Impacts of Rainfall and Temperatures on Socio-economic and Environmental Sectors in the Communes of Tondikiwindi and Ouallam, Department of Ouallam, Region of Tillaberi, Niger Republic

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Abstract

The communes of Tondikiwindi and Ouallam in Niger experience changes in rainfall and temperatures like the whole of ahel. This paper focuses on understanding the impacts of these climate parameters on socio-economic and environmental sectors. The methodology is based on calculations of various indices (Lamb, 1982; Tabony, 1977; FAO / UNESCO, 1979) and determination of temperatures within maxima and minima values. With regard to the rainfall evolution, three periods were noted including a long dry period (1968-1989), a relatively wet period (1990-1998), and a period of great variability with an alternation of wet and dry years (1999 -2015). A trend in the South has been noticed in the start and at the end of the rainy season, with a slight decrease in the rainy days. For the temperatures, an increase was registered from 1968 up to date with some slight changes. This is due to the occurrence of the phenomena related to the El Niño or ENSO Southern Oscillation. In terms of impacts, there were several food crises and population migration both inside and outside of the country. On the other hand, the return to a relatively humid phase has led to a change in the Northern limit of

cultures, whose corollary is the exacerbation of conflicts between shared natural resources users. This return to an increase in rainfall has also led to major floods that have favored the creation of new permanent or semi-permanent pools. Hence, it is necessary to develop a new model of sustainable development for this geographical entity.

Keywords: Rainfall, temperatures, Tondikiwindi, Ouallam, Tillaberi, North Western Niger

Introduction

Climate change in the Sahel, particularly in Tondikiwindi and Ouallam communes, has resulted in severe droughts, leading to floods and heat waves.

The main objective of this study is to analyze these climate events and identify their socio-economic and environmental impacts in these communes.

Specifically, the study aims to:

- ✓ Characterize the rainfall trend from 1968 to 2015 through calculation of various indices in different meteorological stations;
- ✓ Determine the temperatures trend (maxima and minima);
- ✓ Determine the socio-economic and environmental impacts of these climate events.

1. Generalities on the Study Area

1.1 Location of the Study Area

The communes of Tondikiwindi and Ouallam are located in the department of Ouallam and Tillabéri region, which is located in the Western part of Niger. The commune of Tondikiwindi falls between 14° 16 'and 15° 20' North latitude and 1° 10 'and 2° 25' East longitude, and the commune of Ouallam falls between 14° 02'43, 09 " and 14° 22 '48, 33 " of latitude North and 1° 42'52, 32 " and 2° 34'17, 69 'of longitude East (Figure 1).

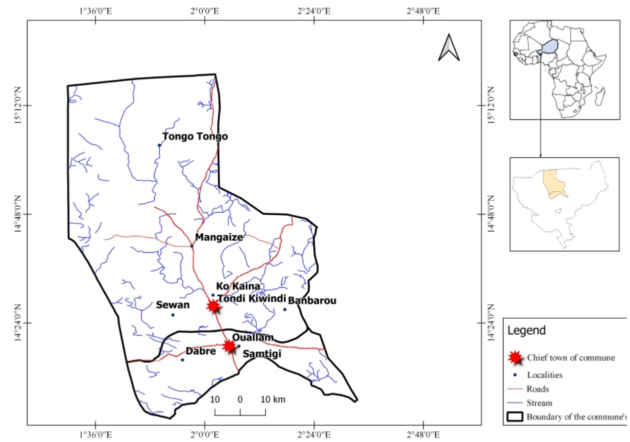


Figure 1. Location of the Commune's of Tondikiwindi and Ouallam

1.2 Hydro-climatology

These communes fall in the dry tropical climate including two major seasons: a short rainy season from June to September and a long dry season from October to May. The annual rainfall amounts of the main synoptic stations vary as follows:

- ✓ Tillabéri is between 250 mm in 1971 and 654.3 mm in 2012;
- ✓ Ouallam is between 193.5 mm in 1984 and 568.5 mm in 1992;
- ✓ Maingaize is between 104.7 mm in 1984 and 492.2 mm in 1998;
- ✓ Banibangou is between 118.7 mm in 1984 and 427.3 mm in 2012.
- ✓ The maxima and minima mean temperatures for the period between 1968 to 2015 are 37.1 ° C and 23.6 ° C, respectively;
- ✓ Average Evapotranspiration (Etp) is 180. 33.

Hydrologically, there is no permanent water body in the study area. However, there are several temporary streams of intermittent flow (koris). The most important is that of Ouallam and other numerous temporary semi-permanent and permanent ponds.

1.3 Social and Economic Activities

The population of the two communes is estimated to 179,681 inhabitants (INS, 2012). The economic activities practiced by the population are mainly agriculture and animal husbandry, but other secondary activities such as trade, handicrafts and exploitation of forest resources are also practiced.

1.4 Flora and Fauna

The vegetation density is very low and less diversified due to combined effects of climate change and deforestation.

The wildlife of the two communes was once rich and diverse with animal species like antelope (Tompson gazelle and Gazelle dorcas), birds, reptiles, insects, giraffes, etc. This fauna is now reduced to small rodents and some migratory or little birds. However, in the border strip (Niger-Mali) of the rural commune of Tondikiwindi, dorcas gazelles, sometimes bustards, wild guinea fowl, hares, squirrels and also giraffes from Koure are commonly seen during the rainy season in Ouallam commune (PDC, 2014).

1.5 Geology and Hydrogeology

Geologically, the Ouallam department is located on the South Western part of the Illumenden Basin. The basement formations are constituted by granites and green series, and sedimentary coverings ranging from infra-Cambrian to tertiary, and finally the sandy and clayey deposits of the old and recent quaternary. According to Greigert (1965), the discontinuous aquifers of the basement and the multilayer aquifers of the Continental Terminal, captive

tablecloth (CT1), semi-captive (CT2), free (CT3) and finally alluvial aquifers are identified.
The indicator of drinking water supply is 100% for Ouallam town. For the rest of the department, more specifically in rural areas and all the municipalities combined, the rates are: geographic coverage 67.4%, access 52.7%, and the percentage of failed hydraulic infrastructure is 10.1% (MH / A, 2017).

