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CLIMATE CHANGE AND ITS IMPLICATIONS FOR AGRICULTURAL PRODUCTIVITY IN THE IHOROMBE

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ABSTRACT

The study conducted in the Ihorombe region focuses on air temperature, rainfall, and humidity in order to identify possible changes in these climatic parameters and to assess the impact of climate phenomena on agricultural production **(Gurib-Fakim, 2006; Burney, 1992)**. The analysis considers rain-fed crops, namely rice, maize, cassava, sweet potato, groundnut, and sugarcane, which are highly dependent on rainfall **(Burney, 1992)**. The research methodology is based on data collection and field surveys. For the analysis of climatic parameters, two analytical approaches were applied: the Fast Fourier Transform (FFT) and the Maximum Entropy Method (MEM), which allowed the identification of anomalies within the climatic time series **(Ghil et al., 2002)**. The results show unusual anomalies in temperature and rainfall, while air humidity was regular during the period 1989–2004. These anomalies suggest the beginning of climate change in the Ihorombe region. The annual rainfall shows a decreasing trend from 2000 to 2004. Agricultural data analysis shows variations in crop yields depending on the type of crop. Rice, maize, cassava, and sugarcane exhibit increasing yields, whereas sweet potato production shows a decline despite an expansion in cultivated area. This indicates a higher sensitivity of sweet potato to climate change compared to the other crops studied. The Ihorombe region is currently affected by climate change. However, the impact of climate change on agriculture is not the same for all crops. This situation requires the implementation of adaptation strategies so that agriculture, which is a major source of food, is not negatively affected by the possible effects of climate change.

KEYWORDS: Climate change, Temperature, Rainfall, Air humidity, Yields.

I- INTRODUCTION

Since the beginning of the twentieth century, scientists have focused on the issue of global climate change. They provide clear evidence based on observations and measurements, which allow them to confirm that the Earth's climate is changing. The main causes are multiple and can be grouped into two categories: natural causes and anthropogenic causes **(IPCC, 2013; Le Treut et al., 2007)**.

Historically, climate change is not a new phenomenon. The Earth's climate has already experienced several changes in the past. These changes played an important role in the evolution of living organisms on Earth. Species that had the ability to adapt survived and developed, while those that could not resist environmental changes disappeared **(Burroughs, 2007; Petit et al., 1999)**.

The climate changes mentioned above cause variations in several parameters such as temperature and greenhouse gases (methane, carbon dioxide, etc.). These factors are also associated with variations in the Earth's orbital parameters around the Sun and changes in the Earth's axis of rotation. This natural phenomenon occurs over a cycle of approximately 100,000 years **(Milankovitch, 1941; Berger, 1988)**.

At present, human activities accelerate climate change through their impact on the environment. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change shows, through graphical data, the evolution of anthropogenic CO_2 emissions from 1750 to the present. The analysis of these data shows that anthropogenic CO_2 emissions increased fourfold since 1750. Moreover, since the 1950s, many observed changes are unprecedented over decades or even millennia. During the same period, the Earth's climate warmed, and many scientists now agree that there is a direct link between the increase in the greenhouse effect and global warming **(IPCC, 2013; Hansen et al., 2010)**.

Indeed, this article focuses on climate change in the Ihorombe region due to the delay in rainfall observed in the Ihosy area. This change affects the agricultural calendar of farmers every year. The objective of this study is to determine, through statistical analysis of several climatic parameters, whether there are significant changes in temperature, rainfall, and air humidity **(Burney, 1992; Direction Générale de la Météorologie & RIMES, 2019)**.

The problem also arises from the observation of the absence of forests on the Ihorombe plateau, which is evident over large areas. The disappearance of forests is not clearly explained. In this region, the relationship between deforested areas and population growth does not correspond **(Rossi, 1996; Burney et al., 2004)**. Forest destruction started before the settlement of the first inhabitants. This observation leads us to consider that Ihorombe may have experienced a natural catastrophe (such as fire or drought) or climate change that negatively affected the environment. However, these hypotheses require further in-depth studies. This situation also justifies the choice of Ihorombe as the study area **(Rossi et al., 2000)**.

