Spatial and Temporal Variability of Climate (Rainfall and Temperature) in the Chaouia Plain: Case of Settat province

El Mzouri Mohamed Amine, Karima Samir, Kamal Alahiane, El Houssine El Mzouri

Abstract— Morocco located in a hot spot geographic zone for climate change has been experiencing lately significant climatic disturbances. For Moroccan cropping systems, the climate change issue arises mainly in terms, of water deficits induced by the decrease in rainfall received and the increase in temperatures. The objective of this study is to characterize the evolution of rainfall on 107 years data set and that of temperatures (min, max and mean) on 60 years of data within local agro-climatic zones of Settat province. The study area extends over a distance of 85 km from North to South and concerned three agro-climatic zones. Results of this study show a remarkable spatial and temporary variability of the climate within the three agroclimatic zones. The analysis of the evolution of rainfall and temperature, confirmed the change of climate in the three zones. This climate change in Settat province is affecting these areas through: A scarcity and significant variability of precipitation with the monthly rainfall averages that are decreasing for all the months and especially those of spring (February, March, April and May), and minimal and maximal temperatures that are increasing in the three zones.

Index Terms— Agroclimatic zones, Climate change, Drought, Semiarid areas, Spatial variability, Temporal variability, Chaouia.

1 INTRODUCTION

Morocco, located in the North-West of Africa between the Atlantic Ocean, the Mediterranean Sea and the Great Sahara, has experienced significant climatic disturbances in recent decades (UNESCO, 2010; IPCC, 2007 and 2013). Several studies have shown the inter- and intra-annual rainfall variability with a rather remarkable downward trend over the last sixty years (Born et al., 2008; Driouech, 2006; Agoumi and Debbarh, 2006), increasingly frequent droughts (Mokssit 2012; Sebbar et al., 2013), more frequent sporadic torrential rains by locality (Adalla, 2019; Hmimsa and Choukrani, 2014; Ait Bella and Samih, 2020) and a rather remarkable rise in temperatures (Sebbar et al., 2012). All these studies, if not their majorities confirm that climate change in Morocco is taking place especially in Semi-Arid, humid and sub-humid zones (Hmimsa and Choukrani, 2014, Sebbar et al., 2013; Mokssit, 2012; Driouech, 2009).

The climate change issue in Morocco arises mainly in terms of water deficits induced by the quantitative decrease in normal rainfall received, the resurgence of drought periods, and the increase in losses by evaporation under the effect of the gradual rise in temperatures, and the resurgence of extreme hazards (Zamrane, 2018; Boubekri et al., 2019; Hanchane et al., 2019). These aspects not only affect agricultural productivity but they also affect cropping systems in particular and agricultural practices in general like crops and animals management, the use of inputs and the allocation of resources (Sinan, 2009; Zinyengere et al., 2015; Maddison, 2006).

The spatial-temporal evolution of rainfall seasons in Chaouia plains of Morocco suggests the existence of three climatic zones: 'Favorable rain fed' zone in the North, the 'Intermediate rain fed' zone in the center and the 'Unfavorable rain fed' zone in the South. The seasonal and annual rainfall trend is decreasing in this plain since the 1980 (Sebbar, 2013; Driouech, 2006, Ait Bella and Samih, 2020). The study of the evolution of annual and seasonal climatic characteristics (rainfall and temperatures) on a limited territory of the Chaouia such as Settat province will allow the climate change characterization and its impacts on local scales.

The hypothesis of this research work is as follows: The climatic parameters (rainfall and temperatures) do not change in the same way in the different agro-climatic zones of a small provincial territory of Chaouia such as the province of Settat. To answer this hypothesis, we considered in this study these two parameters having demonstrated their relevance by previous studies and which are adopted by national organizations & institutions (DMN, INRA) and international (FAO, IPCC etc. …) To characterize climate change in three agro-climatic zones in the province of Settat.

The objective of this study is analyze the evolution

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of precipitations and temperatures (minima and maxima) in three agro-climatic zones of Settat province in order to establish later on the future climate projections trends as well as the repercussions of these changes on agricultural practices in the different agro-climatic zones.