2. Materials and methods

2.1. Data Collection

The data collection includes climatic parameters for the period between 1968 to 2015 (rainfall, temperature and Etp) for Tillabéri synoptic station and the historical data for Banibangou, Mangaize and Ouallam stations (Table 1)

Table 1. Weather Stations covering the study area

Locality	Type of weather station	Creation date	Geographic coordinates	
			Latitude North	Longitude East
Tillabéri	Synoptic	1923	14.20	1.45
Ouallam	Rain Gauge	1947	14.31	2.09
Mangaize	Rain Gauge	1959	14.68	1.95
Banibangou	Rain Gauge	1968	15.04	2.7

Other materials used for gathering data include:
- ✓ Topographic maps and satellite imagery;
- ✓ Reports on the general census of the population;
- ✓ Local Development Plans (PDC) for the 3 communes;
- ✓ Thesis, scientific publications, scientific dissertation and theses;
- ✓ GPS, digital camera and interview questionnaires were used.

2.1 Methods Used

The climate parameters were obtained from the National Meteorological Directorate (DMN) in form of database, for time series of the different synoptic weather stations, and agro-climatic or rainfall stations throughout the country.

The rainy season is linked to the seasonal movement of the Inter Tropical Discontinuity (ITD) from South to North, from April to September, and from North to South from mid-September. In addition, there is some evidence of low rainfall outside the rainy season from October to March linked to the subtropical JET stream, and a high-speed wind from West to East, at an altitude of about 8 km. It attracts high-altitude and warm humid winds from the tropics, as well as fresh winds from the poles to create a band of clouds that is dense at times and visible by men. These clouds formed by this phenomenon can cause low to moderate rainfall with a significant impact in desert area, and on vegetation and wild life.

The survey sheets on the perceptions and impacts of changes in rainfall and temperature have been administered to individuals and groups of people. Thus, it was a question of apprehending the perception and the impacts observed by the communities in relation to the seasons.

The data collected was entered in Excel for analysis. The analysis consists of:

- ✓ Determination of Lamb's standardization index (1982). This is to determine the trends of certain variables. It is calculated as follows:

I = (Xi-Xmoy) / δ

where :

- I = Lamb index
- Xi = Amount of rain for the year
- X avg: Average of rain series 1981-2010
- δ = Standard deviation of the 1981-2010 series.

The values of the Lamb indices make it possible to determine the following years:

Normal wet years = rainfall> mean + δ;

- Exceptional rainy years = rainfall> mean + 2 δ;
- Abnormal deficient year = rainfall <average - δ;
- Excessive dry year = rainfall <average - 2.d.

- Determination of Tabony (1977).

  This index is defined by: IT = (Ri-R̄) / R̄

  Where:

  - IT = Tabony index
  - Ri = Rain of the given year
  - R̄ = Average value (or normal value) of the period.

This index is simple and it is mostly used to characterize the severity of a drought. Moreover, it makes it possible to compare the height of the rainfall for a given duration (week, month, year ...) with long term average or its normal value for a standard period corresponding to the same duration.

- Calculation of the bioclimatic aridity index

This final FAO / UNESCO index (1979) is given as follows = P / Etp;

Where:

- P represents the average amount of the annual rainfall of the series;
- Etp is the average annual potential evapotranspiration of the series.

This index varies from 0 to 1 to classify arid zones according to Baumer (1987) to determine the following areas:

- Hyper arid zone P / Etp <0.03;
- Arid zone 0.03 <P / Etp <0.2;
- Semi-arid zone 0.2 <P / Etp <0.5;
- Subhumid zone 0.5 <P / Etp <0.75.

- Determining the length of the rainy seasons

The parameters of the agricultural season that have been studied are as follows: starting date, ending date, length of rainy and dry seasons.

- **Starting Date of the Rainy Season:** There are several criteria for the starting date of the rainy season. Starting on May 1st, 20 mm of rainfall accumulated in one or two days are recorded (Kadidiatou, 2004). After May 1st, 20 mm of rain collected in 3 consecutive days without dry period, which is greater than 7 days in the 30 days that follow, are also recorded (Siviakumar & Guèye, 1992).
- **Ending of the Rainy Season**: This corresponds to the first day after September 1st when the water balance is less than or equal to 0.5 mm, and when the water consumption of the plant and the climatic demand exhaust the water reserve of the soil (Stern et al., 2006). More so, the daily evapotranspiration of crops at the end of the season has been estimated at an average of 5 mm per day in the area (Morel, 1992).
- **Length of the Rainy Season:** This is the difference between the end and beginning of the rainy season (Sivakumar & Guèye, 1992).
- **Dry Sequence:** The dry sequence is defined for a given period as being the maximum number of consecutive days without rain. Therefore, the definition of a threshold of precipitation height from which one can consider that the day is dry is necessary. The chosen threshold is 0.85 mm (Stern et al., 2006).

- Development of impact charts related to social and environmental aspects.

3. Results and Discussions

3.1 Rainfall Trends

3.1.1 Monthly Average Rainfall for the Period between 1968-2015

For all the studied synoptic stations, the monthly average rainfall shows a monomodal trend marked by a peak value in August (Figure 1, 2, 3 and 4). Moreover, the rainfall recorded between December and March is associated with "mango rains", and the rainy season starts in May in a shallow way and sometimes ends abruptly in mid-September.

