Original Research Article

Examining the vulnerability of agropastoralists to climate change and evaluating adaptation strategies in Mali

Abstract

In Mali, like other developing countries, agropastoralists are particularly vulnerable to the effects of climate change. Despite the important role agriculture and livestock play in the economy and sustaining livelihoods, these sectors face climate challenges. This study aims to examine the impacts of climate change agropastoralists and to evaluate the adaptation strategies in Mali. To this end, an analysis of daily rainfall and temperature data from 1960 to 2020 over Bamako, Ségou and Sikasso station was carried out using Instat+ v3.36, Rstudio, XLSTAT and Rclimdex software. Field surveys were conducted among 355 agropastoralists in three regions of Mali to assess the impacts and adaptation strategies of agropastoralists. The analysis of climate data showed a downward trend in overall rainfall. As for the temperature, it shows an upward trend over the series from 1960 to 2020 at the station of Ségou, Sikasso and Bamako. According to Bamako area, the annual average of maximum temperature is 34.72°C in the period from 1960-2020 times series with increase of +0.16°C. As regards to Ségou region, the upward trend in average annual temperatures was 0.51°C with an average temperature of 36.23°C; however, in Sikasso region the maximum temperature was 33.85°C with an average annual trend of 0.58°C. The results from agropastoralists surveyed analysed revealed that a rise in temperatures, a change in precipitation patterns, an intensification of extreme events such as drought, low rainfall of 50.99%, high heat of 24.79%, strong winds. 81.97% of agropastoralists surveyed said that the current sowing date is later than in the past. Adaptation strategies relating to the improvement of agricultural production, the management of water resources and vegetation were proposed. These include the use of: organic manure, the conservation of crop residues to restore soil fertility, mulching, the use of early varieties, the adoption of new species or varieties, the sowing of early or drought-resistant varieties.

Keywords: Impacts of climate change, Agropastoralists, Adaptation Strategies

1. Introduction

Climate Change is a serious problem for the whole world, it is explained by an upward trend in temperatures measured during the last decades of the 20th century and also a decrease in increased variability of precipitation (Levine and Steele, 2021). According to the Intergovernmental Panel on Climate Change (IPCC) 2007, in its fourth report which more than 2500 scientists and from 130 countries participated, says that it is very likely that 90% of observed global warming has been man-made since 1950 (Idso et al., 2015). According to the IPCC (2013), it is extremely likely that at 95%, human influence has been the main cause of global warming (IPCC, 2013 a). The global average surface temperature on a linear trend, combined with that of land and oceans, indicates a warming of 0.85°C over the period 1880 - 2012. According to the IPCC, this increase in the average temperature on the surface of the globe can cause negative and localized impacts in particular on the agricultural sectors with a downward trend in crop yields (IPCC, 2013). Grazing for animal feed is also subject to climatic vagaries. This high climate variability is a major constraint on the environment and sustainable development (Kongnso et al., 2021). Indeed, it remains one of the greatest challenges facing humanity today.

Africa is the continent most vulnerable and impacted by the adverse effects of climate change. It faces the toughest challenges to adapt, despite contributing less to global greenhouse gas emissions. It is compromising that it is a serious threat to growth and sustainable development. The fifth report of the IPCC (2013), revealed that the period 1983-2012 was probably the warmest 30-year period. Agropastoralism is defined as the practice of agriculture and livestock farming allowing peasant societies to extensively produce the resources necessary for their needs (Marega and Mering, 2018). Thus agro-pastoralists farm during the rainy season and go on transhumance during the dry season in order to take advantage of pastoral resources (water, fodder) which are often distributed randomly in space and time.

Sahelian agro-pastoralists faced with unprecedented socio-environmental changes, challenges, risk and threat of climatic effects, practice transhumance which is one of the ways of adapting to the high climatic variability and the threat of drought that the Sahel has experienced since more than 50 (fifty) years in an economic, social and political context that is more mobile (Birch and Grahn, 2007; Douxchamps et al., 2014; Altieri et al., 2016; Leal Filho et al., 2020). Mali, like other Sahelian countries, agro-pastoralists are vulnerable to the effects of the climate, for which there are few resources to deal with. Indeed, out of a total area of the country of 1.24 Mkm^2, 51% is made up of desert land. Cultivated areas represent 4.8Mha, or

4% of the territory. (ADF, 2011; PDA, 2013) The country's agricultural production remains dependent on rainfed activities, especially in certain arid regions (Kidal, Gao, Ménaka, Timbuktu, Taoudéni) experiencing shortages during the lean season. Mali is a country with an agro-pastoral vocation, the agricultural sector of the country occupies an important place in the Malian economy (FAO, 2017a). Agriculture occupies 80% of the active population, of which 75% of active workers are agro-pastoralists, 10% exclusive stockbreeders and 9% exclusive farmers (Hilson and Garforth, 2012; Sanogo et al., 2017). The cattle herd is the largest in West Africa, thus the livestock sector contributes 8.5% of GDP (2007) (UNDP, 2016). the country's agricultural sector occupies an important place in the Malian economy (Braun and Traore, 2015; Brottem and Ba, 2019; Hilson and Garforth, 2012). Consequently, the highly variable climatic conditions affect production and agricultural yield linked to climatic events such as the overall decrease in precipitation, the increase in temperatures, the seasonal calendar shift and the progression of desertification, extreme weather events, such as droughts and floods (Motha, 2007). This climatic variability aggravates anthropogenic pressures on land, water and various natural resources. Livestock is the main economic activity of populations in the semi-desert regions of the north (Liang et al., 2020), whose environmental conditions do not allow the cultivation of cereals. It is an essential activity historically carried out by nomadic Moorish and Fulani populations (Ciavolella, 2012).

The economic activities of the country whose rainfall is irregular, the population carries out agricultural and livestock activities which are diverse. The expansion of agriculture, which is combined with climatic effects, affects the traditional migration routes of herders (Ayele and Tarekegn, 2020; Unc et al., 2021). With today's climatic conditions, breeders have become more and more sedentary and diversified in fishing and agriculture, adding additional stress to the competition for natural resources and access to arable land (De Saulieu and Testart, 2015; Fanzo et al., 2013; Hilson and Garforth, 2012). These different activities are abundantly exposed to the harmful effects of climate change, then the drought threatens the livestock and consequently weakens. Livestock contributes in the different areas of the country to the advance of desertification, because the animals feed on young shoots, preventing reforestation. Poverty, insecurity, overexploitation of natural resources and the effects of climate change are driving herders towards transhumance.

The ever-increasing proximity of livestock to fields and the increased potential for damage to plantations has increased the risk of conflict between herders and farmers (Gaye, 2018; Chukwuma, 2020). It is in these contexts that understanding the various pressures exerted on the use of natural resources is imperative for agricultural productivity and the feeding of livestock in Mali. Agricultural production systems are exposed to climate change as soon as they mobilize climate-dependent resources. The challenge for the scientific community is to produce knowledge enabling practitioners to anticipate the effects of climate change on production systems, and to develop methods and tools to adapt to them. Grassland farming systems are particularly affected by climate change given that they depend on fodder resources, the seasonality and productivity of which are strongly linked to the climate (Rivera-Ferre et al., 2016). Their adaptation to climate change requires anticipating trends and inter-annual variability.

The objective is to provide advice on the main issues that highlight the challenges in order to learn more about the reality of climate change in agro-pastoral environments of which it is necessary to find adaptation strategies to deal with the impact of climate change on agro-pastoralists in Mali. This will make it possible to integrate agricultural and animal adaptation measures to ensure food security and prevent the risk of food crises.

2. Materials and Methods

1.1.Study zone

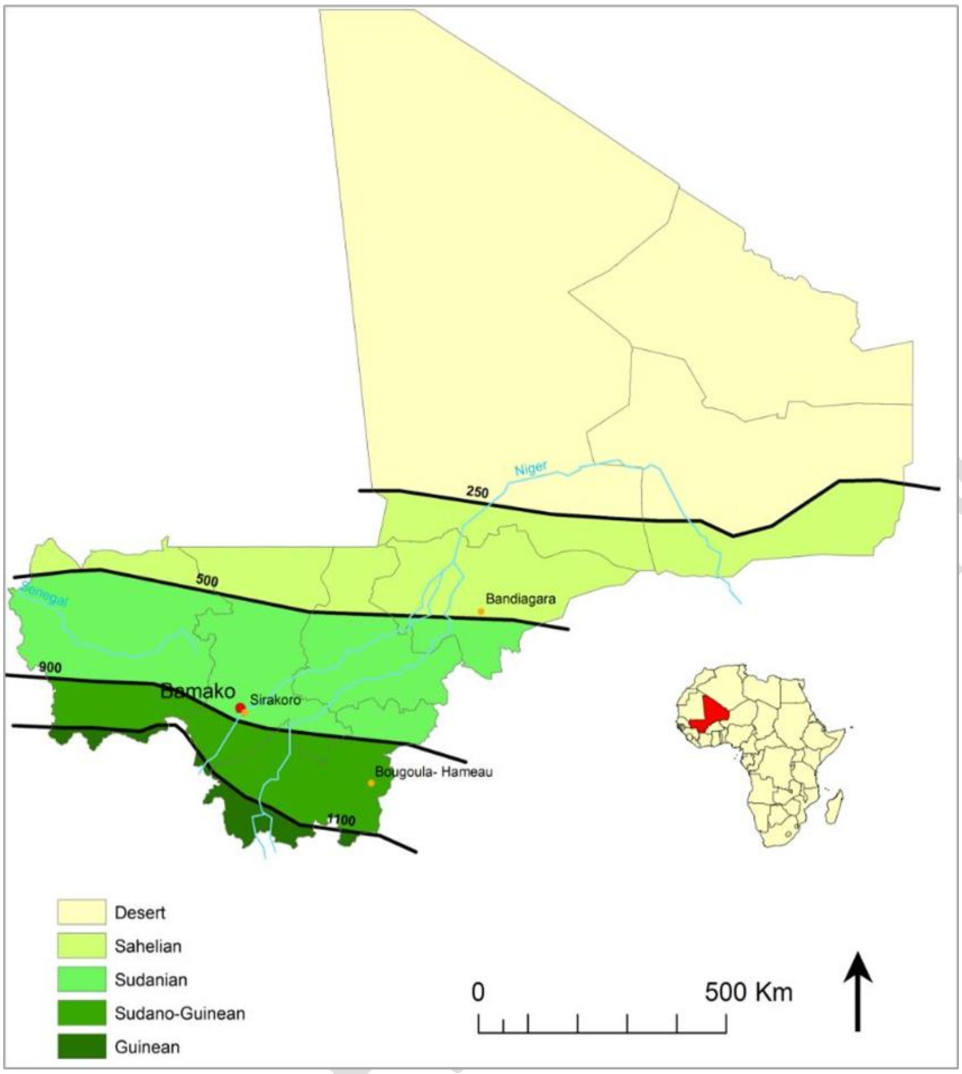
Mali is a vast continental country in West Africa, with a population of 20,137,527 million inhabitants spread over an area of 1,241,238 km². Mali is divided into fourteen (14) regions and one (01) district. These subdivisions are named after their main city. The three northern regions (Gao, Kidal, Timbuktu, Taoudéni, Ménaka) represent two-thirds of the country's surface area for only 10 percent of its population (World Bank, 2019). The country shares its borders with seven other countries Algeria to the north, Niger to the east, Burkina Faso and Côte d'Ivoire to the south, Guinea to the southwest, Senegal to the west, and Mauritania to the west and northwest. Most of the population lives in rural areas. The country's economy is based on agriculture, livestock and fishing (IFAD). In Mali, 60% of the population live in rural areas, where the incidence of poverty is 53%. Agriculture occupies more than 75 percent of the active population. Farmers and agro-pastoralists form the poorest strata of society: the poverty rate there reaches 57% (IFAD, 2020).