2 MATERIALS AND METHODS

2.1 THE STUDY AREA

The Province of Settat, located in the center of the Kingdom of Morocco, covers approximately 7,220 km² that represents 35% of the area of the Casa-Settat region. It covers the southern part of the Chaouia Atlantic plain and all of Beni Mesquines territories that are known for their small grains and livestock productions. The climate of Settat province is Mediterranean semi-arid type with oceanic influence with two distinct seasons: a cool rainy season (October to April), and a hot dry season (May to September). The average monthly temperatures vary between 12 and 29 °C. December-January are is the coldest months with minima reaching 5°C, and July-August the hottest months with maxima that exceed 38°C. The study area is dominated by three types of wind: wind from the West which is cool and humid it prevails during winter, Wind from the South-West wind which is temperate and humid in winter but hot and dry in summer, wind from East (Sirocco) which is cold and dry in winter but hot and dry in summer.

The study area extends over a distance of 85 km from North to South and concerns three agroclimatic zones of Settat province (Fig. 1):

- **The "Favorable Rain-fed" agro-climatic zone** :

This zone, located in the northern part of the province, is characterized by a favorable climate (300 to 340 mm/year) with an oceanic influence on humidity and temperatures. According to Emberger's (1930) climatic classification, with Q2 = 47.7, this zone belongs to the Medium Semi-Arid bioclimatic class with temperate winters.

- **The "Intermediate Rain-fed" agro-climatic zone:**

This zone, located to the south of the previous zone, is characterized by a less favorable climate (240 to 280 mm/year) with a more continental and a less oceanic influence on humidity and temperatures than the previous zone. With an Emberger quotient of Q2 = 34, this zone belongs to the Low Semi-Arid bioclimatic class with temperate winters.

- **The "Less Favorable Rain-fed" agro-climatic zone:**

This zone, located in the south of the province, is characterized by an unfavorable climate (180 to 240 mm/year) with a greater arid continental influence. Emberger's quotient has value of Q2 = 28.8, therefore this zone belongs to the Upper Arid bioclimatic class with temperate winters.

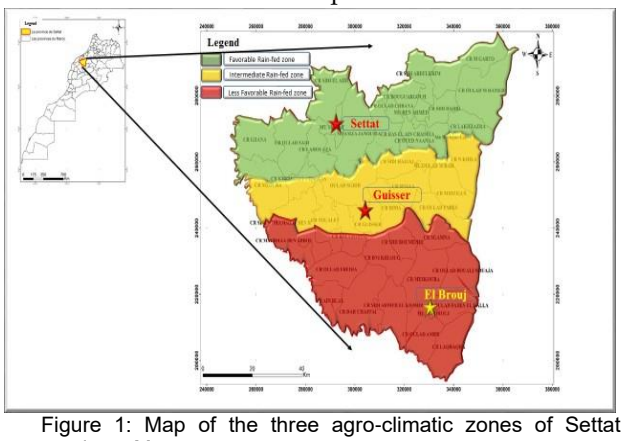

Figure 1: Map of the three agro-climatic zones of Settat province, Morocco.

2.2 CLIMATIC DATA USED

The problems of climatological measurements are crucial in any climatological study. When measurements of climate elements are available, they often suffer from failures such as station representativeness, gaps, data entry errors, erroneous values or homogeneity problems. Along with these obstacles, there is also that of the availability of updated series. The climatic characteristics of the sites (variability, trends, etc.) are highlighted using statistical tools and specific software packages developed for this purpose. The reliability of the results depends on the quality of the climatic series which are used (length, homogeneity, geographical position, gaps, etc.).

The climatic data (rainfall, minimum and maximum temperatures) used in this study are those of the:

- INRA (National Institute for Agricultural Research) data base provided by the stations in Sidi El Aydi, Jemâa Riah, in addition to the national database available in the agro climatology laboratory at INRA of Settat,
- DMN (National Meteorogical Directorate) stations in Ai Nzagh and El Massira Dam,
- Ministry of Agriculture stations available at the Agricultural Extension centers of: Settat, Sidi El Aydi Oulad Saïd, Guisser, Ben Ahmed, Khémis Sidi Mohamed Ben Rahal, El Brouj, and Oulad Gnaou (ORMVA Tadla).

