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*RESEARCH ARTICLE*

# CLIMATE-LAND COVER NEXUS: IMPLICATIONS FOR AGRICULTURAL PLANNING IN KOUTABA, CAMEROON

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**ABSTRACT**

The relationship between climate and land cover is vital for agricultural planning, as it directly impacts productivity, sustainability, and resilience within agricultural systems. Understanding this relationship can help mitigate risks associated with climate change and optimise land use. Climate change affects land cover through rising temperatures, changing precipitation patterns, and an increased frequency of extreme weather events, which in turn affect soil quality, water availability, and lead to habitat loss. Conversely, land cover can influence climate by altering both local and global conditions, such as through deforestation and the establishment of human settlements, which impact evapotranspiration, soil moisture, and greenhouse gas emissions. Changes in climate and land cover have significant effects on agricultural productivity, crop yields, and overall food security. This study aimed to: (1) establish the relationship between climate and land cover, and (2) assess the implications of this relationship for agricultural planning. To achieve these objectives, field surveys, administered questionnaires, and conducted interviews were conducted. Changes in land cover and use using Landsat images from 1980, 2003, 2013, and 2023 were analysed, and complemented this data with rainfall and temperature records from 1960 to 2021, as well as crop production statistics from 2006 to 2023. The results revealed that the Koutaba municipality has lost over 50% of its forest cover, while rainfall levels have been declining along with rising temperatures. Additionally, crop production has decreased due to changes in land cover and climate fluctuations. It is recommended that stakeholders adopt Nature-based Solutions to promote sustainable agricultural practices.

**KEYWORDS**

adaptation, exposure, vulnerability, crop production, food security

## 1. INTRODUCTION

The land is a crucial component of the earth's climate system, consisting of five interrelated components: the atmosphere (air), the hydrosphere (water), the cryosphere (ice), the lithosphere (the Earth's upper rocky layer), and the biosphere (ecosystems) (Tume et al., 2024). Climate refers to the statistical characterisation of this climate system, representing the average weather patterns over a long period (IPCC, 2021). Land and climate interact in complex ways, influenced by various factors and multiple biophysical and biogeochemical feedback mechanisms across different spatial and temporal scales. This interaction means that climate impacts land, and land also influences climate, especially as human activity contributes to these changes. Additionally, humans implement land-based adaptation strategies to counteract climate-negative changes in land cover.

In the tropics, temperatures remain consistently high throughout the year, and there are extreme precipitation events, although there is a concerning trend of declining rainfall patterns (Tume and Nyuyfoni, 2025; Tume, 2019). Land is essential for human livelihoods and well-being, providing food, fresh water, numerous ecosystem services, and supporting biodiversity. Furthermore, land plays a significant role in the climate system. Changes in land use and the intensification of land use practices have led to increased food and feed production. Since 1961, total food production, particularly cereals, has surged by 240% (up to 2017), primarily due to the expansion of land area and rising yields (Mbow et al., 2019).

Climate change is a critical issue that is worsened by human activities. It manifests in various forms, including fluctuations in temperature and rainfall. Changes in land use play a significant role in climate change and can greatly affect climatic conditions, while climate change can also limit or alter land use opportunities (Jia et al., 2019). Understanding this interaction is vital for effective international climate discussions. Greenhouse gas emissions from agricultural and other land use sectors contribute to climate change, and alterations in land use can lead to several negative consequences, such as agro-hydro-meteorological droughts (Tume et al., 2020). Areas facing water scarcity—such as tropical grasslands, semi-arid, and arid regions—are particularly vulnerable to the impacts of climate change. These regions may experience loss of livelihoods, population displacement, and ongoing conflicts between farmers and grazers.

## 2. ANALYTICAL FRAMEWORK

The agriculture and food system is understood through both its supply and demand components. Supply includes aspects such as production, processing, marketing, and retailing, while demand encompasses consumption and dietary choices. These components are influenced by various physical, economic, social, and cultural factors that affect choices, access, utilisation, quality, and safety (Arneth et al., 2019). Food system drivers, which include ecosystem services, economic factors, technology, social and cultural norms, and demographic influences, interact with enabling conditions such as policies, institutions, and governance. Together, these factors shape food system outcomes, including food security, nutrition and health, livelihoods, and the economic and cultural benefits of food systems. Additionally, they impact environmental outcomes, which may include nutrient and soil loss, water usage and quality, and local greenhouse gas emissions (Jafari and Jafari, 2020; Mbow et al., 2019).

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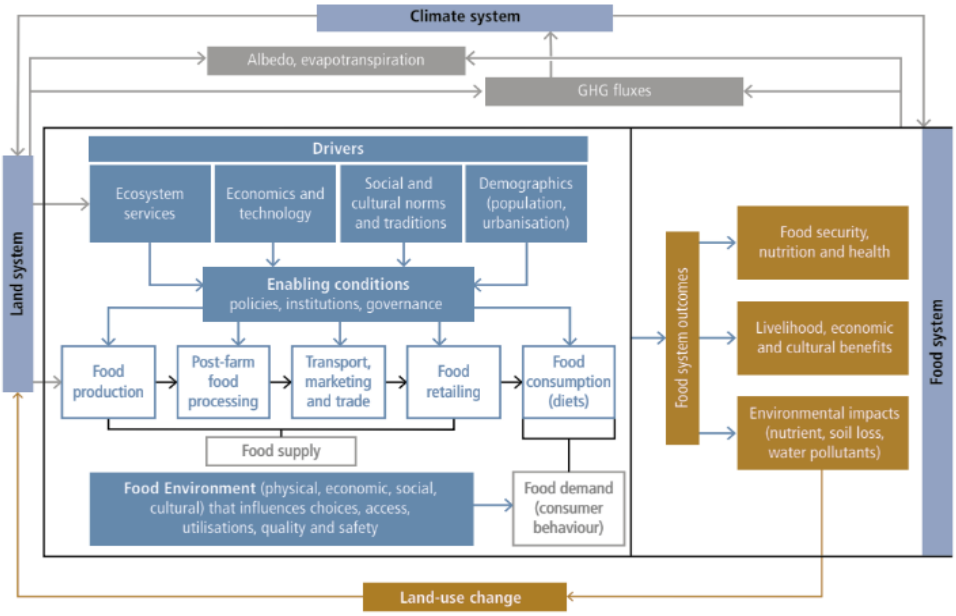



**Figure 1:** Climate-Land-Food System Nexus (Source: Arneth et al., 2019)

Climate variability and change have direct impacts on the food system (productivity, variability, nutritional quality) while the latter contributes to local climate and global warming (Ericksen *et al.,* 2010). The land system (function, structures, and processes) affects the food system directly (food production) and indirectly (ecosystem services), while food demand and supply processes affect land (land-use change) and land-related processes (land degradation) (Awazi *et al.,* 2024).

## 2.1 The Study Area and Methods

Koutaba is found in the Noun Division, West Region of Cameroon. It is situated some 46.4km north-west of the West Regional Capital, Bafoussam. Koutaba is located between latitudes $5^{o}65'$ and $5^{o}39'$ North of the Equator and between longitudes $10^{o}76'$ and $10^{o}45'$ East of the Greenwich Meridian (Figure 2) and covers a total surface area of about 497 km$^2$ (Maphill, 2013). Koutaba is centrally located between Foumbot and Foumban. It is centrally located because it is bordered to the north by Foumban, to the south by Foumbot, to the east by Massagam, and to the west by Bangourain. Koutaba was created by Presidential Degree No.82/455 on September 20, 1982, designating it into the municipal council.

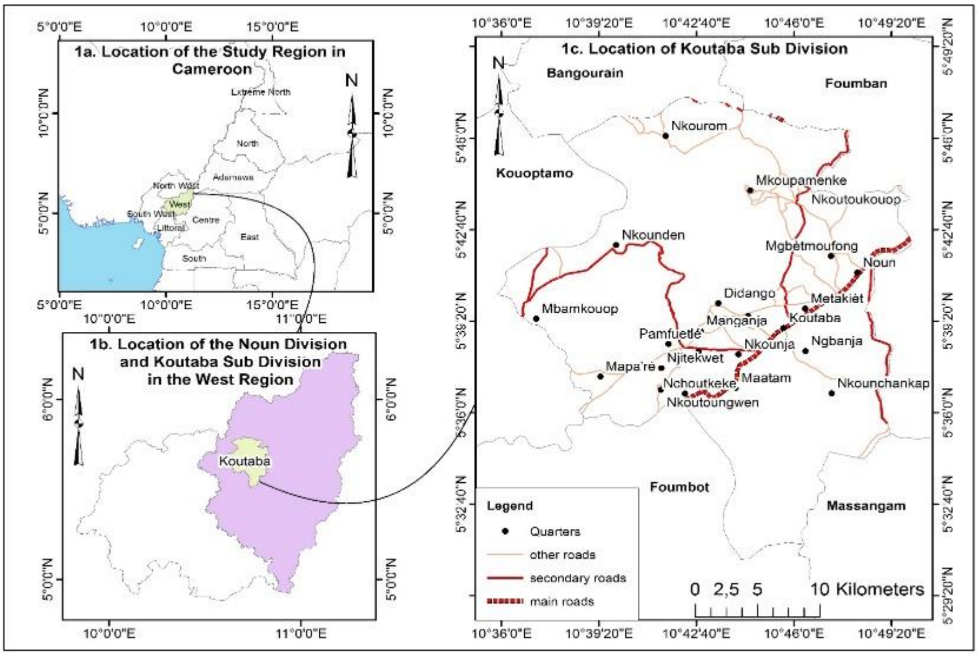



**Figure 2:** Location of Koutaba Sub-Division (Source: Administrative Map of Cameroon (NIC, 2020))

Koutaba generally experiences a humid tropical climate, precisely the Cameroon type. The climate is somewhat similar to the Monsoon type. This climate is both warmer and colder, having two seasons, the dry and rainy seasons. The climate in this area is characterised by two major seasons: the rainy season and the dry season. The wet season lasts 8 months and runs from mid-March to mid-November, while the dry season lasts for four months, from November to March. This climate and the two seasons very much encourage agricultural activities. The total land area of Koutaba, estimated at some 497km$^2$ falls within the vast plains of Koundoum right to the arable land. The relief is made up of three major units: the Western and the Eastern Highland regions, with the highest mountain being the Mbapit and Mount Kogham. The relief is gentle, low-lying, covering flat lands across the municipality. The vegetation is generally characterised by patches of forests, raffia swampy grassland, and grass of different species, such as silver rose. The primary forest montane type has been altered by anthropogenic activities such as farming, deforestation, grazing, and human settlements. The vegetation type is a function of altitude and climate. With the varying climatic conditions, warmer areas have supported the cultivation of palm plantations, pears, mangoes, and plums, as well as cassava, sweet potatoes, beans, and maize.