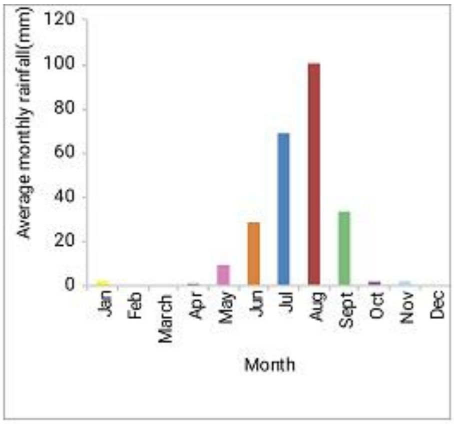


Figure 2. Evolution of monthly average rainfall at Mangaize

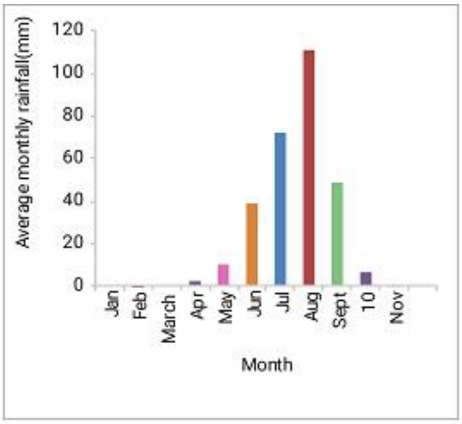


Figure 3. Evolution of monthly average rainfall at Banibangou

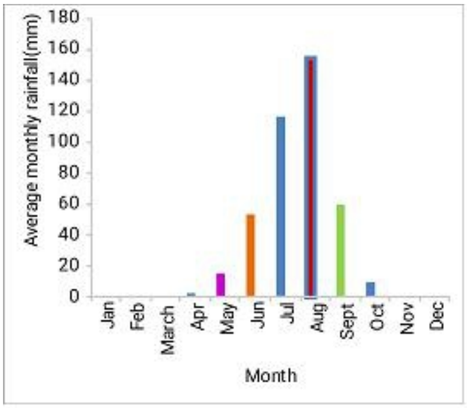


Figure 4. Evolution of monthly average rainfall at at Ouallam

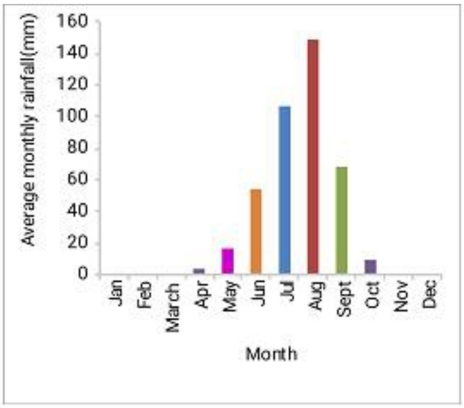
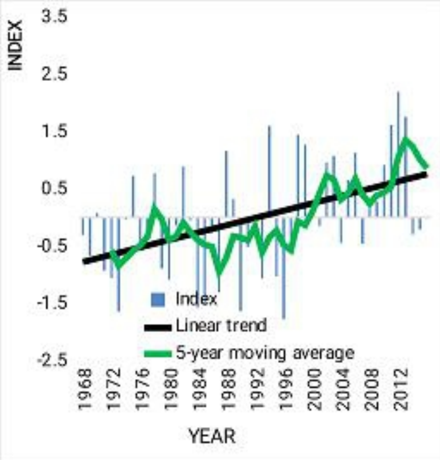


Figure 5. Evolution of monthly average rainfall Tillabéri

3.1.2 Interannual Averages Fluctuation of Rainfall in the Different Stations

The indexes of Lamb (1982) and Tabony (1977) determined for the time series of the Banibangou, Mangaize, Ouallam and Tillabéri stations for the period between 1968 to 2015 (Figures 5, 6, 7, 8, 9, 10, 11 and 12) are shown below:

- From 1968 to 1989, there is a long dry period in all stations. During this period, there are rare wet years (1978, 1980) but it is especially marked by years with a high deficit including 1973, 1974, 1984;
- From 1990 to 1998, there is a relatively wet season in all stations with alternate dry years (1991, 1992, 1993, 1996, 1997);
- From 1999 to 2015, the seasonal patterns are characterized by a great variability of wet and dry years alternatively. Thus, we note that the years between 1999, 2002, 2003, 2010, 2011, 2012, and 2013 is characterized with alternate wet and dry seasons. Also, annual rainfall varies from year to year in space and in time.



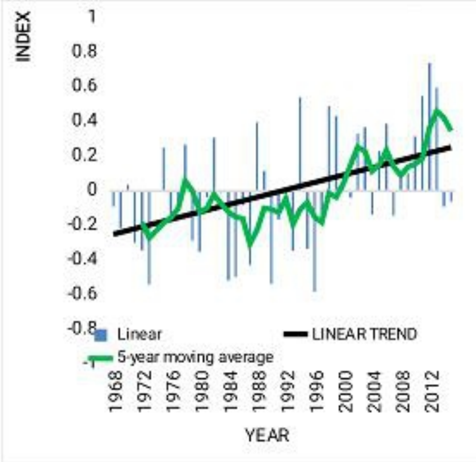
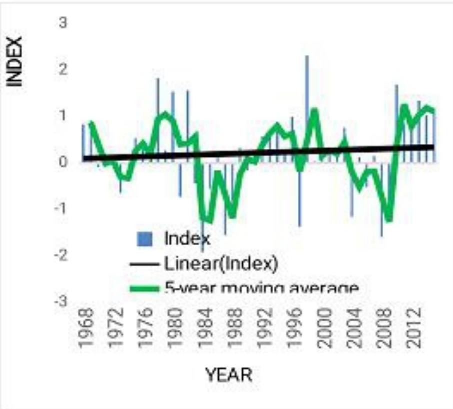


Fig. 6. Evolution of the standardized anomaly, and linear trends , and five-year rainfall in Banibangou

Fig. 7. Evolution of the proportional difference of Tabony, and trends, and five-year rainfall in Banibangou



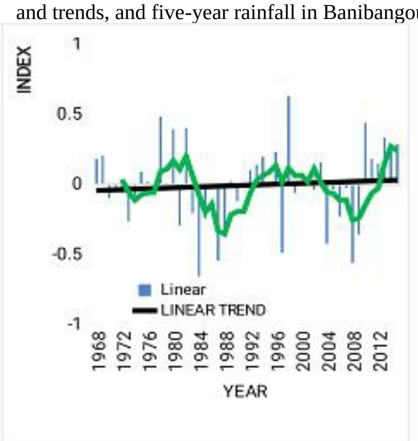
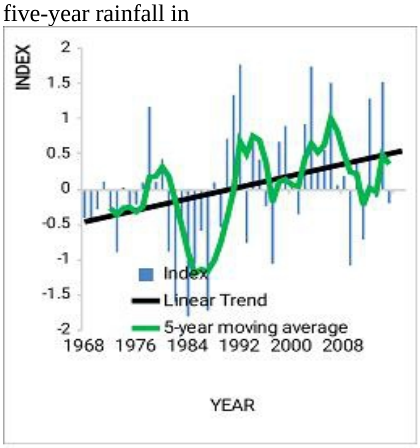