Once the climate data was collected, it was organized, processed and analyzed to bring out the changes and disruptions as well as the extreme phenomena that marked the study area during the

period 1914-2021. Rainfall data was analyzed for the period 1914-2020 and temperature data for the period 1960-2020. The evolution of rainfall and temperatures was compiled by series of daily, monthly and annual data during said periods. For each agro-climatic zone, the evolution and variation of rainfall and temperatures (Min, Max and means) were established with an analysis of spatial and temporal variability for the three zones.

3 RESULTS AND DISCUSSION

3.1 EVOLUTION OF RAINFALL

3.1.1 THE 'FAVORABLE RAIN FED' ZONE

Data collected over more than a century show that rainfall in this zone has always been characterized by very high annual variability (CV = 38) with downward trend (Fig 2). The average rainfall was 400 mm/year in 1914 but declined to reach 315 mm/year in 2020. Three periods were identified for the rainfall patterns:

- The first period (1914-1949) more humid and favorable with fewer dry years, with extremes varying between 220 mm / year in 1925 (dry year) and 593 mm in 1940 (rainy year). The average rainfall for this period was 400 mm / year.
- The second period (1950-1990) highly variable with almost equal numbers of dry and wet yeas, but the rainfall reached extreme values of 106 and 117 mm/year in very dry years (1961 and 1981), and 677 and 599 mm/year in very humid years (1967 and 1987). The average rainfall during this period reached 360 mm /year for this zone.
- The third period (1990-2020) highly variable rainfall with more dry years and less wet and normal years. The extremes rainfall values were 115 mm/year in 2019 (dry year) and 646 mm/year in 2010 (wet year). The current average rainfall for this zone is 315 mm/year.

These results show the downward trend in average annual precipitation with increasing inter-annual variability and high frequency of severe droughts (Fig 2).

The comparison of the distribution of the monthly-received rainfall between two periods: 1914-1944 and 1990-2020, show that there is net decrease for all the months and especially those of spring (February, March, April and May). These results also indicate that the shape of the bell curve (characteristic of the Mediterranean climate) is changing with more drought frequency at the end of the rainy season. The number of rainy days per month has also been significantly reduced over the last century in this zone.

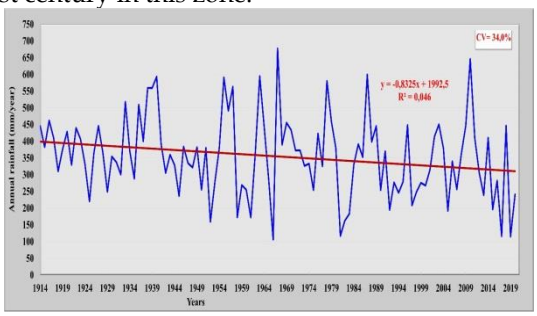

Figure 2: Rainfall Variability (mm/year) over the 1914-2020 period in the 'Favorable rain fed' agro-climatic zone of Settat province, Morocco.

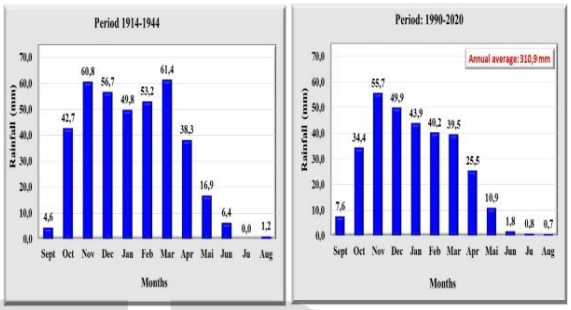

Figure 3: Thirty years' monthly rainfall average (mm) during two periods: 1914-1944 (on the left) and 1990-2020 (on the right) in the 'Favorable rain fed' agro-climatic zone of Settat province, Morocco.