The main hypothesis of this study is whether the climate of Ihorombe experienced a change and whether this change affects agricultural productivity in the region. Climate change is often associated with rising temperatures and insufficient rainfall, which may negatively influence crop yields in Ihorombe **(Lobell et al., 2008; Challinor et al., 2014)**.

The objectives of this study are to

- **Determine** the evolution of climatic parameters using specific methods and identify trends related to climate change.
- **Understand** the mechanisms and impacts of climate change on agricultural production and society.
- **Assess** the consequences and risks associated with climate change.
- **Propose** a set of adaptation options to climate change and mitigate its effects.

II- MATERIALS AND METHODS

This study requires extensive field surveys, direct observations, and data processing in order to transform raw data into usable information. To conduct the fieldwork, frequent trips were made to the study area, mainly by taxi-brousse. Field preparation was not easy. Survey questionnaires were developed to meet the objectives of the study. These questionnaires were designed and tested to minimize the gap between theory and the actual field reality **(David A. Burney).**

Limited material resources were used, but they were sufficient to support effective fieldwork. Basic office supplies such as pens, pencils, and notebooks were included among the required materials. In addition to these physical tools, digital and computer-based tools were also used, including a computer, a USB flash drive for data storage, and a mobile phone. Mobile applications such as Facebook, WhatsApp, Google, mapping tools, text messaging, and voice calls helped to obtain real-time information and to process field data efficiently.

This research conducted in the Ihosy area is based on a scientific approach using the deductive method. Deduction is one of the three main scientific approaches that emerged with modern science. These approaches include deduction, induction, and the hypothetico-deductive method **(Dépelteau, 2003).**

Based on the planning of fieldwork activities, three data collection techniques are used. These include documentary research, direct observation, and data collection through surveys and interviews.

The documentary technique concerns bibliographic research and the consultation of administrative and archival documents at national, regional, and communal levels.

During the observation phase, the use of photographs, audio recordings, and personal involvement in the daily life of the surveyed communities allows the comparison of collected data with the actual field reality and supports progress in the research process **(Caroline B. et al.).**

Data collected through surveys and interviews represent one of the main sources of socio-economic information for this study. The processing of climatic data requires mathematical methods, namely the Fast Fourier Transform (FFT) and the Maximum Entropy Method, which are signal-processing techniques. These methods represent a key feature of this study. They allow the analysis and interpretation of climatic parameters such as rainfall, temperature, and air humidity, which are typically recorded hourly over a period of approximately thirty years.

III- RESULTS

3.1- Temperature

Figure 1 presents the raw daily temperature values from January 1, 1989, to December 31, 2004. The figure indicates a pseudo-periodic variation in temperature over the period from 1989 to 2004. Significant local fluctuations appear from November 30, 2001.

During the study period, the minimum temperature was observed on November 27, 1989, while the maximum temperature was observed on March 18 and 19, 1998.

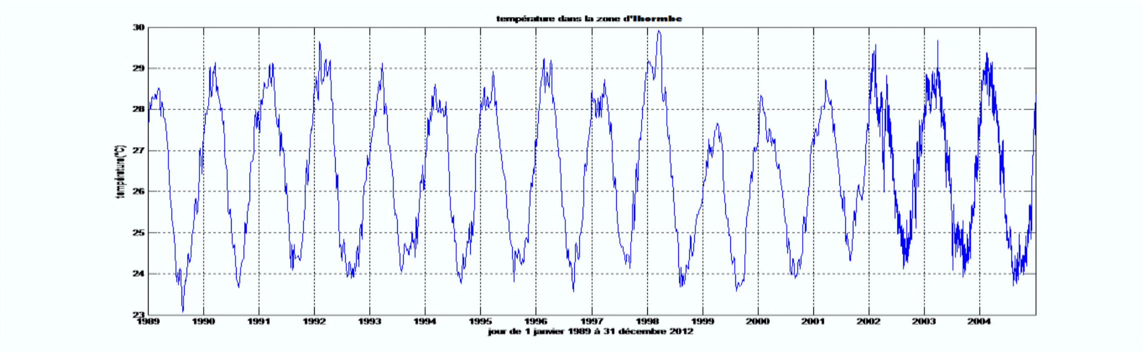

Figure 1: Raw daily temperature values.