Fig. 8. Evolution of the standardized anomaly, and Fig. 9. Evolution of the proportional
difference linear trends, and five-year rainfall in Mangaize of Tabony, and trends, and
five-year rainfall in Mangaize



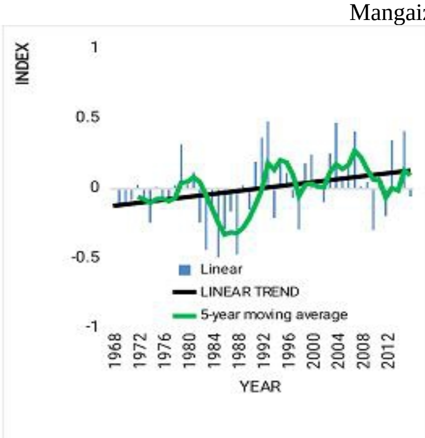


Fig. 10. Evolution of the standardized anomaly, Fig.11. Evolution of the proportional
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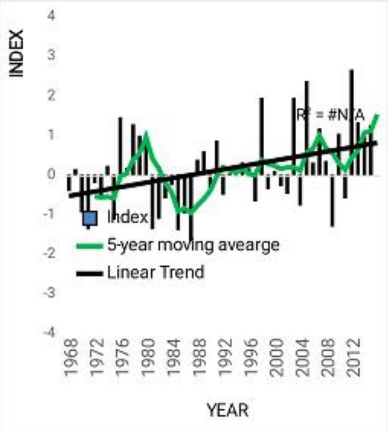

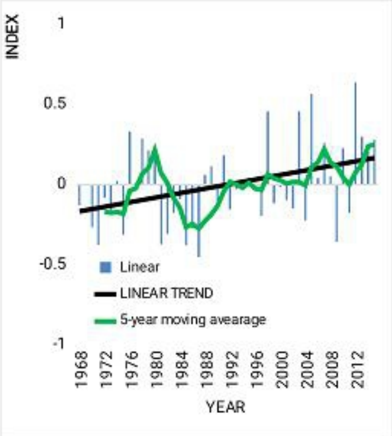

Fig.12. Evolution of the standardized anomaly, and trends, and five-year rainfall in Tillabery trends, and Tillabery

Fig.13. Evolution of the proportional linear difference of Tabony, and five-year rainfall in

3.1.2 Length of the Rainy Season, Number of Rainy Days, and Dry Sequences

For the study of these parameters, only the Ouallam station will be considered. However, the specificities observed on the other stations will be reported.

- **Length of Rainy Seasons**

At the Ouallam station, the lengths of the rainy seasons show an oscillating pattern (Figure 13) with a trend to reduce it, which seems to be caused by a late start and an early end.

These findings were made by agricultural services, national meteorological services, and local populations (Idrissa, 2016).

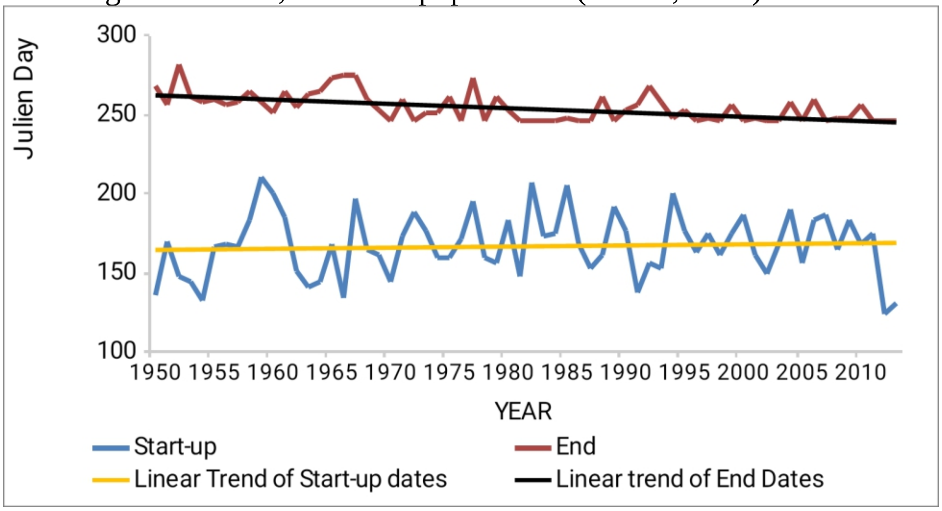

Figure 14. Evolution of the trend of the duration of the rainy season from 1968 to 2015 in Ouallam

- **Number of Rainy Days**

The number of rainy events also evolves in an oscillating saw tooth with a slight trend to reduce it (Figure 14). This number is particularly low for the rainfall shortage years including 1981, 1982, 1983, 1984, 1985, 1990, 1993, 1996, 1997, 2001, 2009, and 2011. Moreover, it is possible that the number is small to have a surplus. Therefore, 1980s situation is noted, with 18 rainy events for 427.7 mm. In 2012, 22 days of rain throughout the season for a total of 517.6mm was also noted.