3.1.2 THE 'INTERMEDIATE RAIN FED' ZONE

In this zone, the rainfall has always been characterized by a very large inter-annual variability (CV = 36) with three distinct periods (Fig. 4): (a) the period 1914-1949 during which the rainfall was more favorable with extremes values varying between 152 mm / year in 1925 (dry year) and 446 mm in 1940 (rainy year). The average rainfall for this period was 290 mm / year. (b) The period 1950-1990 characterized by a higher rainfall variability with extremes varying from 81 mm in extremely dry year (1981) to 596 mm in extremely rainy years (1971). The average rainfall during this period regressed to reach 250 mm / year, and (c) the period 1990-2020 during which, the dry years were more frequent and the rainfall variability was maintained with extremes that varied from 80 mm / year in 2019 (very dry year) and 445 mm /year in 2010 (very rainy year). The current average rainfall in this sub-zone is 235 mm / year for this zone. We register also the downward trend of the average annual rainfall. Not only the average annual rainfall is declining over the last century, but also the monthly averages particularly those of spring (February, March, April and May) (Fig. 5). The first rains tend to increase during the month of October

as thunderstorms but those of the wettest month (November) are reduced in this zone.

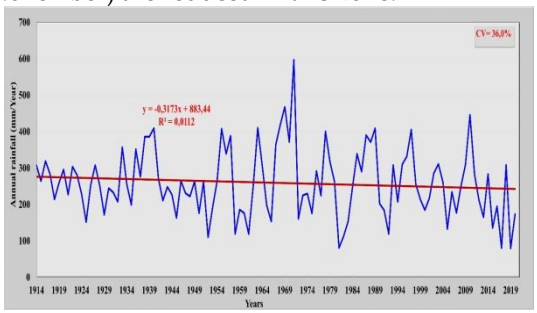

Figure 4: Rainfall Variability (mm/year) over the 1914-2020 period in the 'Intermediate rain fed' agro-climatic zone of Settat province, Morocco.

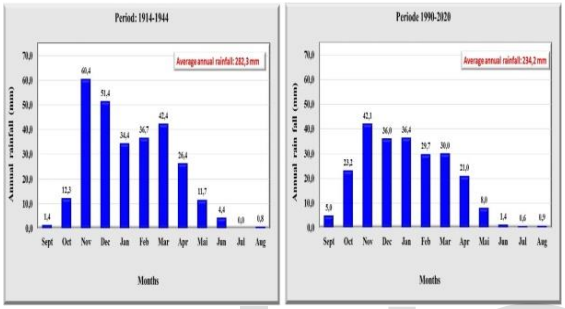

Figure 5: Average monthly rainfall (mm) during the periods: 1914-1944 (on the left) and 1990-2020 (on the right) in the 'Intermediate rain fed' agro-climatic zone of Settat province, Morocco.

3.1.3 THE 'UNFAVORABLE RAIN FED' ZONE

For this unfavorable arid zone, the rainfall has always been characterized by a very high inter-annual variability (CV = 39%) with the three distinct periods previously identified (Fig. 6): (a) The first period characterized by a high number of normal and humid years with extreme varying values of 144 mm/year in dry year of 1925 and 388 mm in rainy year of 1940.

The average rainfall for this period was 268 mm/year.

(b) the second period characterized by a very high rainfall variability with extremes varying from 112 mm in dry years (1981) to 443 mm in rainy years (1967). The average rainfall for this period reached 250 mm / year, (c) the third period with more dry years and reduced number of wet and normal years the extreme rainfall values reached 76 and 75 mm/year in 2017 and 2019 (dry years) and 423 mm/year in 2010 (rainy year).

The current average rainfall in this sub-zone is 245 mm / year. Unlike the previous zones, the downward trend in average annual precipitation is not so great but the inter-annual variability is increasingly important in this arid zone (Fig. 6).