Figure 2 presents the variation of the daily climatological mean temperature over the study period. The temperature remains above 27.5°C from January 1 to May 7 and falls below 27.5°C during the rest of the year. The maximum value of 28.55°C appears on March 21 and 25, while the minimum value of 24.15°C appears on August 30 and 31.

3-1-1- La transformée de Fourier

3.1.1 Fast Fourier Transform

As stated previously, Figure 1 presents large temperature fluctuations from the end of 2001. This raises the question of the physical meaning of these fluctuations. For this reason, the temperature anomaly from 1989 to 2004 is considered **(G. Mégie et al.)**.

Temperature anomaly is defined as the temperature at time *t* minus the mean temperature over the period 1989–2004. This temperature anomaly is then processed using two mathematical transformations:

- the *Fast Fourier Transform* (FFT);
- the Maximum Entropy Method (MEM).

The Fast Fourier Transform is a computational algorithm used to convert discrete data from the time domain into the frequency domain. The Fourier transform is based on the principle that any periodic time function $x(t)$ can be decomposed into an infinite sum of sine and cosine functions. The frequencies start from zero and increase by integer multiples of a fundamental frequency, $f_0 = \frac{1}{T}$, where T is the period of $x(t)$. This mathematical expansion is expressed as follows:

$$x(t) = a_0 + \sum_{k=1}^{\infty}\left(a_k \cos(2\pi k f_0 t) + b_k \sin(2\pi k f_0 t)\right)$$

L'expression du membre de droite est appelée série de Fourier. Le rôle de la transformée de Fourier est de trouver toutes les valeurs a_k et b_k qui composent la série ainsi que la fréquence f_0 de base et la fonction $x(t)$. C'est la détermination de cette dernière qui nous intéresse le plus ici.

The expression on the right-hand side is called the Fourier series.

The role of the Fourier transform is to determine all the coefficients a_k and b_k that compose the series, as well as the fundamental frequency f_0 and the function $x(t)$. In this study, the determination of this function is of primary interest.

The Maximum Entropy Method (MEM) is another mathematical transformation which, when applied together with the FFT, determines the acquisition duration, sensitivity, and resolution of the final spectra.

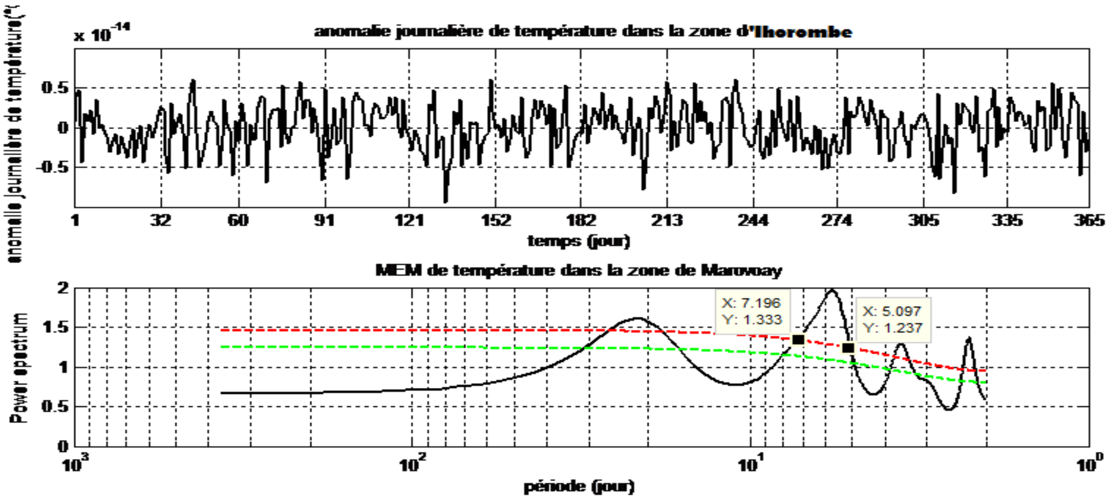

Figure 2: Spectral power of the daily climatological mean temperature from January 1, 1989, to December 31, 2004.