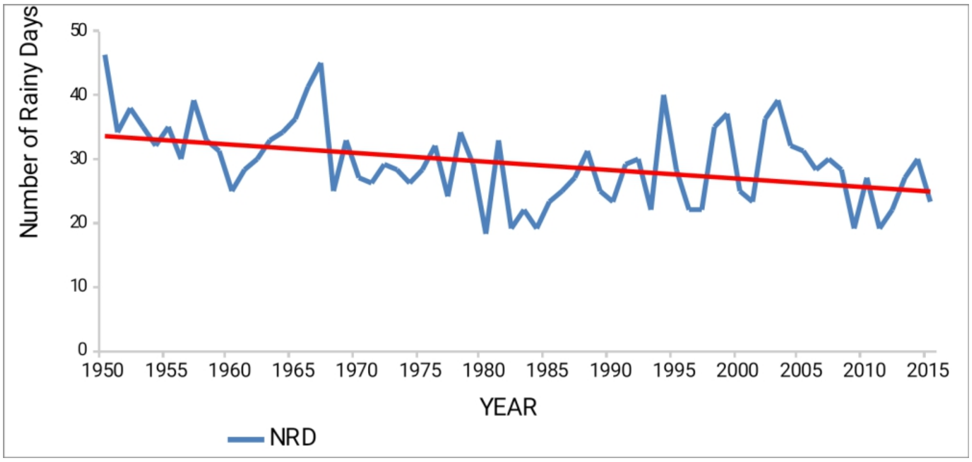

Figure 15. Evolution of the number of rainy days from 1968 to 2015 in Ouallam

- **Dry Sequences**

The graphs for these sequences (Figure 15a, b, d and e) denote:

- A maximum of successive dry days in June and October of each year for all decades;
- The decade (2008-2017) recorded more dry successive days in June and August (Figure 15e) and is followed by that of 1988-1997 (Figure 15c). There is also an absence of rainfall from September except for the decade 1968-1977 (Figure 15a);
- Persistence of dry sequences greater than 10 days in all months of the rainy season (mid-June to mid-September) during the decade 1968 to 1977 (Figure 15a);
- The most severe monthly dry sequences ranging from 18 to 30 days during the months of July to September were observed during the decade 1978 to 1987 (Figure 15b);
- The existence of sequences above 15 days starting from August which continued with more acuity until mid-August, with delays of more than 20 days until the end of the rainy season for the decade 1988 to 1997 (Figure 15c);
- The dry short sequences were observed during the months of June to August, but these were relayed by longer periods of

drought which were rapid from mid-August during the decade from 1998 to 2007 (Figure 15d) ;

- A similar appearance to that of 1978-1987 (but of lower intensity) was observed during the decade 2008 to 2017 (Figure 15e).

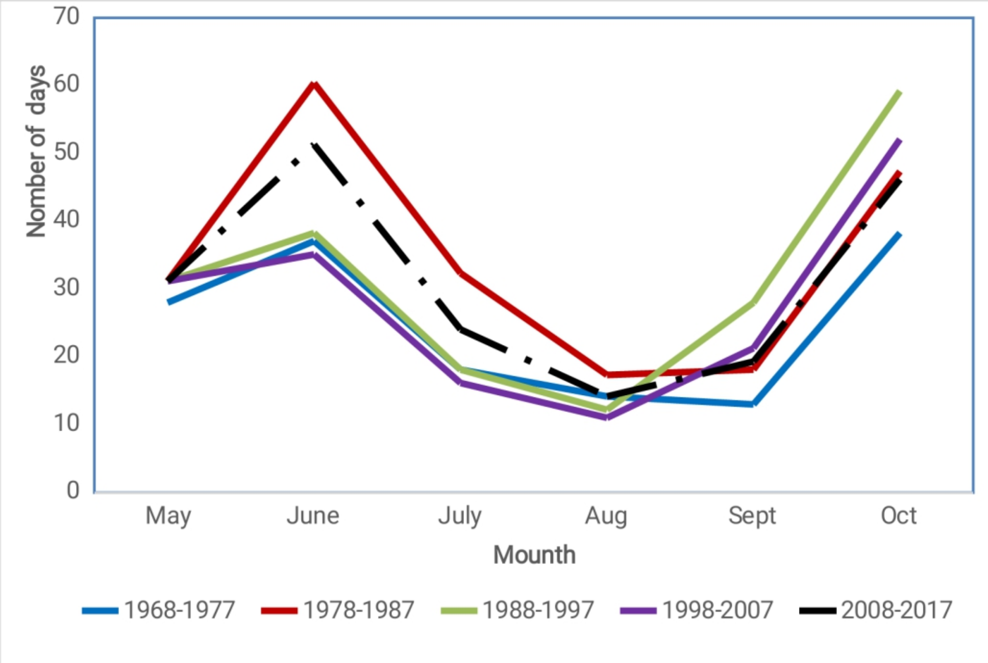

Figure 16. Decadal evolution of dry sequences in Ouallam from 1968 to 2017

3.2 Trends in Temperatures

For the trends in temperatures, only data from Tillabery synoptic station will be considered.

The Lamb index values (1982) on the maximum temperatures of the Tillabery station 1968 - 1969 corresponds to a period that is relatively hot;

- 1973 to 1978 is a period characterized by a short cooling corresponding to a slight drop in maximum temperatures related to the La Niña phenomenon (WMO, 2004);
- 1990 to 2015 is a period marked by a continuous increase in maximum temperatures, with artifacts related to the El Niño or ENSO Southern Oscillation event, during the period between 1997/1998 (WMO, 2015);
- 2004 to 2014 corresponds to the hottest period compared to the average of the 1968-2015 series.

The Lamb index values recorded in 1982 for minimum temperatures (Figure 18) showed a linear trend towards warming that has started in 1968 with a fairly rapid increase since 1980. Nevertheless, there is an artifact from the El Niño phenomenon of the 1970s (WMO, 2004).

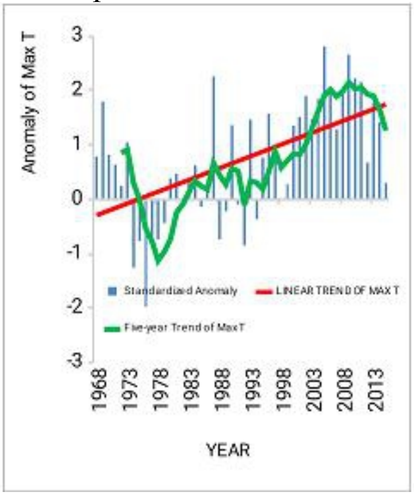

Fig. 17: Evolution of the standardized anomaly of Tmax at Tillabery between between 1968 and 2015

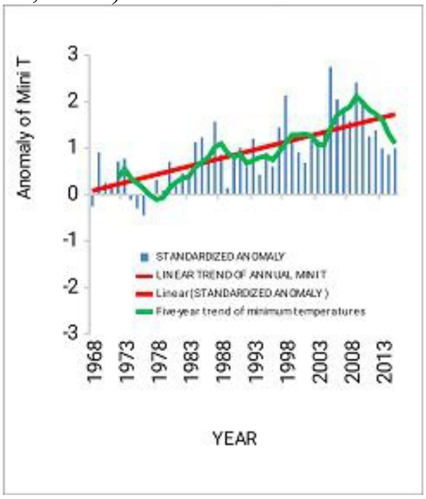

Fig. 18: Evolution of the standardized anomaly from Tmini to Tillabery 1968 and 2015

3.3 Bioclimatic Aridity Indexes in the Study Area

The values of the bioclimatic aridity indices determined by the FAO / UNESCO method (1979) (Figure 18) decreases from South to North. These results are in line with the study of Larwanou (2005).