Mali has areas of cultivable Arab land and cropland occupies 4.7 million ha or 4% of the territory (FAO, 2017b). Slightly ferralitic soils occupy nearly 2 million ha in the extreme south of the country, tropical ferruginous soils cover approximately more than 17 million ha in the northern Sudanian zone and the Sahelian zone. The northern Sudanian and southern Sahelian zones are arid-type soils (FAO, 2017).

The country has three climatic zones:

- The northern two thirds of the country, entirely desert, belong to the southern Sahara, with annual rainfall of less than 127 mm This region is crossed by nomads with their herds (Mougin et al., 2009; Hereher, 2011);
- The centre: the Sahelian region, relatively dry (with relatively insufficient tropical rain), is covered with steppe gradually replaced by savannah towards the south. The Niger Valley is cultivated thanks to some development work: rice, cotton, shea, groundnut, millet, sorghum, corn; (average precipitation in between 300 and 600 mm). However, these amounts can vary greatly from year to year;
- The Sudanese region is an area with precipitation of 1,400 mm per year and average temperatures between 24°C and 32°C (Tekete and Koita, 2010; Bokar et al., 2012). It is, in its northern part, covered with savannah becoming increasingly dense and gradually turning into forest towards the south (Bucini and Lambin, 2002; Laris, 2011).

The relief is slightly accentuated. The alluvial plains, very vast, are however dominated by some limestone and sandstone plateaus (Mandingo and Dogon plateaus) (Gabriel, 1987; K. Traore et al., 2016). Mali’s highest peak is Mount Hombori (1,155 m) (Walther et al., 2009; Hallett, 2018; Apriliani et al., 2021).



Map 1: . three climatic zones of Mali

(Coulibaly et al., 2016)

1.2.Data and method of analysis

1.2.1. Survey method

Household surveys were used as a methodology during this work. To this end, a questionnaire was developed, programmed and administered through the Kobocollect tool to target groups (agro-pastoralists) and other actors in the field of climate change.

The choice of localities was based on the importance of agro-sylvo-pastoral activities in the different regions of the Republic of Mali. As for the choice of villages in the municipalities at the level of the various targeted regions, it was made taking into account the accessibility due to insecurity (jihadism and banditry) of which more than 2/3 of the country escapes the control of the Malian authorities.

Quantitative and qualitative surveys were carried out among the target groups as well as other actors in the field of climate change. The surveys were conducted using phones with the Kobocollect app installed. They involved 355 people, 39.15% of whom were women, in 33 villages in 22 communes in 14 circles and 10 regions of Mali (i.e. 52.26% coverage rate for the regions of Mali). The field survey work was supervised remotely but also through field supervision missions in the regions of Sikasso, Bougouni, Koulikoro and Kita.

The interviews carried out made it possible to collect the essential information required on:

- Modes of exploitation and management of natural resources (water, land and vegetation), agricultural production systems (plants and animals), non-agricultural production systems;
- The natural, social, human and physical resource determining the conditions of agropastoralists;
- Agropastoralists perception of climate change concerning the rainy season, temperature, water resources and their impacts on resources;
- Evaluation of endogenous adaptation strategies (strengths and weaknesses).

1.2.2. Climate data and method of analysis

In the context of this study, we used the data of daily rainfall and maximum and minimum temperatures in the regions of Mali more precisely (Bamako, Segou and Sikasso), over a period from 1960 to 2020 these data come from the database of the National Meteorological Directorate of Mali (Mali-Météo). For the statistical analyses, Instat+ version 3.36 software was used. The software was used to organize the data and make agro-climatic analyzes of trends, risks, climatic extremes, statistical calculations and graphical representations. The XLSTAT software was also used to perform rainfall and temperature rupture tests. The Excel spreadsheet was used for the entry, processing and analysis of the figures and the production of figures and graphs.

The meteorological data collected were used for the various analyses of the agro-climatic parameters.

The analyses were used to characterize and understand various climatic processes related to weather and to follow the fluctuations of meteorological elements over the long term. The analyses were carried out on:

- the precipitation anomaly and the trend of rainfall accumulations, as these play an important role in local agricultural and pastoral production, but also in the productivity of resources exploited by agropastoralists;
- the trend of the duration of the rainy seasons, the number of rainy days and the dry sequences in order to analyse the impact of climate change on agropastoralists;
- the calculation of the length of the rainy seasons through the start and end dates of the rainy season;
- the trend of maximum and minimum temperatures in order to assess local warming and deduce their impacts on the activities of agropastoralists with the software.

1.2.3. Standard anomaly analysis method (Lamb indices)

The study of climate variability and change was approached by the calculation of Lamb index which made it possible to identify the major trends in the time series (Salvati et al., 2019). It is calculated using the weighted moving average method. To better observe the periods of deficit and surplus at the interannual scale, the calculated moving averages have been centered and reduced using the standardized formula, defined as a reduced centered variable and which is the ratio of the deviations from the mean over the standard deviation.
To determine the surplus or deficit periods compared to the 1961-1990 normal, the Lamb index was used (Lamb, 1983).

$$\boldsymbol{I} = \frac{\boldsymbol{Xi} - \bar{\boldsymbol{X}}}{\boldsymbol{\sigma}} \qquad 2\text{-}1$$

- Where is the standardized anomaly (Lamb index), Xi is the variable studied for the weather or rainfall of the year (i), Ẍ is the average of the reference period considered or again Average interannual rainfall over the reference period, σ is the standard deviation of the reference period or the interannual rainfall over the reference period.

1.2.4. Criteria method for agro-climatic parameters

The criteria used to calculate the start date of the season: the rains are considered satisfied when a rain of at least 20 mm has been collected from May 1 in one or two consecutive days without a dry episode more than 10 days is observed within 30 days of (Sivakumar, 1988, 1993).

1.2.5. Start and End dates of the rainy season

For the end date of the rainy season, the criteria are based on the water balance. Such as, the rainy season is considered to be over when, from September 1, the soil water reserve is depleted by daily evapotranspiration of 5 mm and becomes constantly less than or equal to 0.05 mm. (Landry et al., 2017).

1.2.6. Length of the season

Regarding the length of the season, it corresponds to the difference between the end date and the start date of the season at a given station (Balme, 2005; Ozer, 2007).

1.2.7. Mann Kendall trend test

The Mann Kendall test, of the non-parametric type; it makes it possible to measure the degree of significance of the trend observed in the series (Lawin et al., 2011). For its implementation, one calculates for each term Xi of the series of n terms, the number Mi of preceding terms which are lower than it. The statistic dn given by equation (3.2) is the sum of the numbers thus calculated.

$$\boldsymbol{dn = \sum_1^n Mi} \qquad 2\text{-}2$$

For a large enough number n of year of observations, dm follows a normal distribution (null hypothesis of no trend) with an expected value of the mean given by equation (3.3) and a variance given by the equation (3)

$$\boldsymbol{E(dn) = \frac{n(n-1)}{4}} \qquad 2\text{-}3$$

$$\boldsymbol{Var(dn) = \frac{n(n-1)\,2(n+5)}{72}} \qquad 2\text{-}4$$

The null hypothesis is rejected if for a large number of U(dn); the critical value of U(dn) is given by the probability table of a reduced Gauss law (Bruce Langdon, 1992), the null hypothesis is accepted or rejected. The difference between the means of two series will be significant at the 5% risk if U is greater than 1.96 and highly significant at the 1% risk if U is greater than 2.57. If so, it means that there is a significant increase for U(dn)>0 or a significant decrease for U(dn)<0 in the data series U(dn) is given by the equation (2) proposed by Goossens and Berge, (1987).

The dm value will be compared to E(dn) by the statistic:

$$\boldsymbol{U(dn) = \frac{(dn-E(dn))}{\sqrt{Var(dn)}}} \qquad 2\text{-}5$$

The null hypothesis is rejected at the threshold of α = 5%, if U(dn) exceeds the critical value 1.96. If this is the case, it means that there is a significant increase for U(dn) > 0 or a significant decrease for U(dn) < 0 in the data series.

This trend is highly significant if U(dn) exceeds the critical value 2.57 at the threshold of α =1%.