Top: Daily temperature anomaly.
Bottom: Spectral power (FFT) of the temperature anomaly.
The red dashed line represents the Maximum Entropy Method (MEM).
Figure 2-a (top) presents the filtering thresholds of temperature data at $\frac{1}{1333}\,day^{-1}$ and 1/1237 day^{-1}
Figure 2-b (bottom panel) gives the shape of the variation curve of the filtered data.

Figure 2-a (top panel) presents the temperature anomaly. This curve is also pseudo-periodic. To determine its pseudo-periodicity, the spectral power combined with the MEM (in red) is plotted in Figure 4-b (bottom panel). The intersections of these two curves give two coordinate points: (X_1 = 7.196 days; Y_1 = 1.333 W) and (X_2 = 5.097 days; Y_2 = 1.237 W). The dominant model of the temperature anomaly corresponds to the difference between these two values ($X_1 - X_2$ = 7.196 − 5.097 = 2.099 days). Therefore, the pseudo-period of the signal is 2.099 days.

The temperature anomaly data are filtered by extracting the data corresponding to the dominant period modes. This is represented in Figure 5 (bottom). Figure 5 (top) represents the filter threshold.

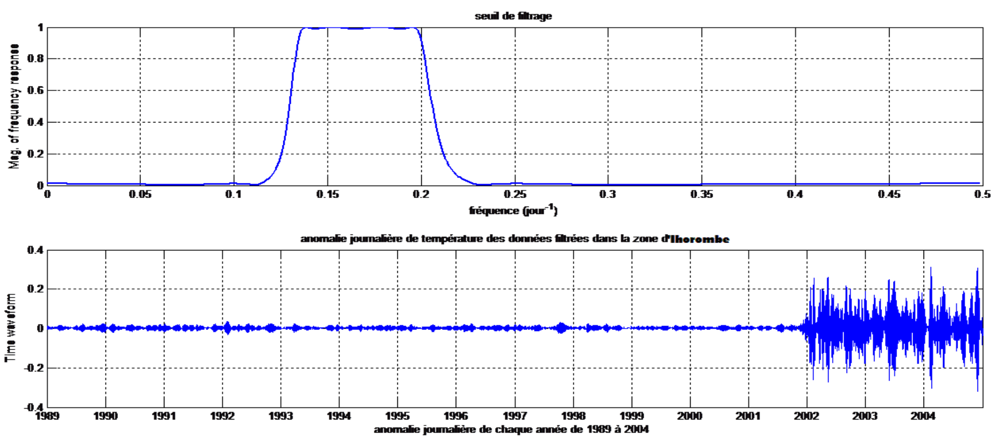

Figure 3: Filtered data from 1989 to 2004.

Between January 1, 1989, and November 29, 2001, the daily temperature anomaly presents very small fluctuations around the zero value. From November 30, 2001, the fluctuation amplitude increases significantly, by approximately 1.6 times. This suggests that, from this date, a change occurs that explains the large temperature fluctuations. This figure may indicate a sign of climate change in the Ihosy district.

3-1-2- Rainfall

The raw daily rainfall values of the Ihosy district are presented in the following figure 4.