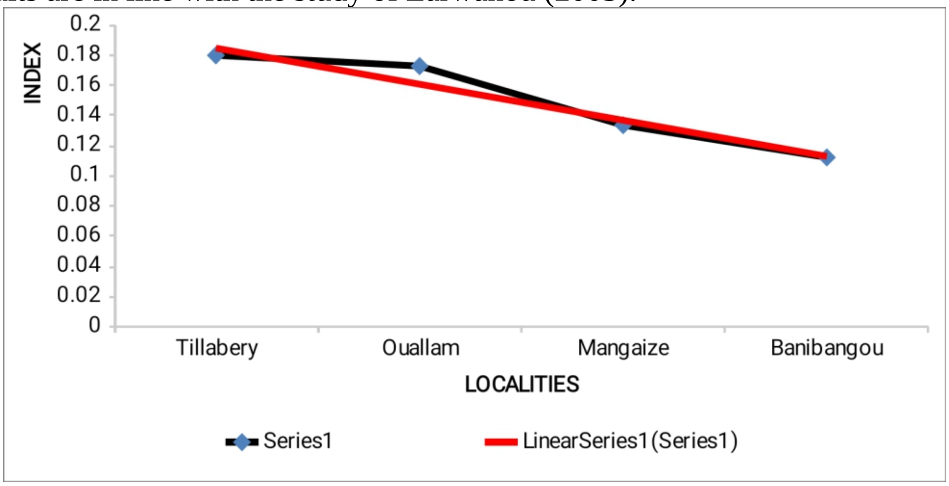

Figure 19. Evolution of the bioclimatic aridity indices in the study area

Moreover, these different values between 0.03 <P / ETP <0.2, have helped to establish a map (Figure 19) confirming that the study area is globally located in an arid environment. However, this aridity also confirms the variation from South to North, ranging from the localities of Tillabery and Ouallam located in the South, when compared to those of Banibangou and Mangaize which is located further in the North.

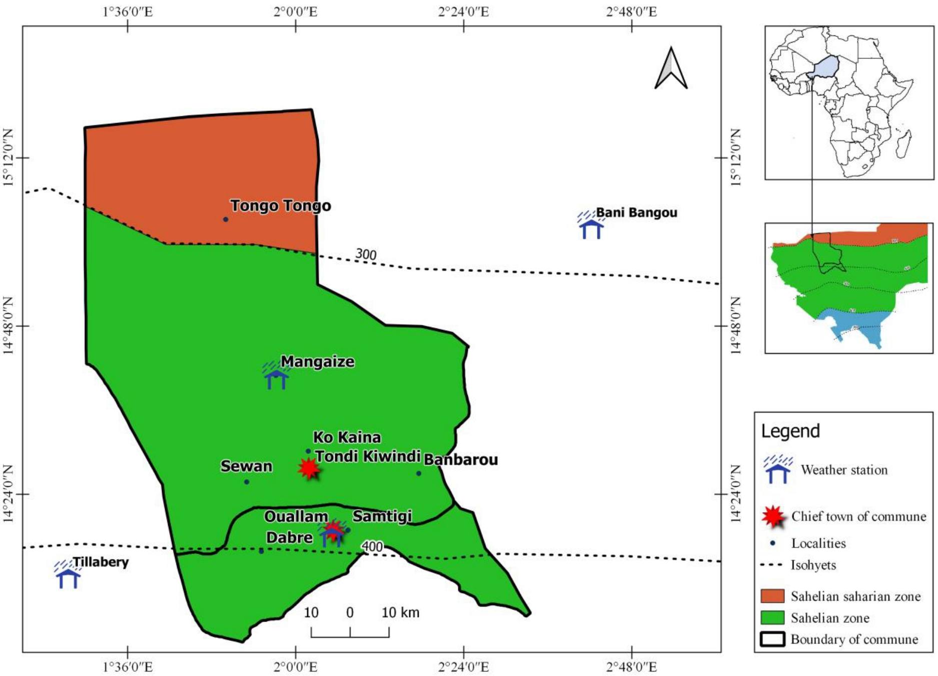

Figure 19. Climatic zones of the communes of Tondikiwindi and Ouallam

3.4 Impacts due to Changes in Rainfall and Temperatures

The impacts mainly concern crop limit, cereal shortage, and variability of crop yields, livestock losses, rarefaction or even the disappearance of certain woody species, migration and floods.

- **Evolution of Crop Limit**

The northern limit of rain dependent crops has changed in recent years due to high rainfall in the northern zone (Tables II and III). For example, Mangaize station at the northern limit of crops passes into the cultivation zone, and that of Banibangou located mainly in the pastoral zone has become the northern limit of crops. This development has contributed to the multiplication of social conflicts that have led to a significant increase in the number of people killed (UNISDR, 2014).