1.2.8. Method of determining the break year in the time series

To check the relevance of the trend observed in the evolution of a time series, two tests are used: The non-change in the pace (homogeneity) of the series we applied the non-parametric test of Pettitt (1979). This test makes it possible to apprehend the breaking points in the pace of a series in order to classify it into sub-series. The Pettitt rupture detection test whose null hypothesis consists of the instability in the equality of the means of two sub-series from the series (Coops, 1992; G. R. Demarree, 1990; Mallakpour and Villarini, 2016). Indeed, the XLSTAT software was used for the Pettitt test.

3. Results and discussions

2.1. Data analysis

2.1.1. Trend of Rainfall Characteristics over Mali (Bamako, Segou and Sikasso)

The analysis of rainfall anomaly index shows the interannual variability in the 1960-2020 series for Bamako (Figure 1). Since 1968, there have been significant year of rainfall deficit with the year 1970, therefore the number of drought events occurred from years 1980 to 1990 and 2000 considered as year of great drought. Our results are identical to those of (Nicholson et al., 2018) who worked on precipitation on the African continent in the 19th and 21st centuries, more precisely the Sahel, these results showed a sharp drop in precipitation that occurred around 1968.

This evolutionary curve of rainfall accumulations from 1960 to 2020 shows a downward trend in accumulations in the 3 different regions of Mali then a very variable trend to normal from 2000 to 2007. However, from 1960 to 2020 there is an increased variability of rainfall. interannual rainfall with a downward trend in rainfall in these three regions of Mali Bamako, Ségou and Sikasso.

The calculation of the standardized index on rainfall from 1960 to 2020 of Bamako station shows a rainfall deficit which increases from 1970, 1972, 1980, 1883 to 1985. The year 1972 (average precipitation of 643mm) corresponds to the year from which there is a general downward trend in the time series of rainfall (Figure.2). A study on the Sahelian droughts showed the rainfall deficit over the whole of West Africa, precisely the ENSO events in the Sahel region from 1972, 76, 82, 83, 92 and 93 (Janicot et al., 1996).

The analysis of rainfall by the Mann Kendall and Homogeneity tests at the Bamako station shows in 1967 with an average precipitation of 1242 mm which negative compared to the average. In addition, the first and second rupture has been observed in the period 1998 and 1994 with an average precipitation of 936 mm (Figure.2). The difference shows a drop in precipitation of 136mm after the break year. The trend analysis of the 1960-2020 series also shows a decrease in precipitation in the zone. Praveen et al., 2020 studied on trend analysis and forecasting of rainfall changes in India using nonparametric and machine learning approaches showed the significant decrease in rainfall for India and that this decrease has been accentuated.

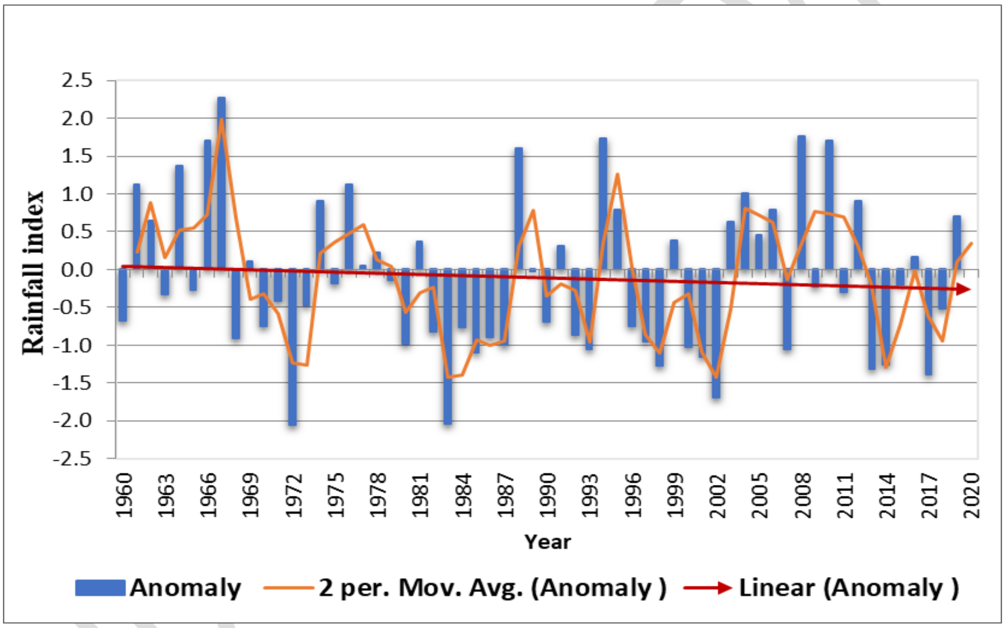


Figure 1. Interannual variability of rainfall for Bamako (orange line is moving average and red line is linear trend forecasting)

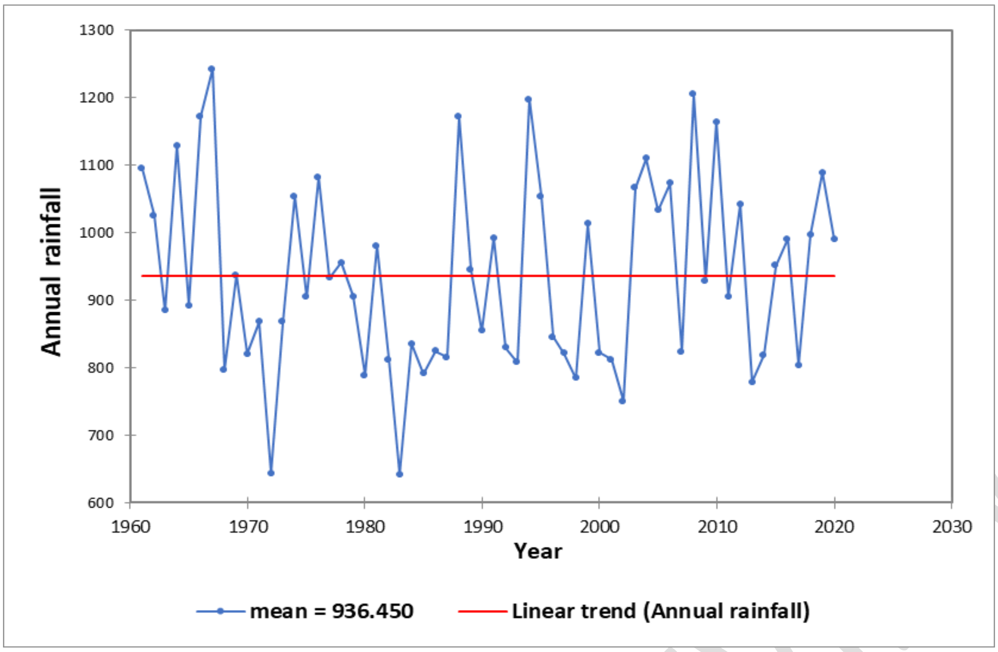


Figure.2. Annual rainfall of Homogeneity test trend test for Bamako (blue line is a mean in the series from 1960-2020 and red line is linear trend)

2.1.2. Trend of annual rainfall in Bamako from 1960-2020

The general trend of the 1960-2020 rainfall accumulation curve for Bamako shows a decrease in precipitation with a linear upward trend (Figure.3). But this trend is not significant because p-value (bilateral) = 0.38 which is higher than the alpha threshold level of significance = 0.05: according to the Mann-Kendall trend test.

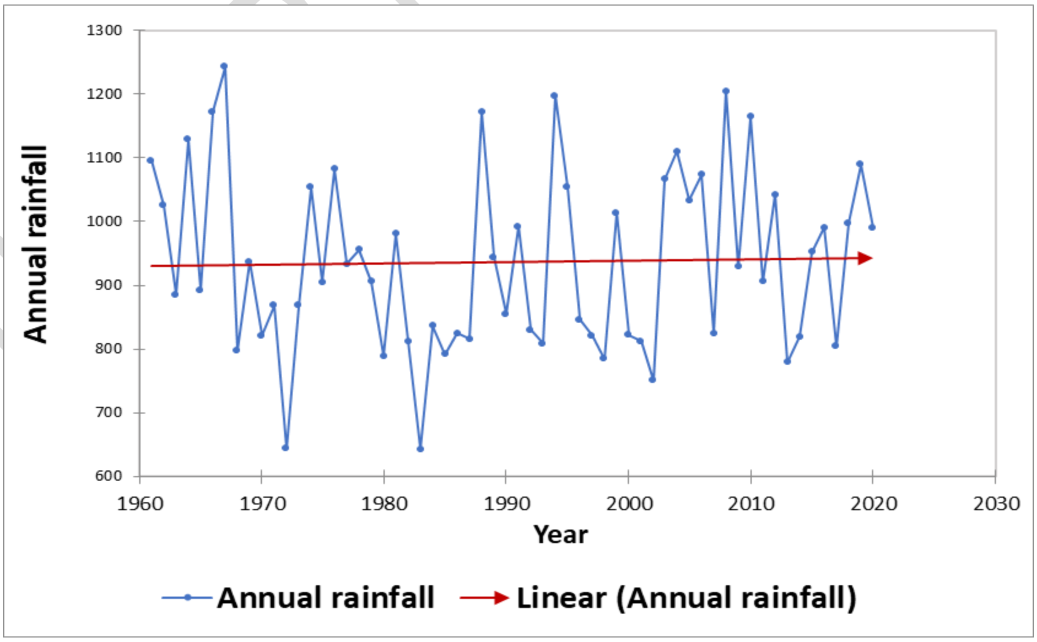


Figure.3. Interannual variability of Man-Kendal trend test for Bamako (orange line is moving average and red line is linear trend forecasting)

2.1.3. Interannual variability of precipitation for Segou

Evolution of rainfall analysis for Ségou region shows a general drop in rainfall accumulations with an average decrease of 13mm from 1960 to 2020. The application of the Pettitt test detected a break from 1970 in the series of rainfall accumulations of Ségou (Figure 4). Our results are consistent with those of a study on climate variability case study in Burkina Faso analyses have shown that rainfall in the region suffered a major break in 1970 using the Pettitt test (Tirogo et al., 2016). The periods with the most marked dry spells were: 1970 to 1974; 1980 to 1987; 2000 to 2006 and from 2012 to 2018.