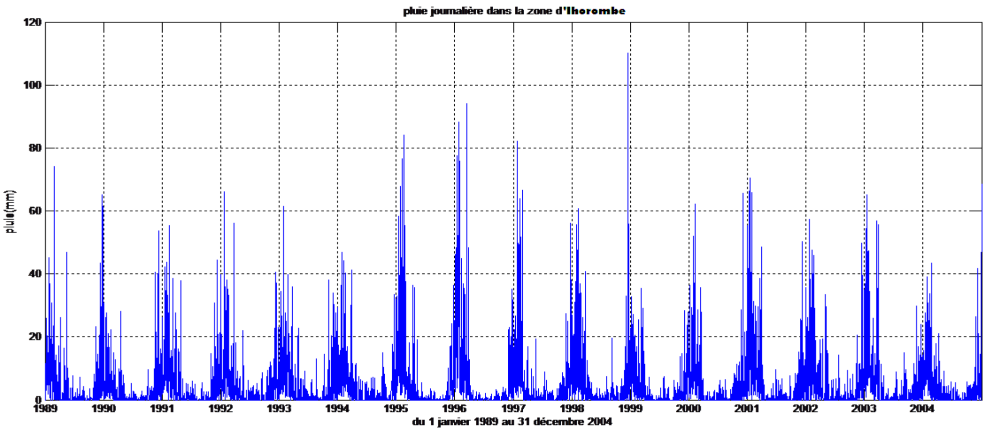

Figure 4: Raw daily rainfall values of the Ihosy district from 1989 to 2004.

The separation between the rainy season and the dry season is clearly visible in this figure. The beginning and the end of the rainy period are characterized by large fluctuation amplitudes, which usually occur from November to April. In contrast, the dry season is characterized by low-amplitude fluctuations, indicating insufficient rainfall, and extends from May to October.

In this figure, the highest fluctuation corresponds to December 1998, with a recorded value of about 110 mm. The lowest rainfall is recorded in 1996, when the dry season is longer and the rainy season is shorter.

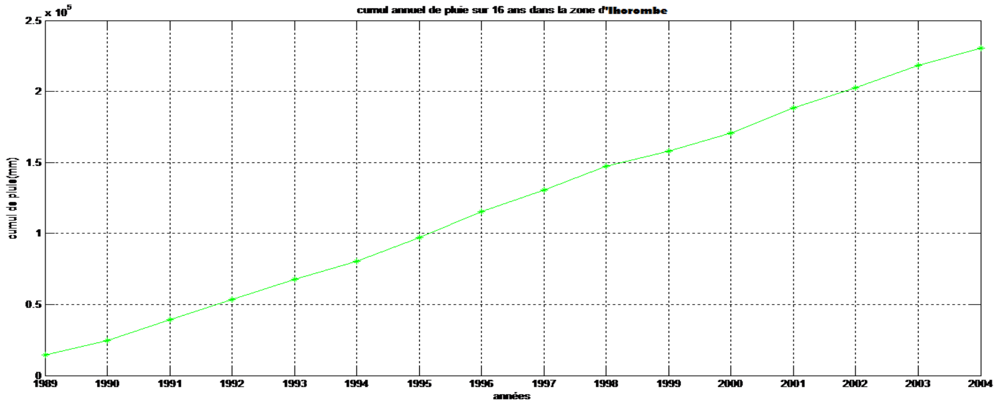

Figure 5: Monthly rainfall cumulative of the Ihosy district from 1989 to 2004.

The analysis of the monthly cumulative rainfall indicates irregularities in rainfall distribution. In general, the cumulative rainfall over the 16-year study period presents an increasing trend. However, from 1998, an irregularity in the monthly rainfall cumulative appears, giving a slight variability in the curve until 2002. From 2002, a slight convexity of the curve is observed until 2004. These features suggest a change in rainfall accumulation starting from 1998. This change in rainfall cumulative, which coincides with the significant temperature fluctuations, may indicate the presence of climate change in the Ihosy area.

3.-2- Specific humidity

In general, specific humidity oscillates annually between 0.002 and 0.0014 (kg/kg) in a pseudo-periodic manner. Specific humidity reaches its maximum during the austral summer and its minimum during the dry season.