## 2.2 Data Sources and Analysis

This is an evidence-based study that made use of primary and secondary data. Primary data sources comprise first-hand information, which is both quantitative and qualitative, from the field. This included field surveys, observations, questionnaire administration, and interviews. This field survey aimed to delimit the study area and to draw up the functions and activities of the population, the effect of climate extremes such as floods, and their effects on the livelihood of the population.

The administration of questionnaires was been one of the methods of obtaining reliable information. This method of data collection is done through a simple random sampling technique (because, from observations, key areas of concern were noticed, with a focus on the key agro-hydrological effects of climate variability on livelihood), as well as stratified sampling of farming households. Random sampling was implemented in distributing the questionnaires to the various villages and also in administering the questionnaires to the various households due to the inaccessibility of most of the areas, since most of them are not farmers. Nevertheless, these questionnaires (120) were shared with the villages based on the latest population count in the Koutaba.

**Table 1:** Population statistics of Koutaba as per the Village

| Village | Total Population | Questionnaires administered | Number retrieved | % Retrieved |
|---|---|---|---|---|
| Koutaba | 2409 | 32 | 26 | 18.57 |
| Matakiet | 1584 | 26 | 22 | 15.71 |
| Didango | 2133 | 42 | 38 | 27.14 |
| Nkounchakap | 1787 | 15 | 12 | 8.57 |
| Nkounja | 5994 | 25 | 22 | 15.71 |
| Total | 13,907 | 140 | 120 | 85.71 |

Two basic sampling techniques were adopted for this study: simple random sampling and stratified random sampling. Simple random sampling is the basic sampling technique where we select a group of objects (a sample) for study from a larger group. The main reason that led to this choice of technique was to ensure a complete representativeness of the target population and also to reduce the cost of administering questionnaires to maximise time. Stratified random sampling was also used because of time constraints, as the researcher could not cover the entire study area. In this method, the study area was carved out into zones, Koutaba. After dividing the population into two sections to ease the comparison between the two areas, the random sampling technique was used to select the appropriate sample size from each subgroup or stratum of the population. Since the study had to avoid bias, it was intended that the sample size should approximate the same relative number from each section.

#### *2.2.1 Land Cover Change*

Change detection of land cover/use was done in this study. The main input data were Landsat images that we acquired for the dry season period to avoid the effects of cloud coverage on images, as well as other atmospheric attenuations. 1980, 2003, 2013, and 2023 were acquired from the US Geological Survey website (Table 1) and processed in QGIS. Acquired image scenes were pre-processed for radiometric corrections and later on, subjected to layer stacking and clipping to the study area. We then employed a supervised image classification technique on the images, which consisted of making training samples of each respective land use based on expert knowledge, field observations, and existing maps (topographic maps), then classifying these training samples based on pixel spectral signatures.

**Table 2:** Sources of Remotely Sensed Data

| Platform | Sensor | Acquisition date | Cell size | Satellite operator |
|---|---|---|---|---|
| Landsat 5 | TM | 1980/12/28 | 30 | NASA |
| Landsat 7 | ETM+ | 2003/12/15 | 30 | NASA |
| Landsat 8 | OLI/TIRS | 2013/12/31 | 30 | NASA |
| Landsat 9 | OLI/TIRS | 2023/02/25 | 30 | NASA |

Source: USGS Landsat images, 1980, 2003, 2013, 2023

#### *2.2.2 Crop Production Data*

Crop production data from the Regional Delegation of Agriculture and Rural Development in Bafoussam (2006-2023). Crop production data from the Regional Delegation of Agriculture and Rural Development in the West Region provides critical insights into the agricultural landscape, productivity levels, and challenges faced by farmers in the area. This data is essential for informed decision-making, policy formulation, and sustainable agricultural practices aimed at enhancing food security and economic development in the region from 2006 to 2023. This period gives more information on the challenges and threats to livelihoods and food security within the region.

#### *2.2.3 Climatic Data*

Mean monthly rainfall and temperature data were obtained from the Koutaba Military Base from 1960-2021.

## 3. Results

Climate variability continuously impacts every region, including the Koutaba Sub-Division and its surrounding areas. This is evident in the changes and fluctuations in temperature and rainfall patterns, which have affected agriculture and water resources, thereby impacting livelihoods both directly and indirectly. The effects of climate variability have been persistent and worsened by human activities such as deforestation, bush burning, shifting cultivation, and urbanisation in marshy areas and on certain slopes within the study area. These factors have led to rising temperatures and irregular rainfall patterns, which directly influence the agricultural calendar of the region, ultimately affecting agricultural productivity.

### 3.1 Land Use/ Land Cover-Climate Nexus in Koutaba

The main land cover classes in Koutaba are forest, farmland, grassland, settlements, and water bodies (which are few). These have been changing for the period under consideration (Table 3; Figure 3a-d). These changes are a result of the intersections between physical/natural and anthropogenic drivers; however, largely contributed by human factors.

**Table 3:** Land cover change in Koutaba (1980-2023)

| Land cover | 1980 | 2003 | 2013 | 2023 | Changes |
|---|---|---|---|---|---|
| **Forest** | 2,998.62 | 5681.25 | 9349.13 | 2,027 | -971.62 |
| **Farmland** | 9576 | 17921.12 | 23385.15 | 26,052 | 16,476 |
| **Grassland** | 31,908.55 | 19,451.14 | 10,293.03 | 14378 | -17,530.55 |
| **Settlement** | 599.49 | 2034 | 2052.56 | 2631 | 2,031.51 |
| **Water bodies** | 29.34 | 24.49 | 32.13 | 24 | -5.34 |
| **Total** | 45,112 | 45,112 | 45,11 | 45,112 | 0 |

Source: USGS Landsat images (1980-2023)

Land cover in the region includes vegetation, cropland, and water bodies, all of which have been subject to significant changes. An increasing population and ongoing urbanisation have transformed forests and cropland into areas for settlements, grazing, and business structures. Water bodies have been greatly impacted by human activities and are almost unnoticeable on maps, reflecting the effects of climate variability alongside anthropogenic influences. Additionally, forested regions have been converted into farmlands as the demand for food rises and farmers seek to provide for their families by selling agricultural products.