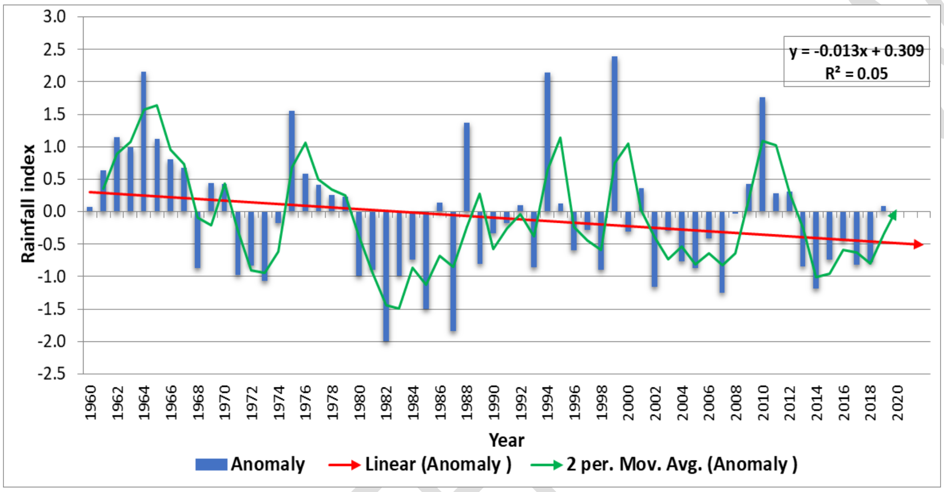


Figure 4. Interannual variability of rainfall for Segou (green line is moving average and red line is linear trend forecasting)

2.1.4. Trend of analysis of rainfall for Segou from 1960-2020

The detection of breaks in the rainfall series of the Ségou region, according to Mann Kendall (Pettitt test) showed that there is no statically significant trend in the series. According to P-value=0.6586 (Figure.5 (a)) and that of P-value=0.224 (Figure.5 (b)) which shows that there is no rupture according to the Pettitt test. Indeed, on the basis of calculations of the two averages, it appears that between the series of 1960-1989 (i.e. 622 mm) and 1990-2020 (i.e. 635 mm), a drop of -13mm (i.e. an annual decrease of -638.2 mm) in the time series 1960-2020. In addition Pettitt's test showed an abrupt change in the 1983 annual series (Figure.5 (b)), however our results are identical to a study carried out in the southwest from Iran which showed that the rainfall abrupt was in 1983 (Dhorde & Zarenistanak, 2013).

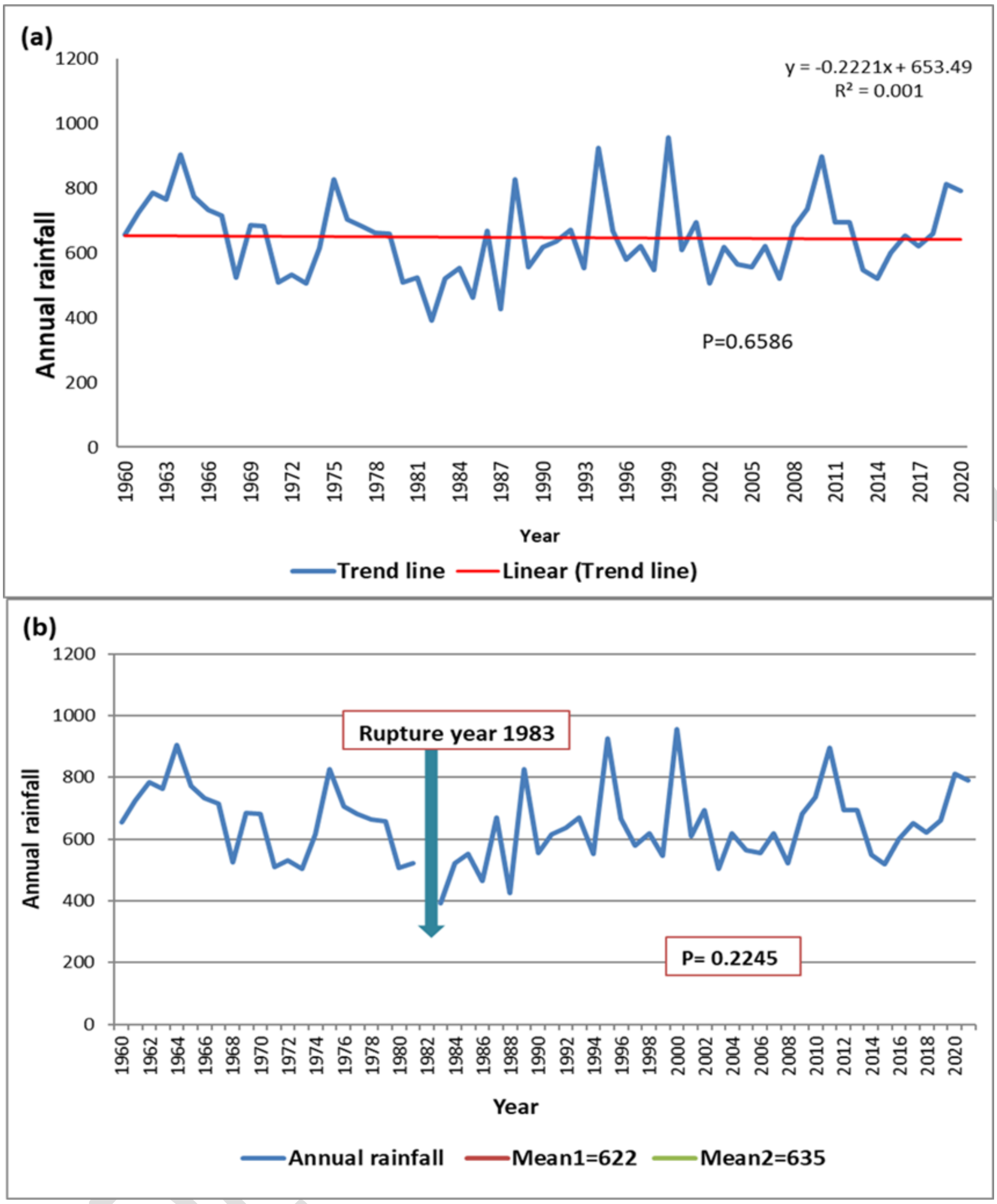


Figure.5. Trend analysis of annual rainfall (a) and the abrupt change in the trend (b) for Segou

2.1.5. Precipitation anomaly of Sikasso from 1960 to 2020

Figure.6 for the Sikasso region indicates the presence of dry period from 1965 which has been observed. However, a period 1968 to 1970 and 1975 to 1980 which is wet in the time series of rainfall. Finally, there is an alternation of dry year between 1994. The results are similar to those studies conducted this last decade revealed that 1994 is considered as a dry period in Sikasso region (Lin et al., 2013; West, 2017). The wettest month of the rainy season is August. However, the trend of annual cumulative rainfall is decreasing. This decrease is statistically significant according to the Man Kendall test at the 5% level (Figure 7 (a)). According detection of breaks in the 1960-2020 rainfall series on Sikasso, the Mann Kendall

(Pettitt test) showed a break in the 1960-2020 series. The breaks years are 1989 and 2010 (Figure 7 (b)).

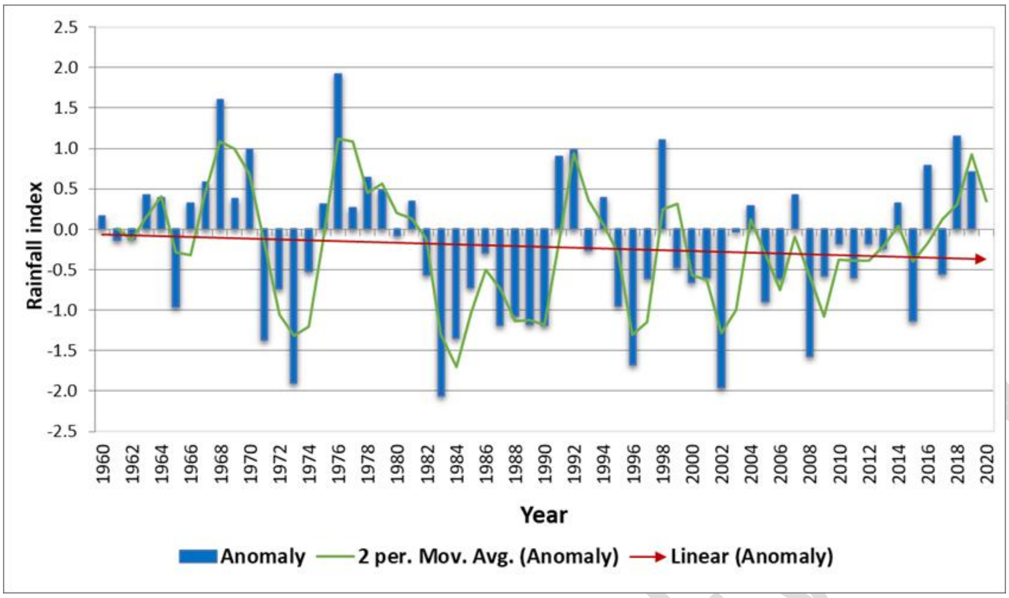


Figure.6. Interannual variability rainfall for Sikasso (green line is moving average and red line is linear trend)

