricultural system and weakens the hydrological system.

Conclusion

Rainfall in the Gharb plain is a fundamental source of water for Mediterranean crops such as cereals, and much of the Plain has become Boor land due to the suspension of many irrigation pumping stations, as a result, crops based on irrigation water are in decline, as in the case of rice crops in the plain, which in 1996 were 9324 ha and in 2022 had become 5400 ha (Gharb Regional Agricultural Development Office), putting 3924 ha in Boor status. This research made it possible to detect the variability of precipitation in the study area, which has agricultural assets and rain plays a vital role in the rural economy of this area, helping local stakeholders to choose the right decision on agriculture suitable for this Plain.

Rainfall on the plain is closely linked to the stability and instability of the Azores anticyclone, resulting in a succession of wet and dry years, which explains the large difference in rainfall over the period from 1987 to 2020. This situation has had a detrimental impact on the Gharb plain, manifested by the drought (IPS) that has lasted for thirty-three years, although the period is interrupted by surplus years that have been the cause of serious flooding. This is explained by the phenomenon of climate change, which has reduced the number of rainy days in Morocco, negatively impacting rainwater reservoirs.

This rainfall deficit, which is included in the overall context of climate change, will hurt other water resources in the plain, as it is characterized by its low altitudes and receives immense quantities of water from various neighbouring geomorphological units (Mamora, Rif, and Middle Atlas). This guarantees the sustainability of water in the plain during drought years when other regions and basins suffer from water shortage problems. In recent years, the severity of the drought has become much more frequent, impacting water resources and forcing stakeholders to look for other alternatives.

Conflicts of Interest: The authors declare no conflict of interest.

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