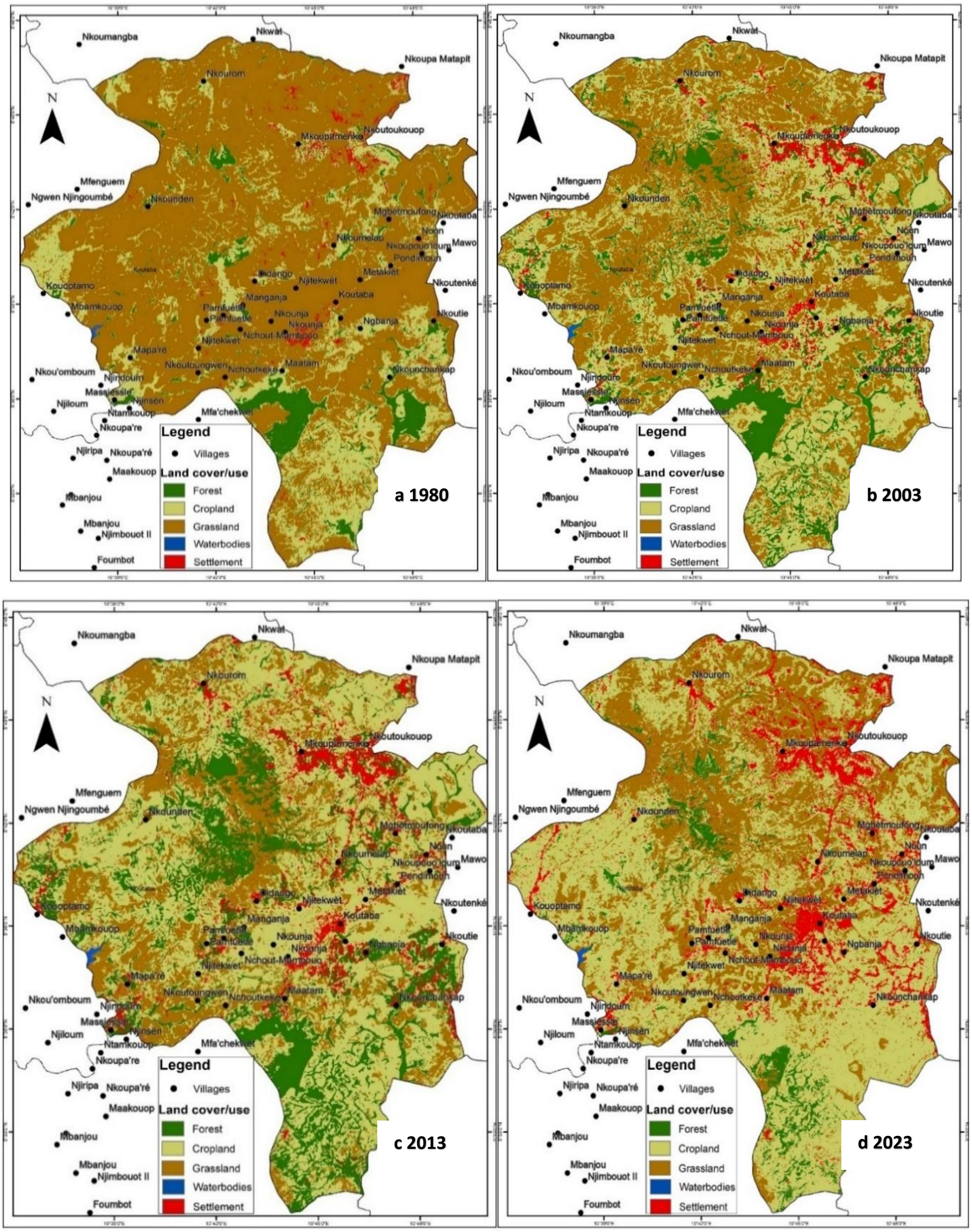



**Figure 3:** Land use for Koutaba (1984 to 2023) (Source: USGS, USGS, 1984, 2003, 2013, 2023)

The area's fertile soils further encourage agricultural activities, attracting residents, especially internally displaced persons, who are in search of work and better means to support their families.

Koutaba has historically been known for its rich forest reserves, but recent years have witnessed a surge in deforestation due to logging and land clearing for agriculture and residential developments. The city has expanded agricultural activities into previously undeveloped areas, leading to the conversion of forests and grasslands into farmland. With the steady growth of Koutaba's population, exacerbated by the sociopolitical crisis in the Anglophone regions of Cameroon, there has been an influx of internally displaced persons who often turn to agriculture as their primary livelihood. This shift has resulted in the city extending its boundaries into new territories. Unfortunately, some regions in Koutaba have experienced unsustainable land use practices, such as overgrazing and improper agricultural methods, which have caused soil erosion and degradation. Overall, the land changes in Koutaba over the past 30 years have been driven by a combination of factors, including population growth, economic development, and policies related to land use and management. By 2023, forests in the area will have nearly vanished (Figure 4).

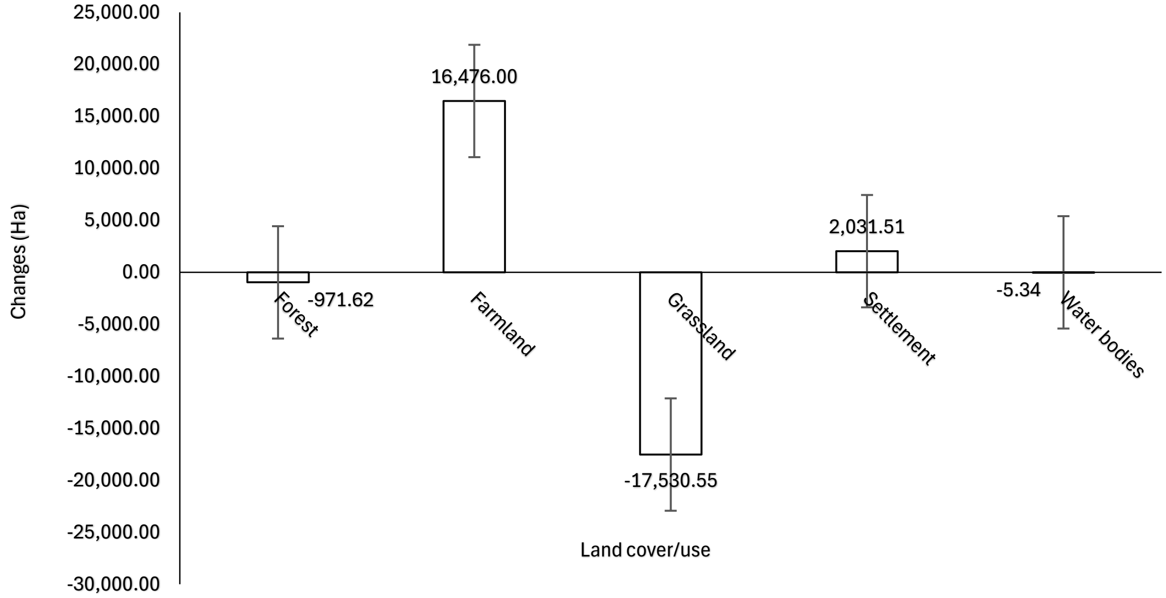



**Figure 4:** Relative land cover change (1980-2023) (Source: Landsat images (1980-2023))

### *3.1.1 The magnitude of Climate Variability*

Climate variability can significantly impact water resources and agriculture. Changes in precipitation patterns, temperature fluctuations, and the increased frequency and severity of extreme weather events—such as droughts, floods, and wildfires—affect crop yields, water availability, and water quality. For instance, the 2018 floods in Koutaba led to decreased water availability for agriculture and urban use, as well as an increase in water-related diseases. Extreme flooding events can cause soil erosion, water contamination, and damage to crops. The evidence of these impacts can be observed through various indicators, including decreases in crop yields, changes in the timing of planting and harvesting, reductions in water availability, and increased water stress on both crops and ecosystems.

Moreover, rising heat waves and prolonged periods of high temperatures can lead to plant stress and reduced crop productivity. These effects can have significant societal and economic consequences, including concerns about food security and rising water scarcity. In the study area, 55.5% of the population believes that the magnitude of climate variability is medium, while 26.7% consider it to be high. Conversely, 18.3% of the population views the impact of climate variability on agriculture and water resources as low. Nevertheless, the community acknowledges that climate variability is indeed affecting crop productivity and increasing water-related illnesses, as evidenced by various indicators.

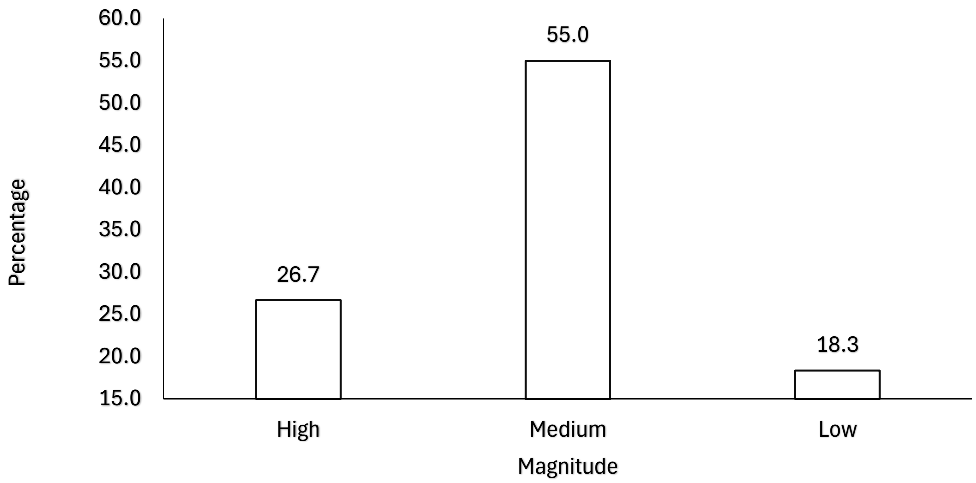



**Figure 5:** Magnitude of climate variability in Koutaba Sub-Division

There are several signs of a changing climate that impact agriculture and water resources. Agro-hydro-meteorological droughts are becoming more frequent and severe in many parts of the world due to changing climate patterns. This results in reduced water availability for agriculture and can lead to crop failures. Additionally, changes in the timing and intensity of rainfall affect the growth and development of crops. Excessive rainfall can cause flooding and soil erosion, while insufficient rainfall leads to water stress and crop failures. Altered climate patterns also create more favourable conditions for pests and diseases, which can negatively impact crop yields and quality. The local population reported observing signs of climate variability (66%). This high percentage can be attributed to the fact that most residents are farmers who have personally experienced changes in crop productivity and yields. Overall, these changing climate patterns significantly impact agriculture and water resources, necessitating both adaptation and mitigation measures to ensure sustainable farming practices and effective water management for future generations.

Extreme temperatures during the dry season and unusually cold conditions during the rainy season are also indicators of a changing climate. Higher temperatures are affecting crop growth and productivity, making some crops less tolerant to extreme heat, which ultimately results in lower yields and poorer quality. The early onset of rains and the fluctuations in dry spells during the rainy season further illustrate the variability in climate patterns that impact agriculture and water resources. Changes in the water cycle due to climate variability can particularly challenge farmers who depend on rain-fed agriculture or have limited access to irrigation water. However, 20% of the population remains unaware of any signs of a changing climate, while 14% believe that there are no indications of climate change.

### *3.1.2 Drivers of Climate Variability*

Climate variability arises from a combination of natural and human-induced factors. Natural factors include solar radiation, volcanic activity, ocean currents, and variations in the Earth's orbit and axial tilt. Human activities, on the other hand, contribute significantly to climate change, primarily through the emission of greenhouse gases (GHGS) from burning fossil fuels, industrial operations, poor agricultural practices, deforestation, and various forms of agriculture. Changes in climate patterns greatly impact agriculture, influencing crop yields, livestock production, and water resources. Extreme weather events, such as floods, droughts, and heat waves, can severely disrupt agricultural output. Additionally, temperature changes can affect the timing of seasons and growing periods, leading to alterations in water availability. Human activities are responsible for approximately 39.2% of the shifts in climate patterns. Natural factors account for 32.5%, while around 28.3% of residents believe that both anthropogenic and natural factors contribute to climate variability.