Table I. Average values per station from 1968 to 2008

Meteorological station	Average value of the series (1968 to 2008)	Climate zone
Banibangou	245.6 mm	Sahelo-Saharan zone
Mangaizé	300.6 mm	Limit of the Sahelo-Saharan zone (northern limit of crops)
Ouallam	384.9 mm	Sahelian zone
Tillabéry	397.9 mm	Sahelian zone

Tableau II. Average value per station from 2009 to 2015

Station météorologique	Valeur moyenne de série (2009 to 2015)	Zone climatique
Banibangou	320.9 mm	Limit of the Sahelo-Saharan zone (northern limit of crops)
Mangaize	357.4 mm	Sahelian zone
Ouallam	399.7 mm	Sahelian zone
Tillabery	450.9 mm	Sahelian zone

- **Evolution of Shortage**

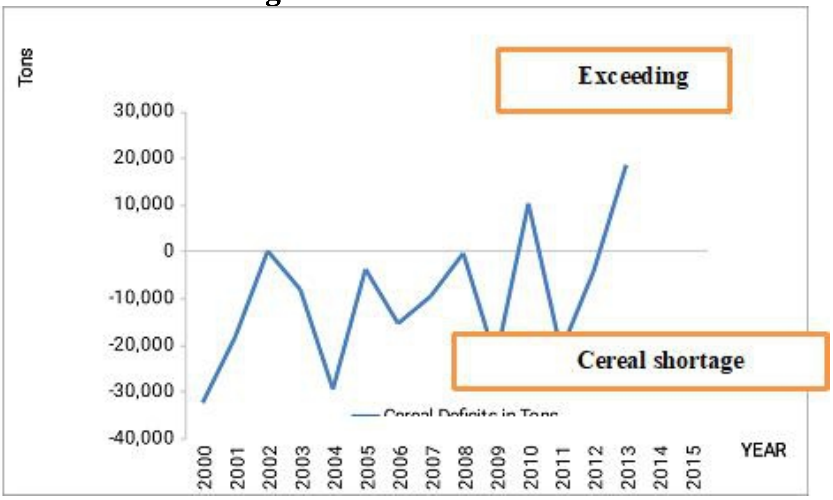

Figure 6. Evolution of cereal shortage and exceeding crops

- **Evolution of Agricultural Yields**

Low crop yields (Figure 21) are also related to rainfall shortage and poor monthly or decadal rainfall distribution. These results are in line with those published by Sultan (2011).

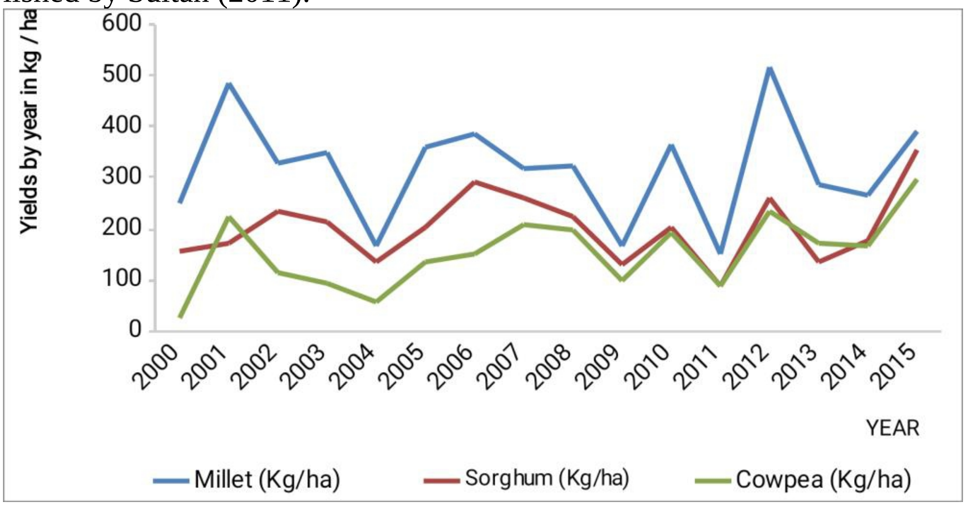

Figure 22. Evolution of millet, sorghum and cowpea

- **Losses of Livestock**

In the department of Ouallam, figures for livestock losses during the two major droughts of 1973-1974 and 1983-1984 are not available. However, the figures on livestock losses in 2010, as a result of the rainfall shortage, are as follow: 18,387 cattle, 38,424 sheep, 16,243 goats, 610 camels, 2,002 insects, 96 horses, totaling 75,762 heads of all animal species combined. This corresponds to 7.12% of the total staff of the Department (MAGEL, 2011).

- **Rarefaction or Even Disappearance of Certain Woody Species**

Several woody species have become rare or extinct in the study area (Idrissa, 2016) (Table IV). Moreover, these species only grow in the wetter southern part of the country today. Bonnet et *al.* (2008) stated that anthropogenic factors also contributed to this disappearance. In fact, 99.1% of households used wood for the construction of their homes, 97.01% used it as fire woods, and 5.7% used it as a source of lighting (Idrissa, 2016). In addition, wood has become a source of income through its commercialization in the main urban centers.

Table III. Rare or missing woody species from the study area

Local name (Zarma/Songhoy)	Scientific Name	Family
Dagna	*Acacia senegal*	Mimosaceae
Forgo	*Bombax costatum*	Bombacaceae
Sinsa	*Cassia sieberiana*	Caesalpiniaceae
Sèè	*Celtis integrifolia*	Ulmaceae
FarkaHanga	*Cola laurifolia*	Sterculiaceae
	Terminalia avicennioîdes	Combretaceae
Korombe (Dargassa)	*Commiphora africana*	Burseraceae
Fantu	*Detarium microcarpum*	Caesalpiniaceae
Kobbe	*Ficus platyphylla*	Moraceae
Sâari	*Grewia bicolor*	Tilliaceae
	Grewia tenax	Tilliaceae
Farrey	*Khaya senegalensis*	Meliaceae
Tarmaza	*Lannea microcarpa*	Anacardiaceae
Zamturi	*Prosopis africana*	Mimosaceae
Tôlo	*Pterocarpus eurynaceus*	Fabaceae
Bossey	*Tamarindus indica*	Caesalpiniaceae
Boî	*Vitex doniana*	Verbenaceae
Mollan= Moraye	*Ximenia americana*	Olacaceae

- **Population Migration**

Many people migrate to the more favorable areas of Niger or other countries (Table IV). Thus, in the commune of Tamou, several villages bear names of origin of those emigrants in order to attract the attention of future generations.