In this zone the monthly averages are falling for all the months and especially for the months of November and December (Fig. 7). The number of rainy days per month and month is also decreasing with fewer rainy days but with more thunderstorms and heavy rains.

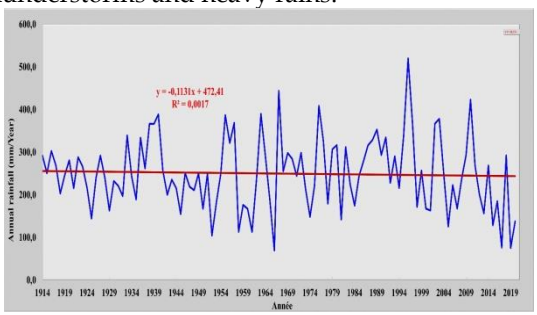

Figure 6: Rainfall Variability (mm/year) over the 1914-2020 period in the 'Unfavorable rain fed' agro-climatic zone of Settat province, Morocco

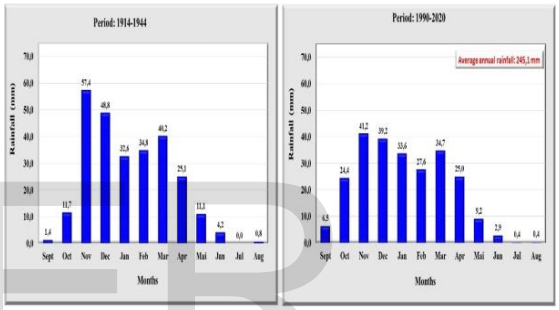

Figure 7: Average monthly rainfall (mm) during the periods: 1914-1944 (on the left) and 1990-2020 (on the right) in the 'Unfavorable rain fed' agro-climatic zone of Settat province, Morocco.

The results presented for the three zones show a significant regression in annual rainfall during the last century. The inter-annual and intra-annual variability of this precipitation, already existing over the last century, has been accentuated during the last decades especially in the 'Favorable rain fed and' the Intermediate rain fed' agro-climatic zones. This reduction in rainfall varies with the geographical position of the area. Indeed, the more we move from the North and North-West towards the South and the South-East of the province (from the favorable zone towards the unfavorable zone), the lower the rainfall regression coefficient becomes. These results show therefore that the "Favorable rain fed" zone experiences more changes in the received annual precipitation amount than the "Intermediate rain fed" and "Unfavorable rain fed" agro-climatic zones. These results confirm those reported by several authors who confirm a net decrease in rainfall in the central zone of Morocco since the 1960s (Driouech, 2006 Agoumi and Debbarh, 2006; Knippertz et al., 2003).

Also we confirm through these findings that climate change is affecting more favorable temperate zones than arid zones in terms of rainfall.

Regarding the distribution of monthly precipitations, a significant reduction in rainfall is recorded between the two periods 1914-1940 and 1990-2020 in the three zones during the rainy months, particularly those of spring. Research work on the inter-annual rainfall variability in semi-arid Moroccan areas shows a remarkable delay in rainfall during crop establishment in autumn (October-November) and a reduction or stoppage towards the end of the growth cycle (François et al., 2016; Sebbar et al., 2011). These two phenomena are qualified as drought at the beginning and at the end of the cycle, respectively (Sebbar et al., 2012, Driouech, 2010; Alahiane, 2019)

3.2 EVOLUTION OF TEMPERATURES

3.2.1 THE 'FAVORABLE RAIN FED' ZONE

The maximum and minimum average annual temperatures are continuously increasing during the period 1960-2020 within the favorable zone (Fig 8). The average minimum temperature of the coldest month (January) increased from 7.2°C during the period 1960-1975 to 8.1°C during the period 2005-2020 (Fig 9). Meanwhile, the average maximum temperature for August, went from 30°C to 33.9°C for the two periods, respectively. A significant extreme inter-annual variations were observed for the years 1996-97 for the both temperatures with an average increase of approximately 2 °C since the year 1960 (Fig 9).