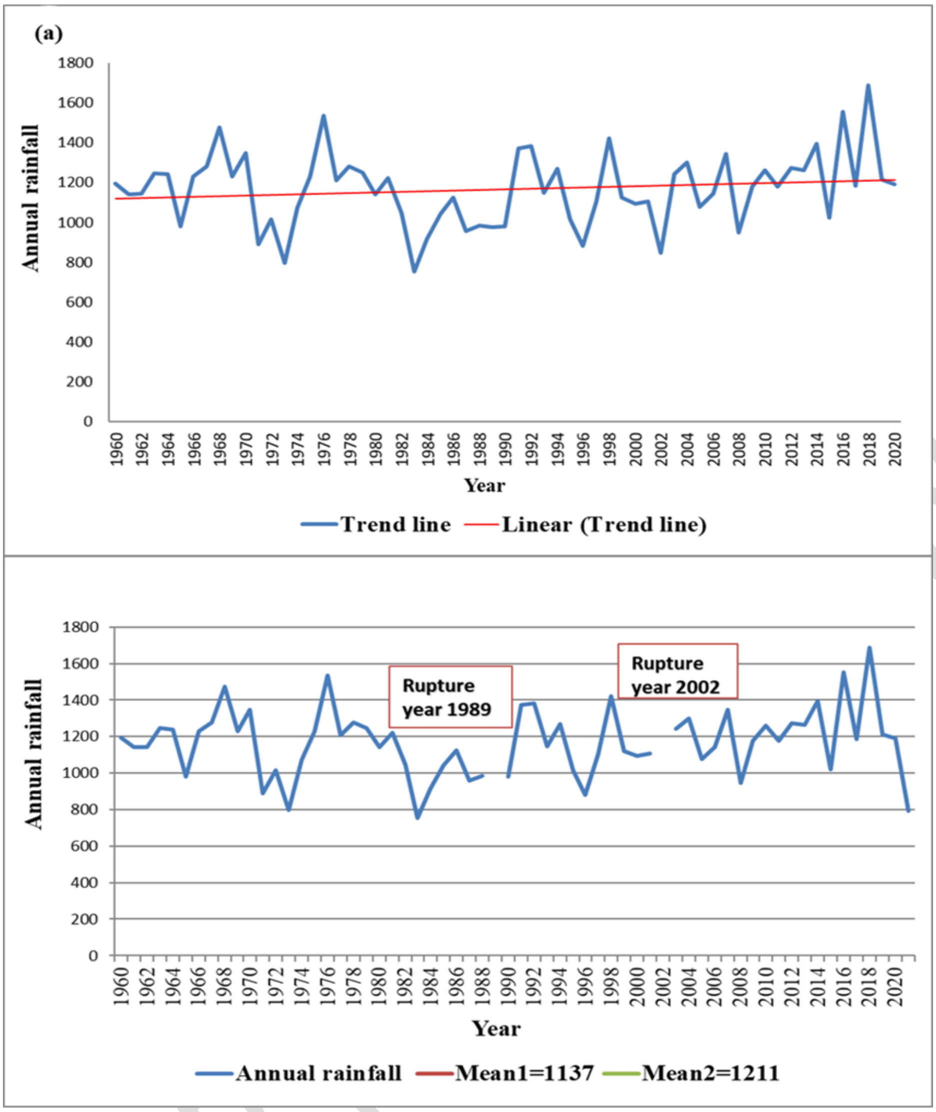


Figure 7. Trend analysis of annual rainfall (a) and the abrupt change in the trend (b) for Sikasso

2.1.6. Start and end date of the rainy season of Bamako in the period from 1960-2020

The results of the statistical analysis of rainfall data for a period from 1960 to 2020 show that the average date of the rainy season starts from May 28 and the average end date of the rainy season is October 6 in Bamako (Figure.8 (a)).

The trend in the length of the rainy season in Bamako has been decreasing for the period 1960-2020 (Figure.8 (b)). This reduction trend is reflected in the variability of rainfall reported by agropastoralists during the field surveys that were conducted.

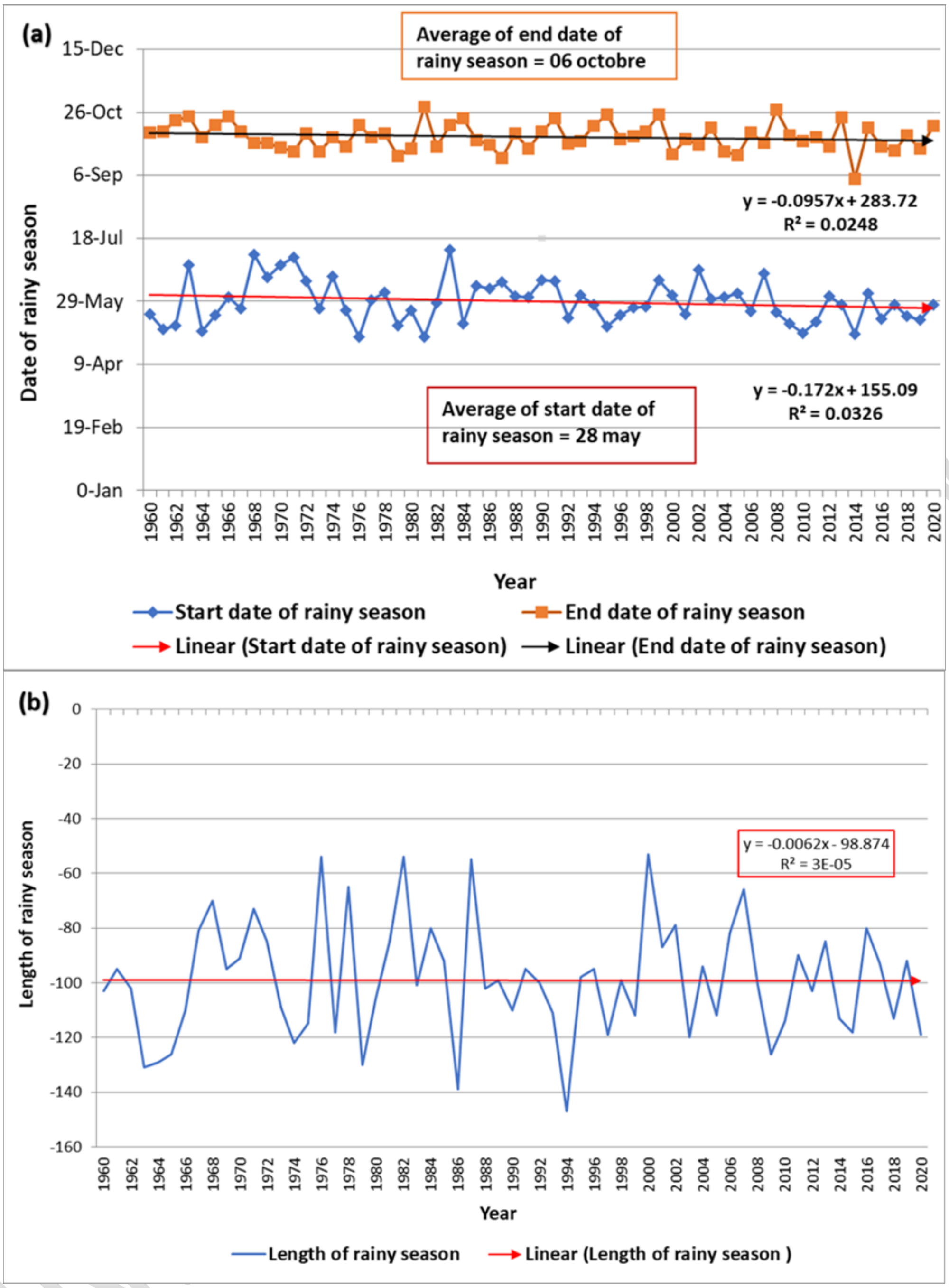


Figure.8. Trend of the start and end of the rainy season (a) and the length trend of the rainy season (b) for Bamako

2.1.7. Start and end date of rainy season of Segou region in the period from 1960-2020

The evolution of the climatic parameters of the rainy season in the region of Ségou (Figure.9 (a)) experiences a high inter-annual variability both for the start date and the end of the rainy season. We note an increasingly late installation of the rainy season on June 16 for the 1960 to

2020 series. On the other hand, the end of the season is getting earlier and earlier with a date of September 23.

The length of the season shows a downward trend, which results in the reduction of the wet period. This tendency to reduce the length of the season is estimated at 7 days (Figure.9 (b)). These results confirm the perception of the agropastoralists surveyed who perceive that the start of the rainy season is late and the end is early.