Table IV. Villages of displaced climate change from Ouallam to Tamou

Name of the village in Zarmaganda	Municipality of origin	Name of the village in the rural commune of Tamou	Year of emigration
Kabe- Kaina	Tondikiwindi	Kabe- Kaina	1984
GabdaBorey-Do	Simiri	GabdaBorey-Do	1984
Séno- Konkodje	Tondikiwindi	Seno- Konkodje	1984
Gosso	Dingazi-Banda	Gosso	1984
Koulagou	-	Koulagou	1984
Tonga- Koira	Tondikiwindi	Tonga- Koira	1984
Sabako	Tondikiwindi	Sabako	1984

- **Floods in the Study Area**

In the communes of Tondikiwindi and Ouallam, several floods have been observed, making them at 5th and 7th position respectively in the Tillaberi region (ANADIA, 2014). These floods are linked to the high frequency of rainfall, with daily quantity exceeding 50 mm (Figure 22). This frequency was observed by SARR et al. (2007).

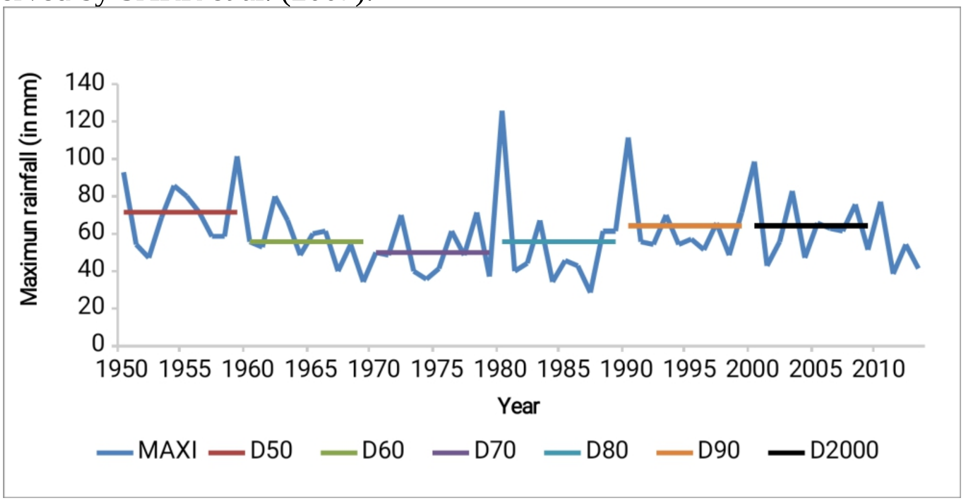

Figure 23. Decadal evolution of daily rainfall above 50 mm between 1968-2015 in Ouallam

- **Socio-economic and Environmental Effects**

Significant damage to social infrastructure (Photo 1), communication routes (Photo 2), and livelihoods have been recorded from major floods after the 1990s (Idrissa, 2016). In addition, they favored the establishment of temporary, semi-permanent, and permanent water bodies all along the kori line of Ouallam (Figure 24).


Photo 1. School building abandoned


Photo 2. Niamey-Ouallam road damaged

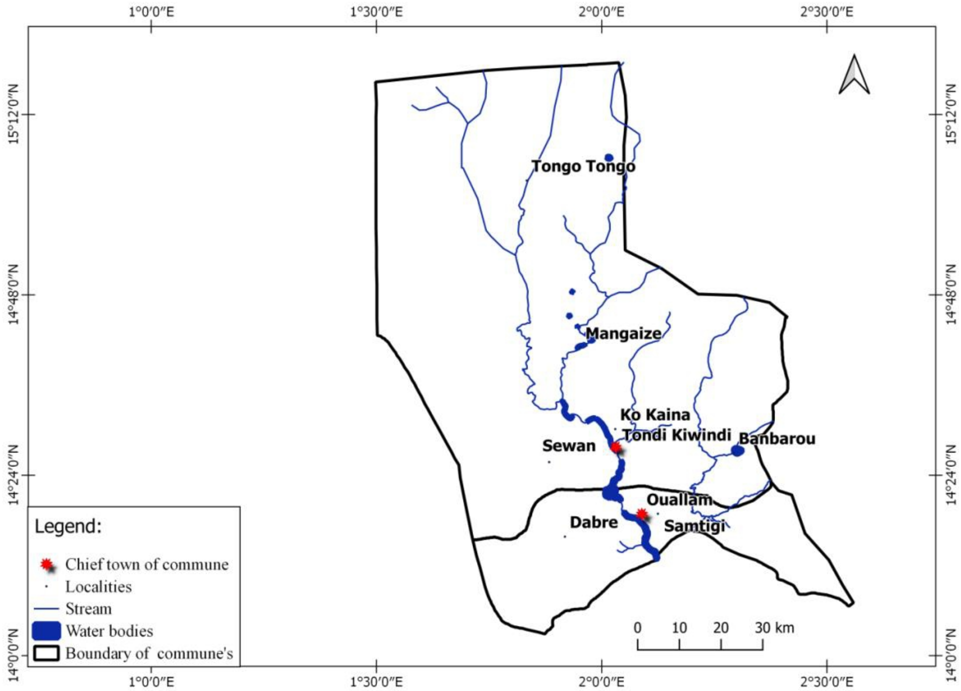

Figure 24. Map of permanent and semi-permanent water bodies

Conclusion and Recommendations

The indexes of Lamb (1982) and Tabony (1977) determined for the time series of the Banibangou, Mangaize, Ouallam and Tillabery stations for the period between 1968 to 2015 had shown a long dry period in all stations from 1968 to 1989, rare wet years (1978, 1980), and relatively wet season from 1990 to 1998. The seasonal patterns are also characterized by great variability, and marked by wet and dry years alternatively from 1999 to 2015.

The analysis of the evolution of rainfall and temperatures in the study area has made it possible to highlight the important socio-economic and environmental impacts in the communes of Tondikiwindi and Ouallam. Thus, changes are noted in the limit of crops, fodder and their associated shortage, animal death, rarefaction or disappearance of certain woody species, as well as various socio-economic and environmental impacts. Therefore, it is very important to upscale best practices for land management and other livelihood strategies in the study areas.

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