Human activities play a significant role in climate variability, particularly through the emission of greenhouse gases (GHGs), which have led to rising global temperatures, one of the primary causes of climate change. To mitigate the effects of climate variability and ensure food and water security for future generations, it is essential to reduce GHG emissions and adopt sustainable agricultural practices. In Koutaba, inappropriate farming practices aimed at combating food insecurity contribute to climate variability. Anthropogenic drivers, such as burning fossil fuels and deforestation, release greenhouse gases into the atmosphere, trapping heat and causing the Earth's temperature to rise. This temperature rise can lead to climate variability in local communities like Koutaba, resulting in altered precipitation patterns, an increased frequency and severity of heat waves, and extreme weather events such as droughts, floods, and thunderstorms.

Deforestation, often driven by human activities such as logging and farming, has further contributed to climate variability in Koutaba. Trees absorb carbon dioxide, and when they are cut down, this carbon is released back into the atmosphere. Additionally, deforestation reduces shade and evapotranspiration, which can lead to changes in the local climate. Local industries, such as bakeries that rely on firewood for heating ovens, significantly contribute to high deforestation rates, as firewood is a primary resource for these businesses. The influx of internally displaced persons has intensified the demand for arable land and space for construction, leading to further deforestation for both agricultural and building purposes. This exposes land to direct heat and increases carbon dioxide emissions into the atmosphere. Key anthropogenic drivers affecting the locals in Koutaba include poor farming techniques, population growth, urbanisation, and inadequate waste management. Evidence shows that population growth (45%), poor waste management (35%), poor farming techniques (14.2%), and urbanisation (5.8%) are significant human factors contributing to climate variations in the Koutaba municipality.

### 3.2 Actual Climate Variability in Koutaba Sub-Division

The actual climate variability in Koutaba is analysed under inter-annual rainfall, the Standardised Precipitation Index, and temperature trends.

### *3.2.1 Inter-annual Rainfall Variability*

Climate variability refers to the variations in climatic statistics, such as temperature and rainfall, over a specific period (for example, a month, season, or year) compared to long-term averages for the same time frame. This variability is measured through deviations known as anomalies. It can arise from natural internal processes within the climate system (referred to as internal variability) or from changes in external factors, which may be natural or human-induced (known as external variability). Inter-annual variations occur between different years or from one year to the next, providing insights into the dynamics of the climate system over time. Climate change and variability can be indicated by climatic variables such as temperature, rainfall, wind, and sunlight. In Koutaba, climate variability has been particularly noted through fluctuations in rainfall (Figure 6).

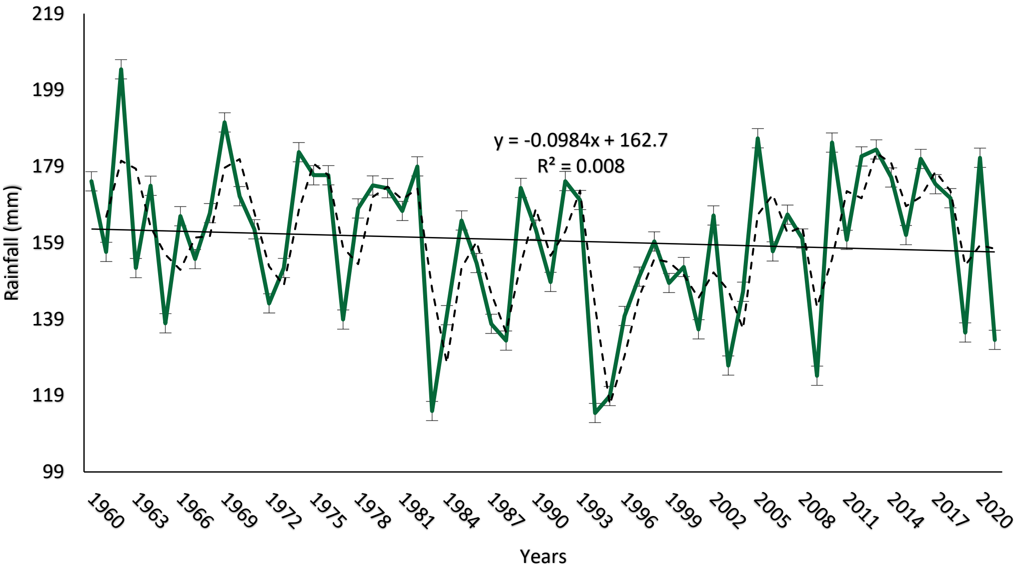



**Figure 6:** Inter-annual rainfall trend in Koutaba (1960-2021) (Data source: Koutaba Military Airbase, 2023)

The inter-annual variability in rainfall indicates variations in rainfall from 1960-2020. The degree of variation of rainfall here is indicated by the coefficient of determination ($R^2$). In 1963, rainfall was at 199 mm and drastically dropped in 1984 to 119 mm. The fluctuations continued and from 2008, 2011, 2014, 2017, the fluctuations were between 159 mm to 180mm. These fluctuations are due to the influence of human factors and anthropogenic factors.

### *3.2.2 Inter-annual Standardized Precipitation Index (SPI)*

The Standardised Precipitation Index (SPI) is the most commonly used indicator worldwide for detecting and characterising agro-meteorological droughts. The SPI indicator measures precipitation anomalies at a given location based on a comparison of observed total precipitation amounts for an accumulation period of interest (1, 3, 12, 48 months) with the long-term historic rainfall record for that period (McKee *et al.,* 1993). The SPI is used to define drought intensities and criteria for a drought event for different timescales. From 1960 to 2021, significant climate change was observed in Koutaba, characterised by increases in temperature and decreases in rainfall. These changes had profound impacts on hydrology and agriculture in the region. The temperature in Koutaba experienced a notable rise during this period. Higher temperatures can lead to increased evaporation rates, causing more water to be lost from the land and rivers. This increase in temperature likely intensified evapotranspiration processes, leading to drier conditions overall. Concurrently, there was a decrease in rainfall amounts during the 1987-2005 period. This decline in precipitation could be attributed to several factors, including changes in atmospheric circulation patterns or shifts in global climate phenomena like El Niño. The reduced rainfall (Figure 7) directly affected hydrological systems and agricultural practices.

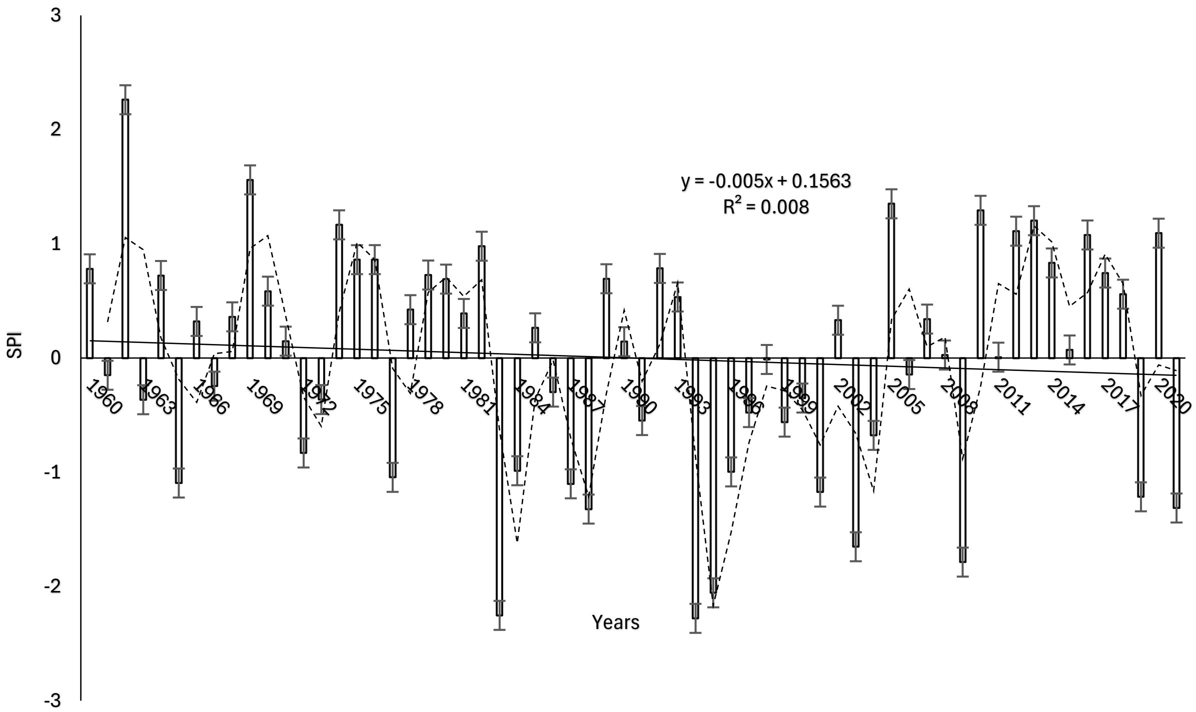
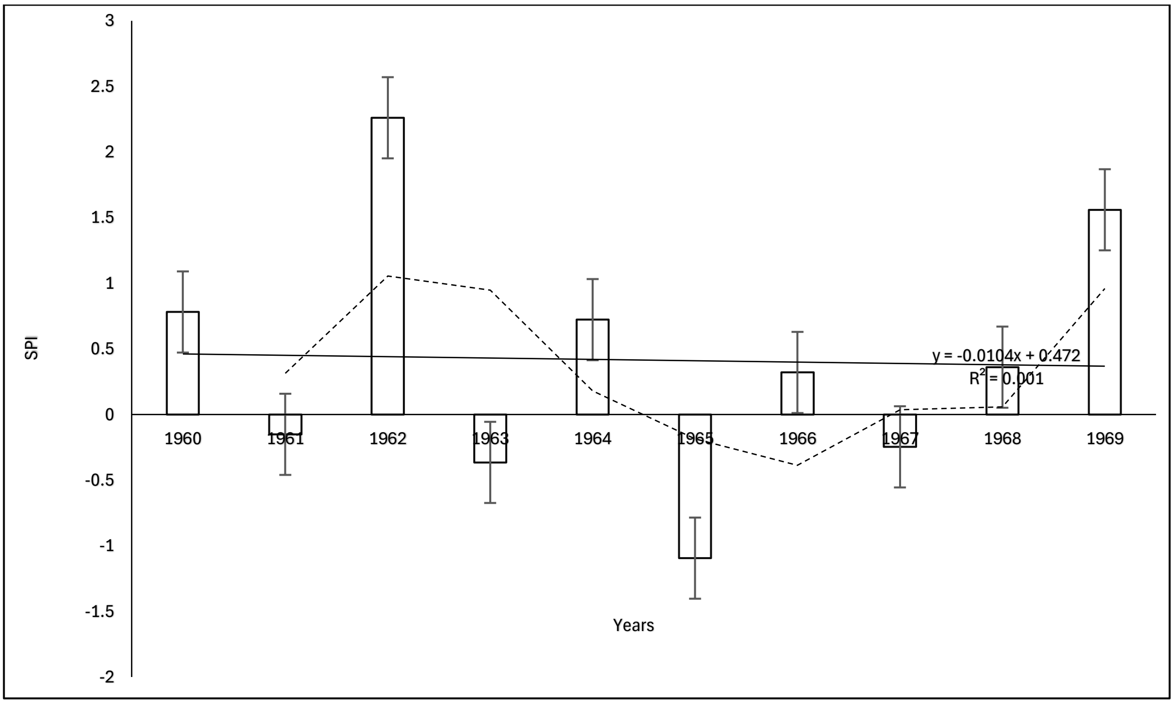