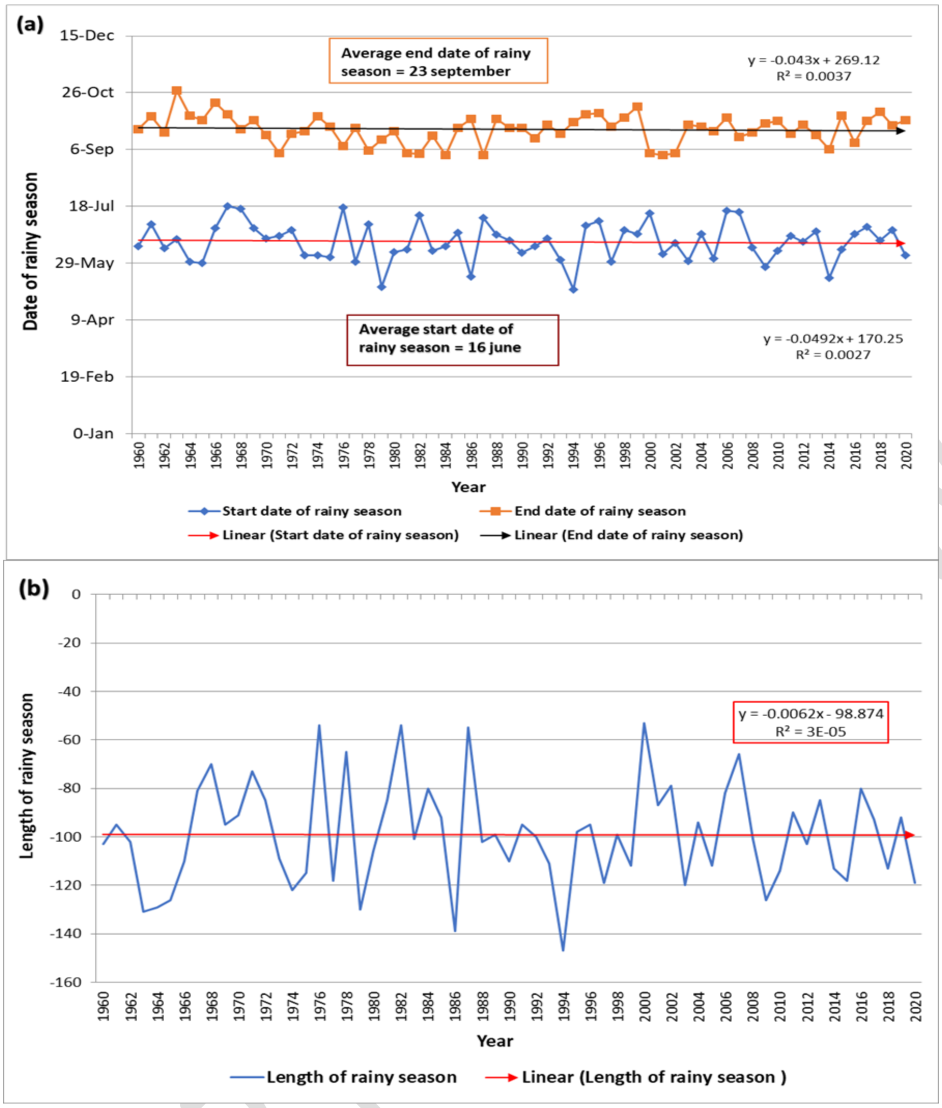


Figure.9. Trend of start and end of the rainy season (a), and the length trend of the rainy season (b) for Segou

2.1.8. Start and End date of rainy season of Sikasso region in the period from 1960-2020

The analysis of climatic parameters shows that the rainy season in the Sikasso region starts on average on May 20 and ends on October 14 (Figure 10 (a)). It is deduced a longer duration of the rainy season in the region of Sikasso compared to Bamako and Segou.

The trend of the length of the rainy season in Sikasso is experiencing a reduction in the series of 1960-2020 (Figure 10 (b)) This decreasing trend results in increased rainfall variability. These results confirm the perception of agropastoralists concerning the length of the rainy season mentioned during the surveys that were carried out in the field.

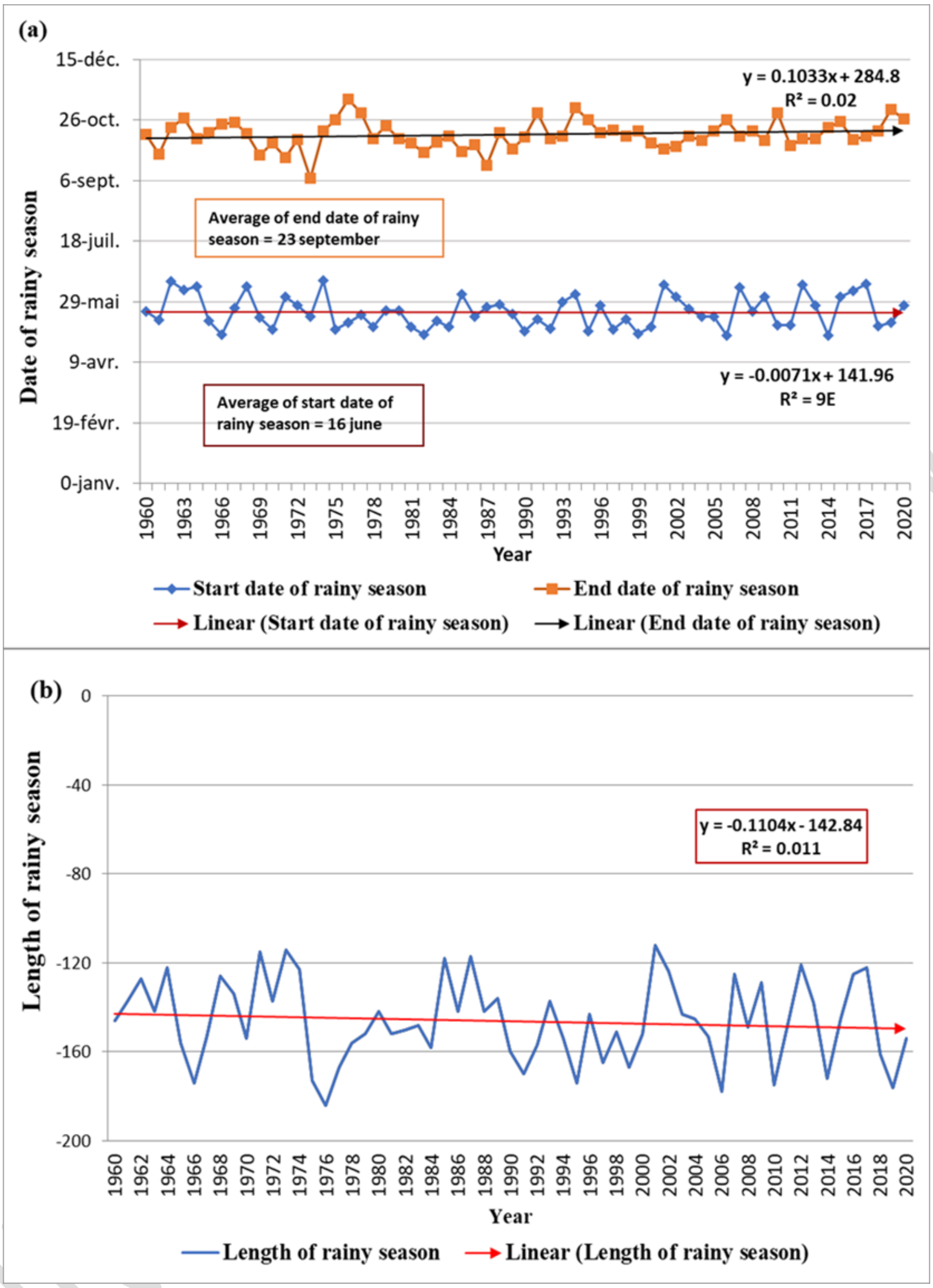


Figure 10. Trend of start and end of the rainy season (a), and the length trend of the rainy season (b) for Sikasso

2.2. Trend of Temperature Characteristics over Mali

2.2.1. Analysis of maximum and minimum temperatures over Bamako, Ségou and Sikasso

2.2.1.1. Temperatures for Bamako

The analysis of the maximum temperatures shows an anomaly of a general upward trend (Figure 11 (a)) for an average of 34.65°C in the time series of 1960-2020. According to the

Mann-Kendall test, this trend is significant because the p-value = 0.03 which is lower than the threshold significance level alpha=0.05. The risk of rejecting the “no” significance of the trend is 0.03%. The average of the two ruptures in the series from 1960-1989 is estimated at 34.57°C and from 1990-2020 is at 34.72°C (increase of +0.15°C). The analysis of minimum temperatures (Figure 11 (b)) shows that the trend is increasing with an average of 21.18°C in Bamako during the period 1960 to 2020 and this increase in minimum temperatures is in accordance with the perception surveyed agropastoralists.

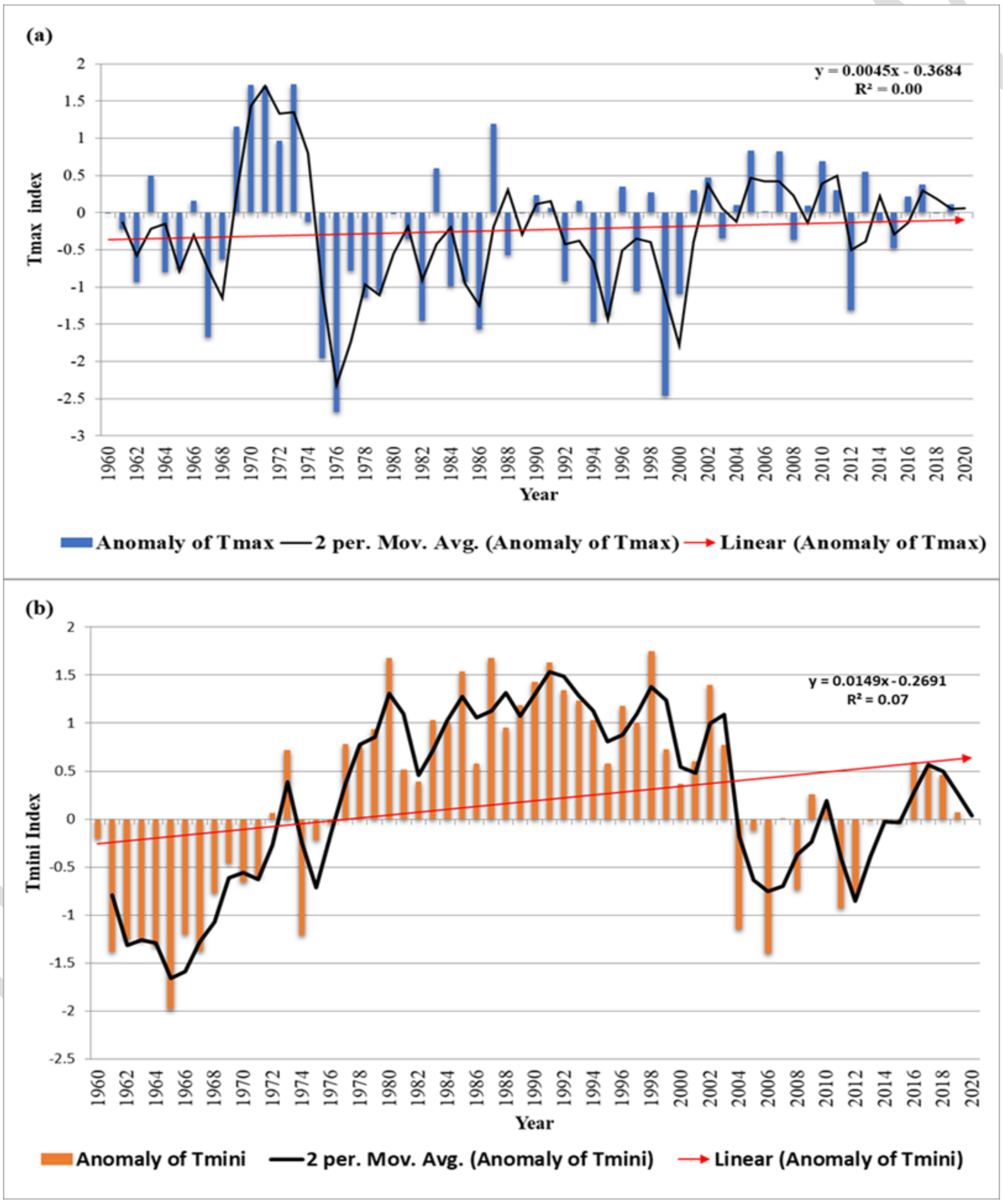


Figure 11. Anomaly trend of maximum (a) and minimum temperature (b) for Bamako from 1960-2020 (red line a, b is linear trend and black line is moving average)