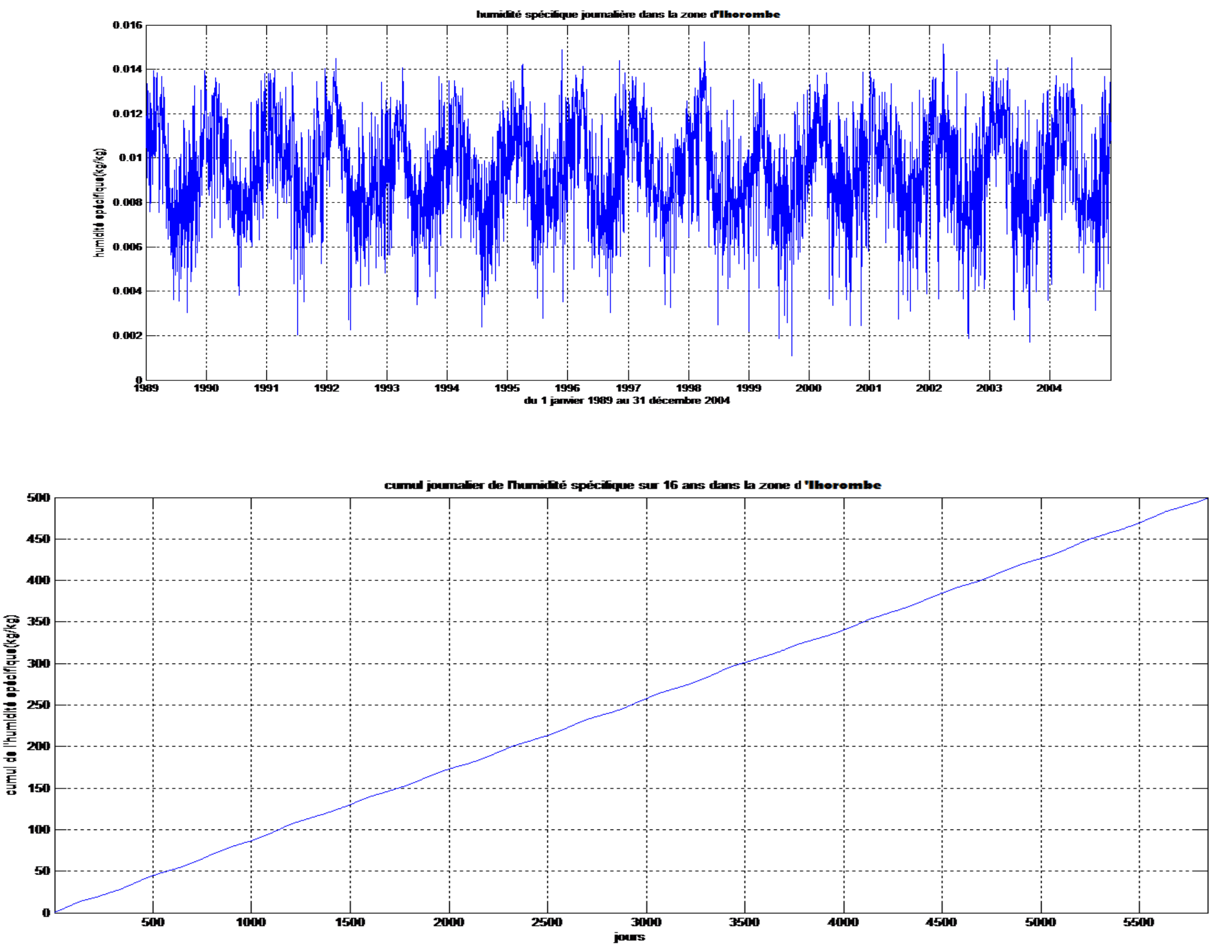

Figure 6: Daily cumulative specific humidity.

The analysis of the daily cumulative specific humidity curve indicates an almost linear pattern. This situation highlights the regularity of specific humidity from 1989 to 2009.

3-3- Agricultural production

For this study, agricultural data are collected from the Agricultural Yearbook of the Ministry of Agriculture and from the Regional Directorate of Agriculture of Ihorombe for the period from 1997 to 2022. The analysis considers the production of rice, maize, cassava, sweet potato, sugarcane, and groundnut.