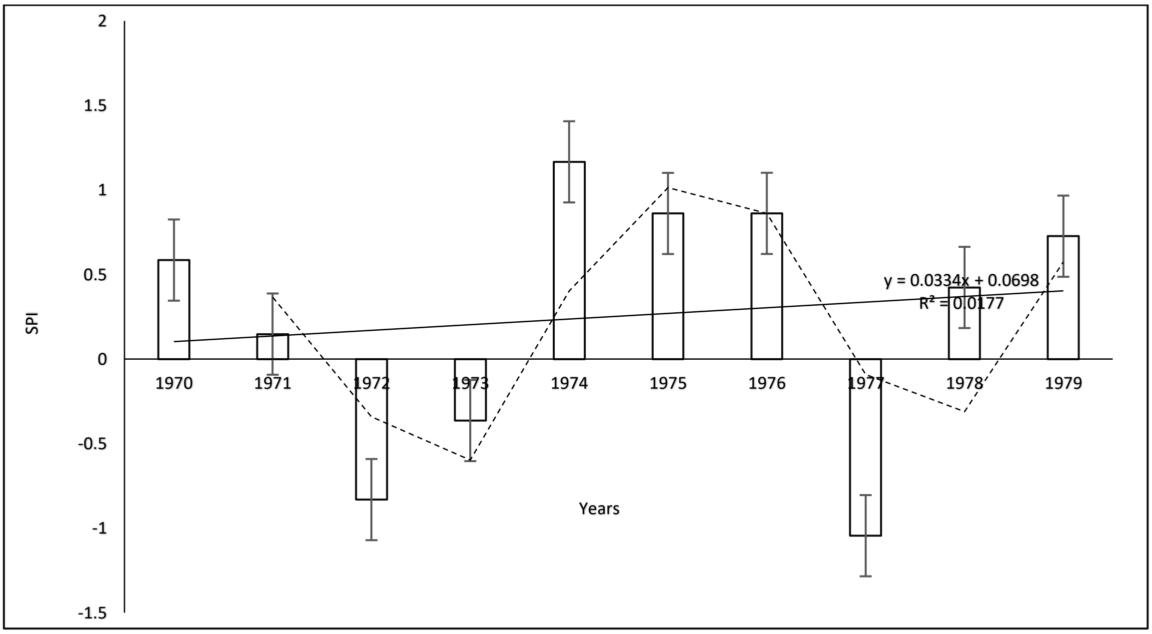

**Figure 7:** Inter-annual Standardized Precipitation Index for Koutaba (1960-2021) (Data source: Koutaba Military Airbase, 2023)

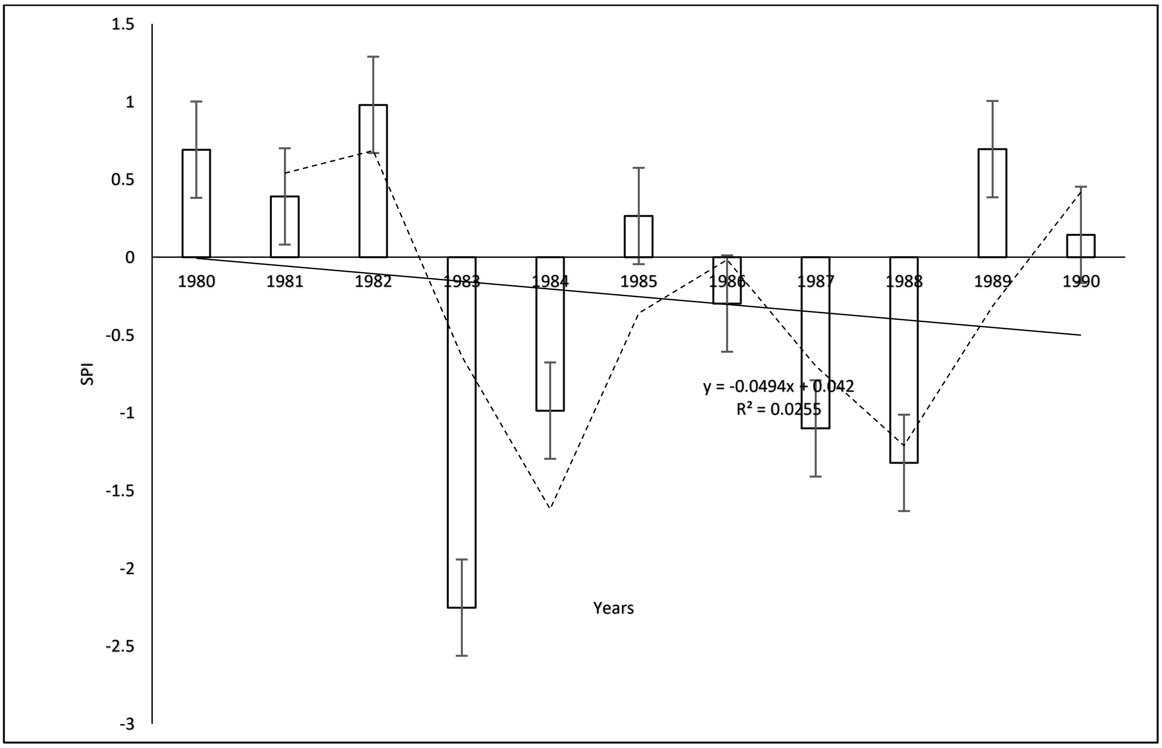
The reduced rainfall resulted in decreased water availability in rivers, lakes, and groundwater systems. As a consequence, river flows diminished, and water tables dropped, influencing the hydrological balance in the region. Water scarcity affected the availability of water for various purposes like irrigation, drinking, and domestic use, thereby challenging the local hydrological infrastructure. Decreased rainfall and higher temperatures adversely affected agricultural activities in Koutaba. Insufficient water availability limited irrigation capabilities, hampering crop growth and productivity. The reduced precipitation also led to soil moisture deficits, adversely impacting crop yields and overall agricultural sustainability. Moreover, prolonged drought periods and altered temperature regimes potentially intensified pest and disease occurrences, exacerbating agricultural challenges further. The changing climatic conditions during the 1960-2021 period in Koutaba, characterised by increased temperature and decreased rainfall, had significant implications for hydrology and agriculture. The reduced water availability, accompanied by elevated evaporation rates, challenged the local hydrological systems, while the agricultural sector suffered from water scarcity, reduced crop yields, and increased vulnerability to pests and diseases. Such impacts highlight the importance of understanding long-term climate trends and their consequences for effective water resource management and agricultural planning in the region. However, this agricultural community also witnessed extreme rainfalls in 2019, which led to floods that hindered yields and resulted in water-related illnesses, which affected so many inhabitants.