2.2.1.2.Temperatures for Segou

The maximum temperature for the Segou region shows an increasing trend in the time series of 1960-2020 with an average of 36.23°C (Figure.12 (a)). This upward trend is 0. 51°C for the whole period (Table.1Table.1). These results of the evolution of the maximum temperature of the series considered are in agreement with the perception of the agro-pastoralists who declared an increase in temperature. Also other studies have shown an upward trend in maximum temperatures in the Segou region (Touré et al., 2017; Diop and Barro, 2021).

Table.1. Segou maximum temperatures

Ségou Station	Year of ruptures	Mean	Average increase
	1960-2020	36.23°C	+0.24°C
	1960-1989	35.96°C	+0.51 °C
	1990-2020	36.47°C	+0.75°C

Data from the analysis of minimum temperatures in the Ségou region showed an interannual change in temperatures recorded throughout the 1960-2020 series with an average increase of 22.67°C (Figure.12 (b)). Ruptures were observed during the period 1960-1979 with an average of 22.48°C and from 1980-1999 with an average of 22.74°C (Table.2).

Table.2. Ségou minimum temperatures rupture

Ségou Station		
Year of ruptures	Mean	Average increase
1960-1979	22.48°C	+0.19
1980-1999	22.74°C	+0.30°C
2000-2020	22.77°C	+0.49°C

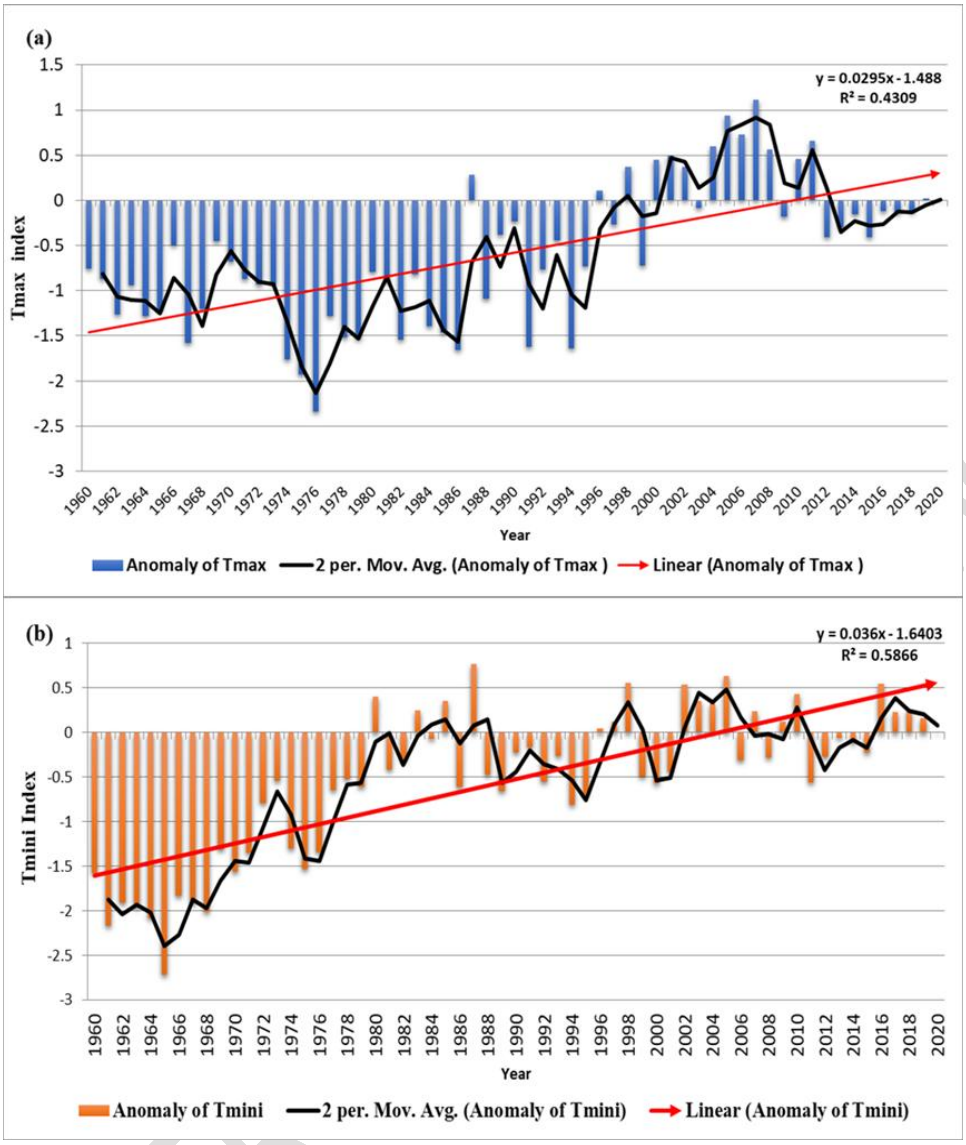


Figure.12. Anomaly trend of maximum (a) and minimum temperature (b) for Segou from 1960-2020 (red line a, b is linear trend and black line is moving average)

2.2.1.3.Temperatures in Sikasso

The evolution of minimum temperatures shows an upward trend of +0.58°C under two time series (1960-1989 and 1990-2020) for the period 1960-2020 (Figure 13 (a)). The average maximum temperature is 33.85°C. Since 1979, year of temperature increase have generally been recorded until 2010. The trend is statistically significant since p-value equal to 0.0001, therefore lower than the alpha threshold of 0.05 (Mann Kendall test) (Figure 13Figure 13 (b)).As for the annual average minimum temperature, the application of the Pettitt test has made it possible to highlight a significant break from 1982, thus dividing the series into two homogeneous sub-series. The average for the 1960-1989 series is 21.36°C against 21.94°C for the 1989-2020 series (Table.3. Sikasso minimum temperature ruptureTable.3). Therefore, similar results showed that the increase in the annual minimum temperature of +0.58°C of Sikasso station (B. Traore et al., 2013).

Table.3. Sikasso minimum temperature rupture

	Station de Sikasso	
Year of ruptures	Moyenne	Average increase
1960-1989	21.36°C	
1990-2020	21.94°C	+0.58°C

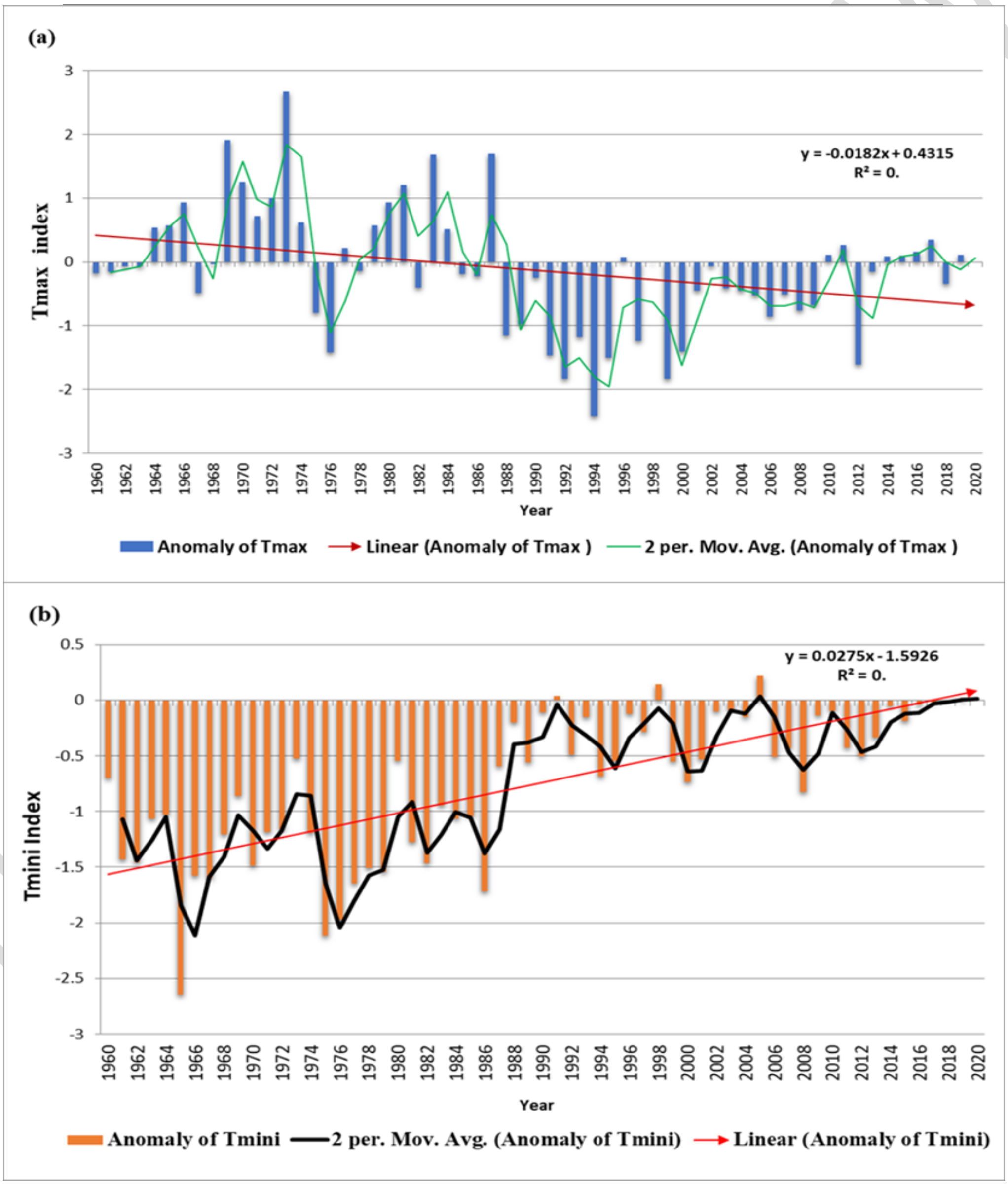


Figure 13. Anomaly trend of maximum (a) and minimum temperature (b)for Sikasso from 1960-2020 (red line a, b is linear trend, green and black line is moving average)