The temperature change observed from November 30, 2001 does not have the same impact on all crop types. It may be beneficial or negative depending on the crops considered. Variations in yield and production are also influenced by the use of fertilizers and improved agricultural techniques. In addition, the condition of agricultural infrastructure, such as the lack and deterioration of water retention basins and main irrigation canals, as well as locust invasions, further accentuates variations in agricultural production.

IV- DISCUSSION

The analysis of climatic variability in the Ihorombe region indicates that the daily cumulative temperature and rainfall from 1989 to 2004 present alternating periods of rainfall deficit and abundant rainfall. The period of abundant rainfall occurs between 1995 and 1999. The monthly climatological mean over the study period from 1989 to 2004 indicates that February records the maximum rainfall, while the minimum occurs in September. A similar pattern is observed for temperature. The monthly climatological mean temperature over the 16-year period indicates that the maximum occurs in March and the minimum in June.

It is important to note that from January 2001, a temperature anomaly is observed, and from 2002, a rainfall anomaly appears. The analysis of these anomalies using the Fast Fourier Transform combined with the Maximum Entropy Method leads to the conclusion that these anomalies mark the beginning of climate change in the Ihorombe region. These results also suggest that forest scarcity in the Ihorombe buffer zone is not directly caused by recent climatic changes, since forest disappearance occurred before 2001.

The impact of these changes on agriculture varies according to crop type. From 2003, rice yield increases and reaches 2.5 tons per hectare. From 2002 to 2008, maize yield remains around one ton per hectare despite an increase in cultivated area from 540 ha to 5,550 ha over the same period. Cassava yield, which is about 10 t/ha between 1998 and 2003, reaches 35 t/ha from 2004. In contrast, sweet potato yield decreases from 7 t/ha before 2000 to about 1 t/ha from 2001, despite an increase in cultivated area. Sugarcane productivity increases significantly from 30 t/ha to 60 t/ha.

Overall, the changes observed in temperature and rainfall have positive or negative effects depending on the crop type. The sensitivity of each crop to climate change also varies by production system. In this study, sweet potato productivity decreases immediately from 2001, which corresponds to the onset of temperature fluctuations. Other crops experience the effects of climate change two to three years after the appearance of significant temperature and rainfall fluctuations. These results indicate that sweet potato is particularly sensitive to climate change.

A decreasing trend in rainfall is also observed. The interval between the first and second rainfall events becomes longer, leading to water stress in agriculture and increasing the risk of crop drying.

This study strengthens existing scientific tools and aims to improve the resilience of agricultural yields to current climatic challenges. It confirms the existence of climate change in the Ihorombe region and highlights the sensitivity of different crop types to climatic variability. These findings help farmers and agricultural technicians identify adaptive crop choices under changing temperature and rainfall conditions in order to maximize yield.

Ihorombe, a region with strong agricultural potential, may reduce the negative impacts of climate change if timely climate analysis leads to the identification and implementation of appropriate adaptation strategies suited to future conditions.

V- CONCLUSION

Madagascar is among the countries most vulnerable to the effects of climate change (PNLCC, 2011, p. 7). The internal situation of Madagascar, characterized by socio-economic vulnerability and the fact that about 80% of the population depends on agriculture, a sector highly sensitive to climate change, indicates that this issue is serious and requires close attention.

Climate, as a key factor in agricultural production, creates uncertainty for farmers due to its changing nature. In the Ihorombe region, the analysis of climatic variables such as temperature, rainfall, and specific air humidity leads to the following conclusions:

- The monthly cumulative temperature presents significant fluctuations from November 30, 2001. The presence of these fluctuations indicates the beginning of climate change in the region.
- Rainfall analysis indicates that rainfall amounts tend to decrease from year to year, particularly between 2000 and 2004.
- Specific air humidity, in contrast, remains relatively stable from 1989 to 2004.

Agricultural yields in this study vary according to crop type. The temperature change observed from November 30, 2001 does not have the same impact on all crops. Variations in yield and production are also influenced by the deterioration of agricultural infrastructure, such as water retention basins and main irrigation canals, the shortening and irregularity of the rainy season, and the continued use of traditional farming techniques.

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