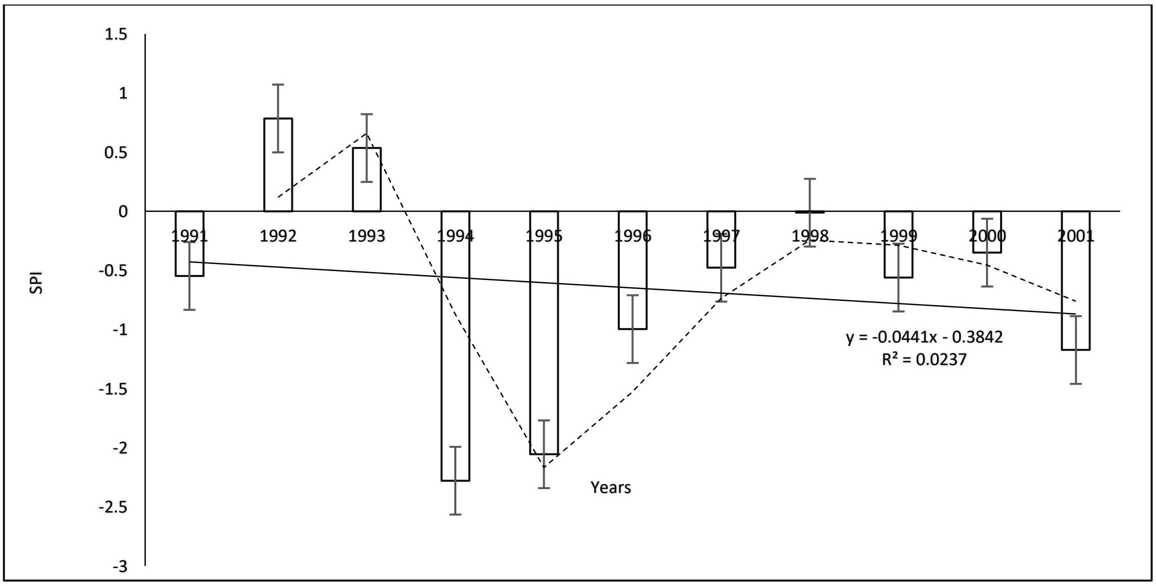
### *3.2.3 Decadal Standardized Precipitation Index 1960-1969*

Decadal analysis of SPI gives a clearer picture of the rainfall trend in Koutaba. The 1960-1969 decade was characterised by a near-stable rainfall trend (Figure 8).




2
1.5
1
0.5
0
-0.5
-1
-1.5
SPI
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
Years
y = 0.0334x + 0.0698
R² = 0.0177


1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
SPI
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
Years
y = -0.0494x + 0.042
R² = 0.0255


1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
SPI
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Years
y = -0.0441x - 0.3842
R² = 0.0237

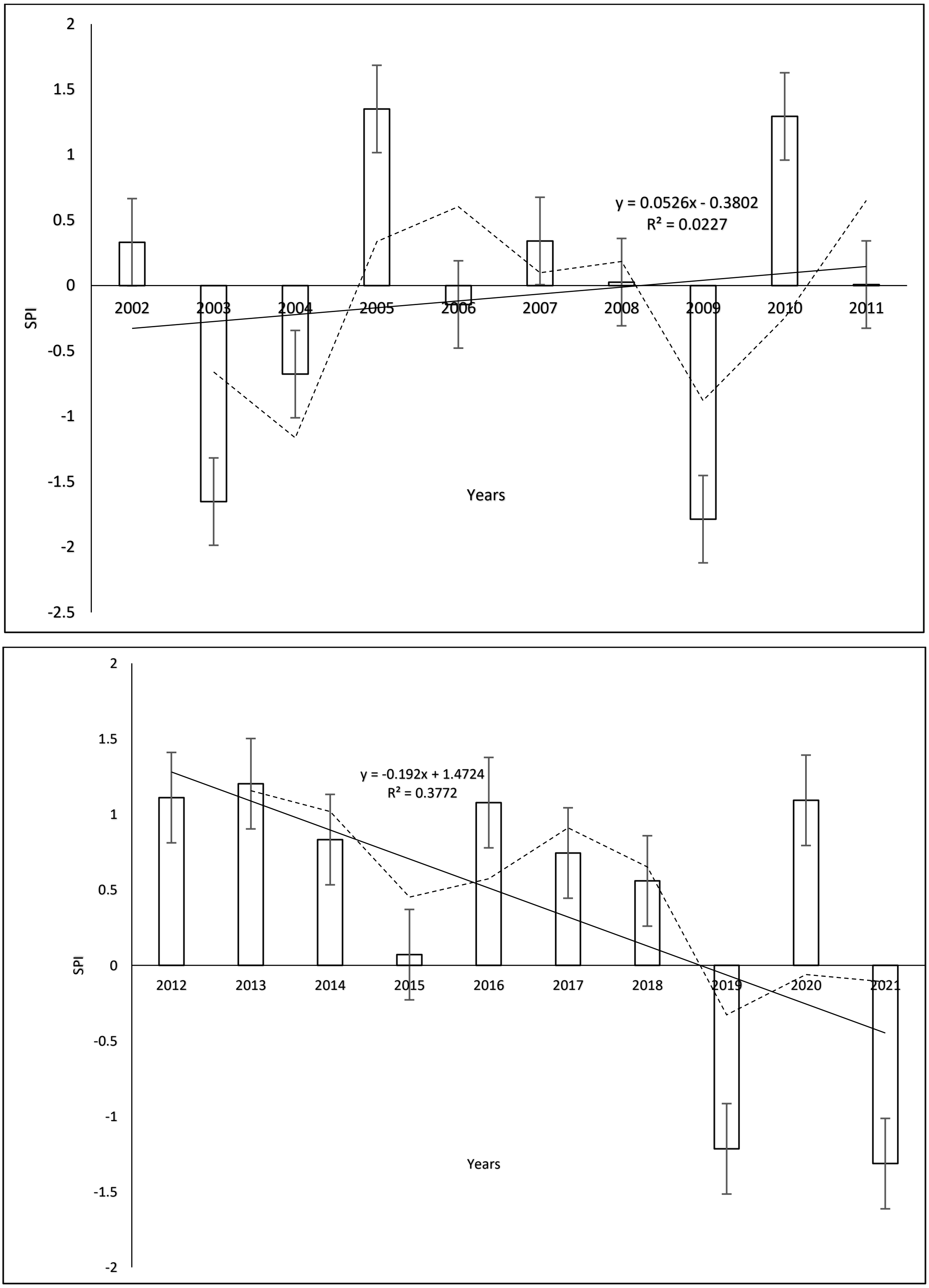



**Figure 8:** Standardized Precipitation Index trend for Koutaba (1960-2021) (Data source: Koutaba Military Airbase, 2023)

***1970-1979***

The mean SPI was 0.42 (mildly wet conditions). The rainfall pattern was reliable with a Coefficient of Variation of 11.55%. The 1970-1979 period was marked by an increasing rainfall trend.

***1980-1990***

The mean SPI was 0.25 (mildly wet), with a reliable CV of 9.14%. From 1980-1990, there was a decrease in rainfall below the average.

***1991-2001***

The mean SPI was -0.25 (mild dryness), with a reliable CV of 13.17%. The 1991-2001 decade was characterised by a decreasing rainfall pattern below the average, as in the 1980-1990 decade.

***2002-2011***

The mean SPI was -0.65 (mild dryness), with a reliable CV of 12.83%. From 2002-2011, the rainfall trend witnessed an increase.

***2012-2021***

The mean SPI was -0.09 (mild dryness), with a reliable CV of 13.52%. From 2012-2021, there was a steep decrease in rainfall. The mean SPI was 0.42 (mildly wet) and a reliable CV of 10.79%.

### *3.2.4 Temperature Trend*

The temperature trend in Koutaba, like in other areas in the tropical grasslands, has witnessed a steady increase (Figure 9).

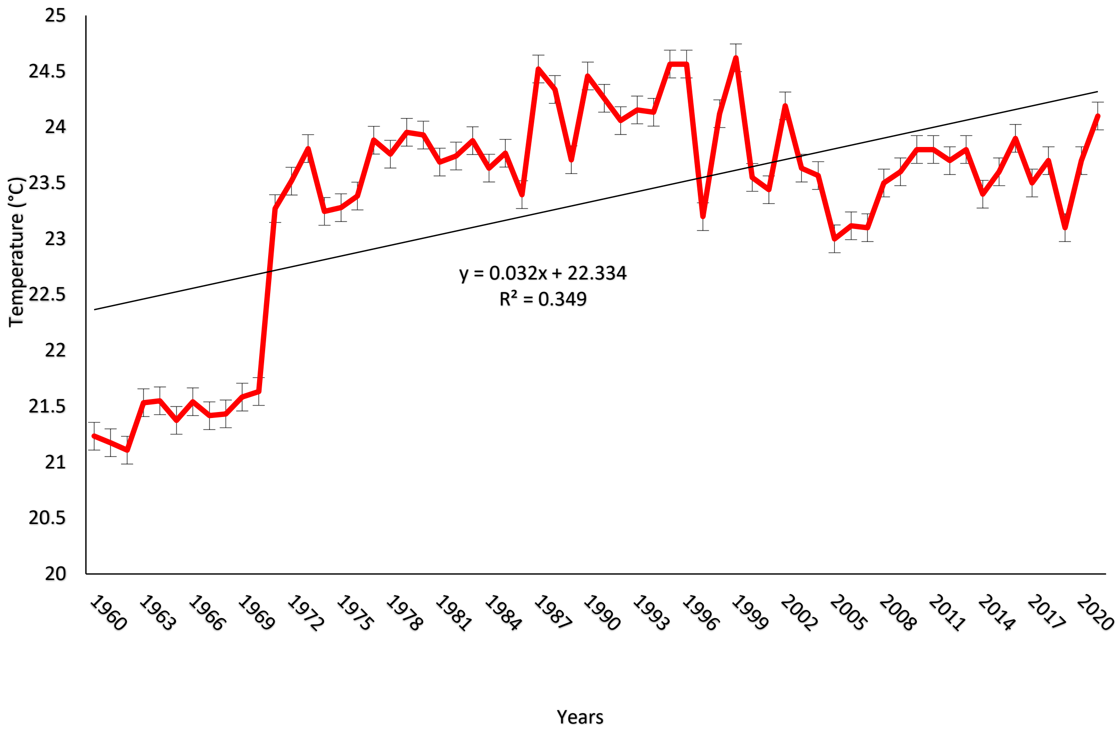



**Figure 9:** Inter-annual temperature trend for Koutaba (1960-2021) (Data source: Koutaba Military Airbase, 2023)

From 1960 to 1972, temperatures rose gradually, and from 1972 to 2002, temperatures rose to extremes. From there, the temperatures reduced, and as of 2020, temperatures began to rise significantly. Global temperatures have undergone periods of enhanced warming and pause over the last century, with greater variations at local scales due to internal variability of the climate system. There has been great interest in Koutaba recently, given the fluctuations in climate in recent decades concerning extreme values of temperature that have been observed, particularly during the warmest part of the year in December, January, and February, the period preceding the onset of the rainy season. Such observations are consistent with global trends in temperature.