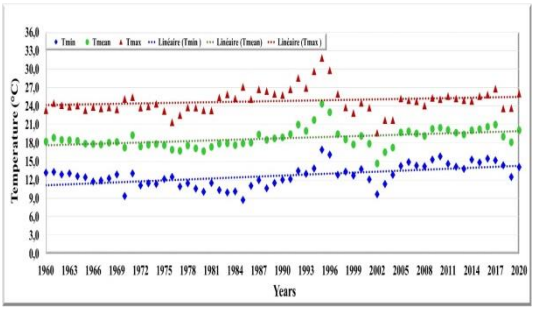

Figure 8: Evolution of minimum, maximum and average temperatures during the period 1960-2020 in the "Favorable rain fed" zone of Settat province, Morocco

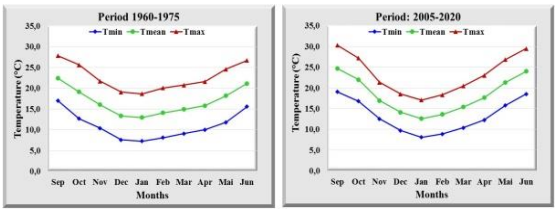

Figure 9: Evolution of monthly temperatures (minimum, maximum and average in °C) during the periods 1960-1975 (on the left) and 2005-2020 (on the right) in the agro-climatic zone "Favorable rain fed" of Settat province.

3.2.2 THE 'INTERMEDIATE RAIN FED' ZONE

For the intermediate zone, the maximum and minimum average annual temperatures increased significantly during the period 1960-2020 but with higher average annual thermic amplitude than the Favorable (Fig 10). Indeed, the average minimum temperature of the coldest month (January) increased slightly from 6.4 °C during the period 1960-1975 to 6.9°C during the period 2005-2020 (Fig 11). But, The average maximum temperature for August, increased by 4°C from 31.5 °C to 35.8 °C for the two periods, respectively. Likewise, a significant extreme inter-annual variations was observed during 1996-97 years for the both temperatures with an average increase of 2.4 ° C on average since the year 1960 (Fig 11).

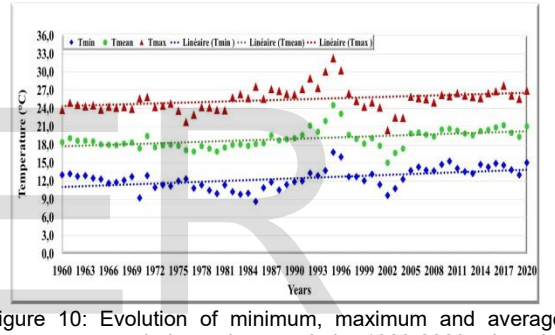

Figure 10: Evolution of minimum, maximum and average temperatures during the period 1960-2020 in the "Intermediate rain fed" zone of Settat province, Morocco

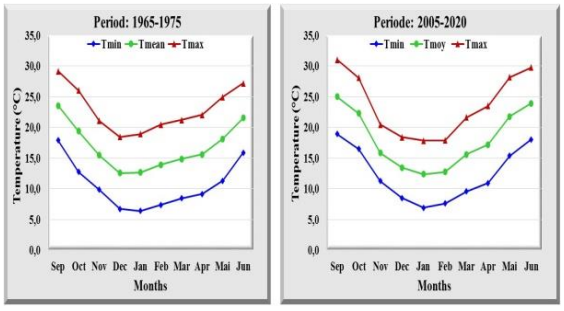

Figure 11: Evolution of monthly temperatures (minimum, maximum and average in °C) during the periods 1960-1975 (on the left) and 2005-2020 (on the right) in the agro-climatic zone "Intermediate rain fed" of Settat province, Morocco.

3.2.3 THE 'UNFAVORABLE RAIN FED' ZONE

Concerning the Unfavorable zone, the average maximum and minimum annual temperatures recorded an average increase of 3 °C on average during the period 1960-2020 but with more amplitude than the two previous subzones (Fig 12). The average minimum temperature for the coldest month (January) did not vary greatly for the two

periods: 5.6 °C during the period 1960-1975 vs 5.7 °C during the period 2005-2020 (Fig 12). While the average maximum temperature for August, increased from 33 °C to 37.7 °C for the two periods, respectively.