2.2.2. Impacts of climate change on production sectors

2.2.2.1. Perception of agropastoralists on climate variability of the rainy seasons and vegetation

The analysis of information collected from agropastoralists on the perception of climate variability shows an increased variability of the start date of the rainy season in the last 30 year compared to that of now. About 55% of respondents said that the rainy season began in May for the past 30, while currently it begins in July according to 51% of respondents. According to the results of the analyses of the surveys of agropastoralists, it appears that the rainy season could last up to five (05) months in the southern regions of Mali (9%) during the last 30 year and four (04) months mentioned by 58% of the surveys. Nowadays, the same people said that the duration is shortened to three months (03) according to 55% of people.

Surveys of agropastoralists on vegetation revealed a rate of 88% who declared that the current vegetation is less dense than compared to the last thirty (30) year and this figure 14 a show that 65% affirmed that the current biodiversity is very degraded with the disappearance of plant species expressed by 59% of those surveyed. These species in local languages and scientific name in bracket are: Balanza (Faidherbia albida), N'toro (Laggera alata), Doubalén (Canarium schweinfurthii), N'djoun (Mitragyna inermis), Bànà, N'gaba, Néré (Parkia biglobosa), Bôjiri, N'galajiri, Boina, Saboye, Dani, Guele, Sama-nère (Entada Africana), Ntongue, Sindia, Koronifi (Vitex doniana), Zamba, Sounsou (Annona senegalensis), N'gueni.

The results of the surveys revealed that 61% of agro-pastoralists were victims of at least one climate-related disaster and which caused several damages in particular: loss of crops (44%); loss of fields (26%), loss of animals (12%), insufficient pasture (5%), farmer-herder conflicts (4%) (fugure 15). These various damages suffered by agro-pastoralists have been caused by flooding, drought, locusts, erosion, wandering animals, low rainfall, insufficient water available for agriculture and for breeding.

2.2.2.2. Adaptation strategies practiced by agro-pastoralists in the face of climate change

It emerged during field surveys that in the face of climate variability, 85% of agro-pastoralists have adopted and practice new techniques:

- in agriculture, these are namely the use of new varieties of adapted early seeds, the use of organic manure (41%) or the spreading of household waste, chemical fertilizer (15%) (Urea 46%, Nitrogen 17%, Phosphorus 17%, and Potassium 17%), ridging

(22%), ploughing (12%), cover plant (11%), Zaï (7%), half-moon ploughing (5%) and tree planting (5%), stone cordon for the fight against water erosion (13%), crop rotation, crop diversity, flood recession cropping, rainwater harvesting. The effects of climate change led 72% of the people surveyed to re-sow their fields. In order to cope with the effects of runoff and strong winds on crops, 39% of agropastoralists surveyed said they had adopted tree planting (windbreak).

- in breeding, it is: the cultivation of fodder cowpea for animals, the sowing of pastures, the cultivation of forestry cultivation in ponds (Echinochloa stagnina) and lowlands for fodder, the storage of straw, the creation of livestock feed banks, cattle and sheep fattening. Agropastoralists have taken steps with various technical and financial partners to help them in the development of pastoral spaces (drilling of pastoral boreholes, materialization of pastoral tracks), the construction of livestock feed storage warehouses, animal health support Agropastoralists used other types of strategies during periods of household food deficit but also during livestock fodder deficit in order to support:

- the strategies adopted and mentioned in relation to the food deficit in households were: market gardening (47%), the sale of animals (31%), petty trade (11%), external transfer (6%), exodus (3%), loan or debt (1%), temporary labour, village solidarity and aid from projects or NGOs.
- the strategies adopted and mentioned in relation to the fodder deficit of livestock focused on: the sale of animals/destocking (53%), loan or debt (27%), transhumance (13%), aid from projects and NGOs (5%) and the reduction of the food ration (1%).

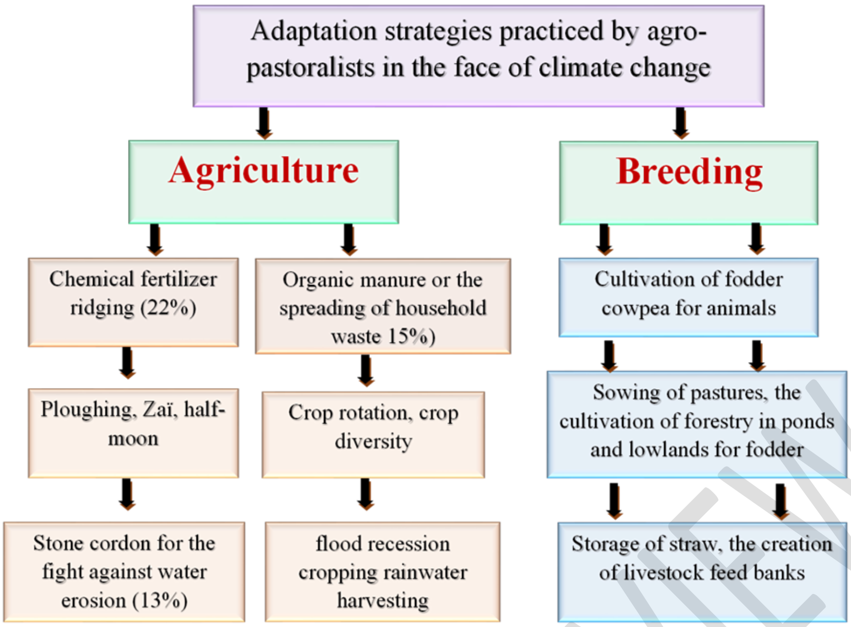


Figure14. Diagram of adaptation strategies of agropastoralists (agriculture and breeding) in the face of climate change

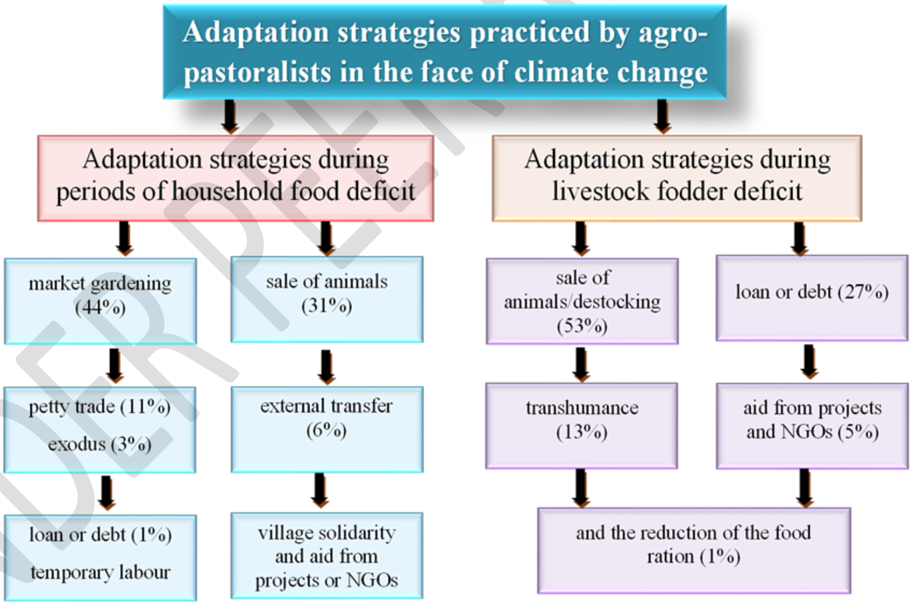


Figure 15 Diagram of adaptation strategies of agropastoralists during periods of household food and livestock fodder deficit

2.3.Conclusions

It became clear that agropastoralists in Mali perceive climate changes in precipitation, temperature and high wind patterns and the impact of these on their activities. Agriculture and livestock, the main activities of agropastoralists, are experiencing an unprecedented crisis. It emerges from the impacts of climate change on agricultural activities: a rise in temperatures, a change in precipitation patterns, an intensification of extreme events such as drought, low rainfall (51%), high heat (25%), strong winds, 82% of agropastoralists surveyed said that the current sowing date is later than in the past. Production and income from agricultural activity are significantly down compared to previous year. Pasture surfaces are reduced because they are threatened by soil erosion. Water resources dry up quickly and undergo the phenomenon of silting up and the water tables deepen. The natural vegetation is degraded, some very rich plant species eaten by animals have completely disappeared because they can no longer adapt to these current climatic conditions. Faced with the effects of climate change, agropastoralists have developed adaptation strategies to guard against climatic hazards and manage their livestock capital. Adaptation strategies relating to the improvement of agricultural production, the management of water resources and vegetation have been proposed. These include the use of organic manure, and the conservation of crop residues for the restoration of soil fertility, mulching, use of early varieties, adoption of new species or varieties, sowing of early varieties or resistant to drought, agroforestry, maintaining soil for to reduce water and wind erosion, reforestation.

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