Decadal climate variability (DCV) is the variations in global and regional climate that distinguish one decade from another. DCV can arise from internal interactions within the climate system and in response to external forces. From 1960 to 1969, this decade was marked by fluctuation in temperatures, with the lowest being 21.10°C and the highest being 21.64°C. From 1970 to 1979, this decade was marked by fluctuation in temperatures, which, however, has increased compared to the previous decade (1960-1969), with the lowest being 21.63ºC and the highest being 23.95ºC. From 1980 to 1990, this decade was marked by a decline in temperatures, which, however, has increased across the years compared to the previous decade (1970-1979), with the highest at 23.95ºC, declining to 23.95ºC and sharply increasing to the highest being 24.55ºC in 1987 and to 24.48ºC in 1990. From 1991 to 2001, this decade was marked by a normal temperature flow range till about 1997 when there was a sharp fall in temperature.

In 2002, temperatures dropped from 24.19% to 23.00% in 2005 and by 2008, there was an increase to 23.5ºC. In this decade, from 2011 to 2021, the temperatures fluctuated; however, they increased in 2020. The results reveal that for Koutaba (2011-2021), high temperatures were recorded in 2016, 2020, and 2021. On the other hand, in some years like 2011, 2012, 2013, 2015, and 2018 temperatures were fairly normal, and in 2014, 2017, and 2019, the deficits in temperatures were records. In summary, rainfall and temperature in Koutaba have been oscillating like in other locations around Cameroon and the wider tropics. Most of the decades have witnessed decreasing rainfall (1980-1990, 1991-2001, 2012-2021), while most of the decades have witnessed increasing temperatures (1960-1969, 1970-1979, 1980-1990, 2002-2011) (Table 4).

**Table 4:** Summary of Rainfall and Temperature Characteristics for Koutaba

| Decades | MRF (mm) | Mean Temp (ºC) | Mean SPI | RSD | RCV (%) | Rainfall trend | Temperature trend | SPI class | Rainfall reliability |
|---|---|---|---|---|---|---|---|---|---|
| 1960-1969 | 167.83 | 21.37 | 0.42 | 19.38 | 11.55 | Near stable | Increasing | Mildly wet | Reliable |
| 1970-1979 | 164.63 | 23.37 | 0.25 | 15.03 | 9.14 | Increasing | Increasing | Mildly wet | Reliable |
| 1980-1990 | 154.56 | 23.91 | -0.25 | 20.36 | 13.17 | Decreasing | Increasing | Mild dryness | Reliable |
| 1991-2001 | 146.75 | 24.06 | -0.65 | 18.83 | 12.83 | Decreasing | Decreasing | Mild dryness | Reliable |
| 2002-2011 | 160.3 | 23.56 | -0.09 | 21.52 | 13.52 | Increasing | Increasing | Mild dryness | Reliable |
| 2012-2021 | 167.12 | 23.66 | 0.42 | 17.97 | 10.97 | Decreasing | Stable | Mildly wet | Reliable |
| Mean | 160.20 | 23.32 | 0.02 | 18.85 | 11.86 | Decreasing | Increasing | Mildly wet | Reliable |

MRF: mean rainfall; RSD: rainfall standard deviation; RCV: rainfall coefficient of variation

Despite these oscillations, rainfall is still reliable for agriculture and other rain-fed systems in the Koutaba Municipality.

## 4. Climate and Agricultural Planning Implications

Hydro-meteorological services for agriculture refer to the provision of weather, climate, and water information and services to farmers, land managers, and other stakeholders in the agricultural sector. These services aim to help farmers make informed decisions about planting, harvesting, and managing their crops and resources in an efficient, sustainable, and climate-resilient manner. Some of the hydro-meteorological services for agriculture in the Koutaba Sub-Division include Weather forecasting and monitoring: Providing information on current and future weather conditions, such as temperature, precipitation, wind, and humidity, to help farmers plan their agricultural activities. Soil moisture and water management: Providing information on soil moisture levels and water availability to help farmers manage irrigation and other water-related activities.

Providing information on pest and disease outbreaks and how to control these outbreaks using weather and climate information. Climate risk management: Providing information on climate variability and change, and how to adapt agricultural practices to reduce the negative impacts of climate change on crops and livelihoods (Table 5). Regarding livelihoods, the inhabitants of the study area employ self-weather prediction, which had an agreeable rate of 55.5%. This margin informed the researcher that the inhabitants have older traditions of relying ad predicting weather and season, and even the outcome of the seasons. Further, the population of the study area depends on rain-fed agriculture, with 85.8% of inhabitants confirming that they are dependent on rain for agriculture.

**Table 5:** Hydro-meteorological needs for agriculture in Koutaba Sub-Division

| Services | Yes (%) | No (%) |
|---|---|---|
| Use water for irrigation | 76.7 | 23.3 |
| Have enough water for home use | 80.0 | 20.0 |
| Sources of water are safe for drinking | 70.8 | 29.2 |
| Dependence on rain for agriculture | 85.8 | 14.2 |
| Self-prediction of weather and seasons | 55.0 | 45.0 |
| Traditional weather prediction | 30.8 | 69.2 |
| Use meteorological services | 57.5 | 42.5 |

Market gardeners do not depend only on rain to carry out their farming activities, but also carry out irrigation, especially during the dry season, to be able to feed the growing population in all seasons, having 76.7% of the population attesting to it. They also agreed with 80% that they have enough water, which is mostly from rain during the rainy season and from boreholes, which are a common source of water in Koutaba. It can also be noticed that 80% of the population believes that they have enough water for home use, which means that if there is enough water for home use, then there will be water available for agriculture.

Assessment of meteorological information needs during the crop production cycle involves identifying the types of weather and climate information that farmers require at different stages of the crop production cycle, from planning and preparation to planting, growth, and harvest. Some of the assessments that may be done to determine meteorological information needs during the crop production cycle include: Understanding the local climate and weather patterns: This involves analysing historical climate data and weather records to identify long-term trends and patterns in the local climate. Identifying the most critical stages of the crop production cycle: This involves determining the stages of crop growth and development that are most sensitive to weather and climate conditions, such as planting, germination, flowering, and maturity. Assessing the vulnerability of crops to weather and climate hazards: This involves identifying the risks that weather and climate hazards pose to crops, such as drought, floods, heat waves, pests, and diseases (33.33%) (Table 6).

**Table 6:** Meteorological information needs for crop production

| Meteorological Information | SA (%) | A (%) | SD (%) | D (%) | N (%) |
|---|---|---|---|---|---|
| During land preparation | 24.17 | 46.67 | 5.00 | 5.83 | 18.33 |
| During planting preparation | 39.17 | 43.33 | 3.33 | 5.83 | 8.33 |
| During weeding | 22.50 | 49.17 | 10.83 | 11.67 | 5.83 |
| In pest and disease control | 25.00 | 33.33 | 10.00 | 20.00 | 11.67 |
| During harvesting | 35.83 | 34.17 | 7.50 | 9.17 | 13.33 |

Evaluating farmers' current meteorological information sources and practices: This involves analysing how farmers currently access and use meteorological information, such as through local weather stations, mobile phone apps, or extension services. Identifying gaps and needs in existing meteorological information services: This involves identifying the types of meteorological information that farmers currently lack or need to make better decisions about their crops and resources. Information is needed during land preparation (46.67%), during planting (43.33%), during weeding (49.17%), pest and disease control (33.33%), and harvesting (35.83%). However, not everyone in the study area believes that they need meteorological information, especially during pest and disease control.

### 4.1 Changes in Crops Cultivated

Koutaba has witnessed a small shift from traditional crops to cash crops, crops such as maize, cassava, and plantains, to cash crops such as rice, coffee, tomatoes, and oil palm. This shift has been driven by market demand and the potential for higher profits from cash crops. Farmers in Koutaba have started cultivating new crop varieties that are more resilient to climate change, pests, and diseases. These crops include drought-resistant maize varieties, disease-resistant cassava varieties, and high-yielding hybrid varieties of crops. Farmers in Koutaba have engaged in crop diversification to reduce risk and improve resilience to changing environmental conditions.

Farmer's perceptions of crop production in Koutaba are shaped by a complex interplay of practical, economic, cultural, and environmental factors, and these perceptions have influenced their decision-making and approach to farming. For many farmers, crop production is deeply connected to their livelihoods and cultural traditions. They perceive farming as a way of life that is tied to their identity and heritage, and they may prioritise preserving traditional farming practices while also seeking opportunities for economic advancement. Farmers understand the importance of selecting the right crops to cultivate based on factors such as soil fertility, climate suitability, and market demand. They perceive crop selection as a critical decision that can significantly impact their overall success and profitability. Farmers often perceive crop production as a risky endeavour due to factors such as unpredictable weather patterns, pest and disease outbreaks, and market fluctuations. They are concerned about the potential for crop failure and the financial implications of such risks. These factors have shaped the perceptions of farmers in Koutaba and have accounted for the shift in crop production. This is evident in cultivating a mix of crops such as grains, legumes, fruits, and vegetables to spread out the risk of crop failure. Increased adoption of modern farming techniques such as irrigation, mechanisation, and the use of fertilisers and pesticides to improve crop yields and productivity. This has led to the cultivation of a wider range of crops that require these modern techniques for successful cultivation.