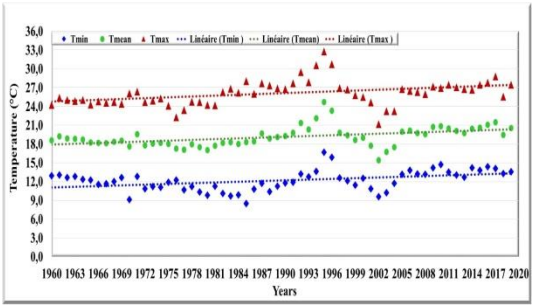

Figure 12: Evolution of minimum, maximum and average temperatures during the period 1960-2020 in the "Unfavorable rain fed" zone of Settat province, Morocco

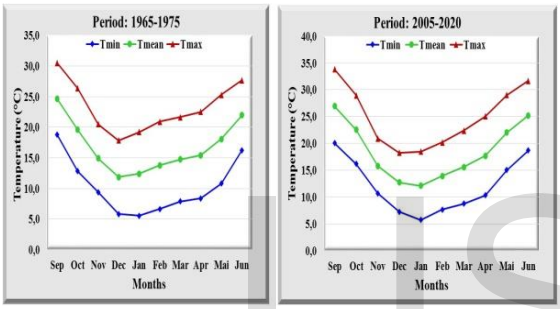

Figure 13: Evolution of monthly temperatures (minimum, maximum and average in °C) during the periods 1960-1975 (on the left) and 2005-2020 (on the right) in the agro-climatic zone "Unfavorable rain fed" of Settat province, Morocco.

During the last 60 years, the whole province of Settat have recorded a significant increase in maximum and minimum temperatures. But, the temperature rise was greater in the Unfavorable arid 'area than in the intermediate and the favorable. The change of monthly temperatures increases as we go from the north to the south of the province. Several authors (Alahiane, 2018a & b; Mokssit, 2012) have reported increases ranging on average from 1.5 °C and 2.5 °C for minimum winter temperatures (December January) and from 2.0 °C to 3 °C for minimum summer temperatures (July-August). These results confirm that Morocco is a "climate change hot spot" (Diffenbaugh and Giorgi, 2012) and that heat stress imposes an upper limit on adaptation to the most pessimistic warming scenarios (Sherwood and Huber, 2010; Lelieveld et al., 2016). If global warming reaches + 4 °C, some regions, such as this region could see their average summer temperature increase by + 5 °C by the end of the century (Lelieveld et al., 2016; François et al., 2016; François et al., 2016).

4 Conclusion

The analysis of climate data of Settat province over a series of more than a century (1914-2020) highlights the spatial and temporary variability of the climate within this province. Three agroclimatic zones exist within this province: 'Favorable rain fed' zone belonging to the Middle Semi-Arid bioclimatic stage, 'Intermediate rain fed' belonging to the Lower Semi-Arid bioclimatic stage and 'Unfavorable rain fed' belonging to the bioclimatic Superior Arid Stage. The study of the evolution of the climate in the three zones, through the analysis of the evolution of rainfall and temperature, confirmed the change of climate in the three zones. This climate change in Settat province is affecting these areas through:

A scarcity and significant variability of precipitation with

- A significant annual rainfall variability and reduction in the three zones during the last decades. This decline varies with the geographical position of the area.
- The "Favorable rain fed" zone is experiencing a greater reduction in rainfall than the other two zones.
- The monthly averages are decreasing for all the months and especially those of spring (February, March, April and May).
- The number of rainy days per month has significantly decreased over the past three decades.

A significant increase in minimum and maximum temperatures with:

- Greater temperature rise in the "Unfavorable" zone than in the other two zones.
- An average increase since 1960 of: 2 °C on average in the Favorable zone, 2.4 °C in the intermediate zone and of 3 °C in the Unfavorable.

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