Actual crop production data for the Koutaba Sub-Division shows great variability from 2006 to 2023 (Table 7, Figure 10).

| **Table 7:** Summary of crop production trend in Koutaba (2006-2023) | | | |
|---|---|---|---|
| **Crops** | **Average output (tons)** | **Output change (tons)** | **Production trend** |
| Maize | 57033 | 44049.12 | Increasing |
| Yams | 484.94 | -12498.93 | Decreasing |
| Groundnuts | 21955 | 8971.12 | Increasing |
| Beans | 37151.06 | 24167.18 | Slight decrease |
| Cocoyam | 5684.61 | -7299.27 | Decreasing |
| Soybeans | 2962.89 | -10020.99 | Decreasing |
| Cucumber | 292.78 | -12691.10 | Decreasing |
| Tomatoes | 26946.92 | 13963.04 | Stable |
| Solanum potato | 185.72 | -12798.16 | Increasing |
| Arabica coffee | 628.67 | -12355.21 | Decreasing |
| Robusta coffee | 3546.72 | -9437.16 | Decreasing |
| Cocoa | 63.39 | -12920.49 | Decreasing |
| Sweet potato | 41159.41 | 28175.53 | Decreasing |
| Plantain | 4548.11 | -8435.77 | Decreasing |
| Banana | 4476.94 | -8506.93 | Decreasing |
| Pears | 621.89 | -12361.99 | Decreasing |
| Average | 12983.88 | 0.00 | Decreasing |

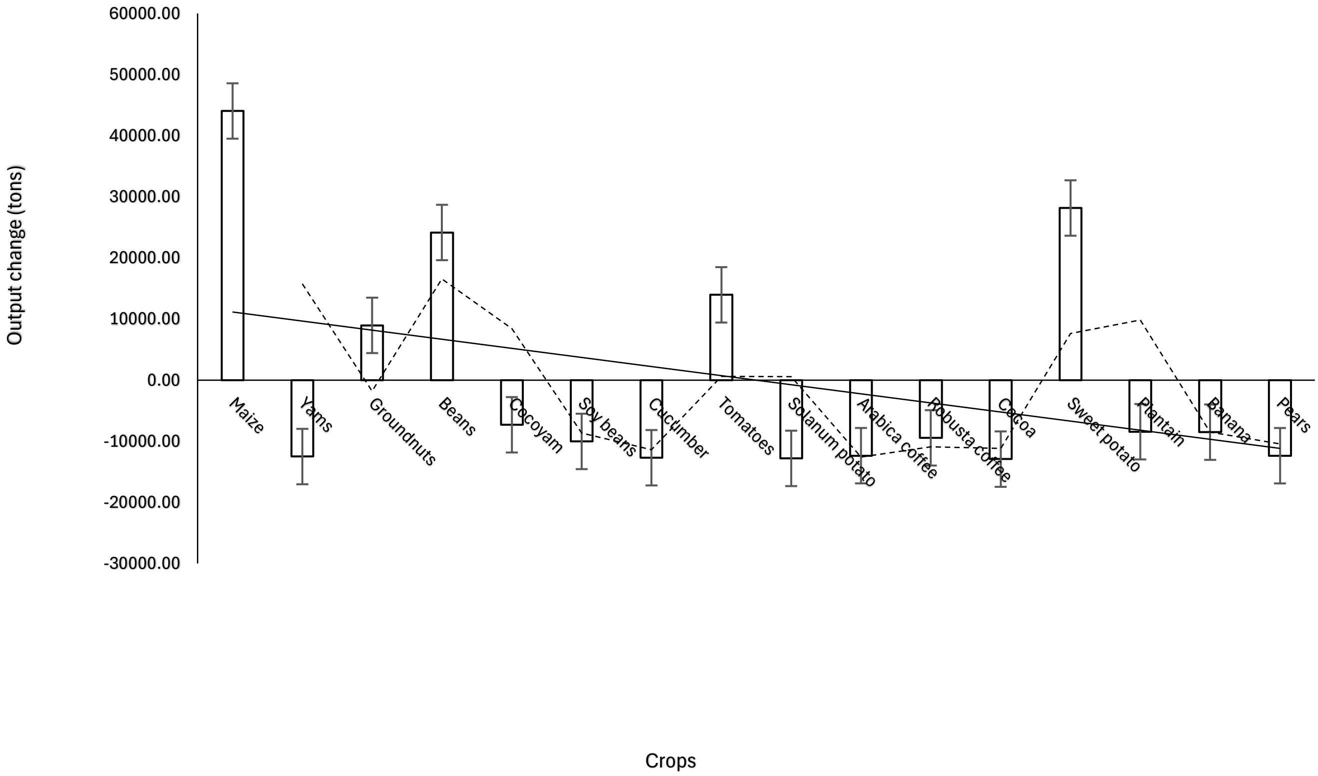



**Figure 10:** Summary of crop production trend in Koutaba (2006-2023)

Eight (8) of the crops (yam, cocoyam, cucumber, Arabica coffee, cocoyam, sweet potato, plantain, and pears) are decreasing in production. This has given a general decreasing trend in the study area.

## 5. Discussion

Accurate and timely data on crop production is essential for effective decision-making in agriculture. Analysing factors such as yield, acreage, and crop types serves as a vital indicator of agricultural productivity. This information not only guides farmers and policymakers but also enhances our understanding of how agricultural practices adapt to changing climate conditions and market demands. Climate variability is a significant concern for farmers and other stakeholders in the agricultural sector due to its substantial impact on livelihoods. In the Koutaba Municipality of Cameroon, researchers have discussed the effects of climate variability on agriculture and hydrology, providing valuable insights into this issue.

The exploration of different crop production systems highlights the diverse agricultural practices employed worldwide. From traditional subsistence farming to modern, technology-driven agriculture, each system presents unique challenges and opportunities. The findings emphasise the importance of understanding these systems to tailor interventions that meet the specific needs of various farming communities while promoting sustainable practices. Over the years, shifts in crop varieties and practices have reflected broader agricultural trends influenced by climate variability, environmental factors, market dynamics, and technological advancements. For example, the rise of climate-resilient crop varieties demonstrates the agricultural sector's response to increasing climate variability. Understanding these changes is crucial for predicting future agricultural trends and ensuring that food systems can adapt to ongoing environmental pressures. The analysis of land cover and land change in Koutaba reveals the significant impacts of agricultural expansion, urbanisation, and deforestation on ecosystems. Changes in land use not only affect biodiversity but also alter the carbon dynamics of regions, which have implications for climate change mitigation.

Researchers have specifically examined the agricultural effects of climate variability. For example, a study investigated the impact of climate variability on various sectors in Sub-Saharan Africa (Boko et al., 2007). The findings revealed that changes in rainfall patterns and temperature have adversely affected crop production. Similarly, it emphasised that crop production is declining in the Western Highlands of Cameroon as a result of climatic shocks, which invariably affect other production factors, including land cover change (Tume et al., 2020). Additional studies found that regions in the Bamenda Highlands of Cameroon are particularly vulnerable to climate change and food insecurity (Tume et al., 2019; Ngwani et al., 2024a, b; ume et al., 2024). Increased occurrences of droughts, floods, and pests have negatively impacted agricultural productivity. The studies stress the necessity for climate-resilient agricultural practices, improved water management, and support for local adaptation strategies.

## 6. Conclusion

Climate variability significantly affects agriculture, agricultural systems, crop production, and water-related issues in Koutaba. The region has seen changes in rainfall patterns, prolonged dry spells, rising temperatures, and shifts in pest and disease occurrences, all of which negatively impact crop productivity and agricultural systems. These changes have led to food insecurity, reduced income for farmers, and an increased risk of water-related problems such as drought, erosion, and decreased soil fertility. To mitigate the impacts of climate variability on agriculture, farmers must adopt climate-smart farming practices and implement strategies that conserve water and enhance soil fertility. This requires the use of sustainable and resilient agricultural systems capable of withstanding the challenges posed by climate variability.

The effects of climate variability on agriculture and livelihoods are complex and can vary based on local climate conditions, farming practices, and available resources. Local interventions, such as organising water-efficient farming techniques and implementing drip irrigation, can help farms adapt to changing climate conditions and protect rural livelihoods. Governments, NGOs, and international aid agencies can support the promotion of sustainable farming practices, including the management of fisheries, livestock, and forestry, to mitigate climate-induced impacts. Adopting water-efficient technologies and practices, such as drip irrigation, rainwater harvesting, and precision agriculture, can address challenges related to water use in agriculture. This paper emphasises the importance of sustainable land management practices that balance agricultural needs with environmental preservation.

The insights gained from this study highlight the urgent need for integrated approaches to crop production that consider ecological, social, and economic dimensions. Future research should focus on these aspects. As we navigate the complexities of crop production in a rapidly changing world, it is clear that a multifaceted approach, informed by robust data and scientific research, is essential. The findings presented illustrate the interconnectedness of crop production data, systems, and land cover dynamics, underscoring the necessity for cooperation among farmers, researchers, policymakers, and communities to foster sustainable and resilient agricultural practices. By doing so, we can ensure that agriculture continues to play a crucial role in food security and socio-economic development while also protecting the environment for future generations.

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