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Frequency Analysis and Exploratory of Rainfall Variability in Bounkiling River Basin in a Context of Climate Change and Variability

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ABSTRACT: *The goal of this article is to conduct a frequency analysis and exploratory of rainfall in the Bounkiling watershed. Usingrainfall time series of Bounkilingrain gauge, we have first conducted the frequency analysis to determine the rainfall distribution and define the future occurrence probabilities. Hydracess software is used to calculate the frequency of the rains, return periods and the coefficients of severity and irregularity. Next, we have performed exploratory analysis based on graphs to highlight the alternation between wet and dry periods. Analysis of the results allowed classifying the rainfall of Bounkilinginto four levels (very heavy rainfall, heavy rainfall, low rainfall and very low rainfall).Results also show that the gap between a wet year and a dry year of the same frequency, increases with recurrences. At the annual scale, level, the gap between the maximum and the minimum is very significant and varies greatly from year to year. Indeed, 2005 is the most surplus year in 1980 and the most deficits. At the monthly scale, August is the wettest month and May the less rainy. This study represents a real opportunities for decision makers in the management of irrigation schemes and strategies against the hydroclimatic risks.*

Keywords: *Frequency and exploratory analysis, Rainfall trend, climate monitoring, sustainable water resources, Bounkiling river system, Senegal.*

I. INTRODUCTION

Nowadays, climate change and variability constitute one of the greatest challenges which humanity must face. They become a potentially major threat for the environment and sustainable development [1].According to [2],these climatic eventshave a great impact on economic and social human activities related to water resource such as agriculture. So, there is strong likelihood of effects of climate change on agricultural productivity and food security in much of the arid regions [3, 4].The collective awareness of the profound influences of climate on populations, ecosystems and their survivals, has led to numerous studies on the subject at worldwide scale [5]. It is through this work to seek a better understanding of the interactions between the negative effects of climate and adaptation strategies for sustainable development[6,7].Climate events are mainly a blend of several factors of natural and / or anthropic orders [8]. It is therefore important and necessary to take into account the parameters allowing monitoring and apprehending the essential aspects of climate evolution. That would constitute according to [9,10], an undeniable condition to develop adaptive development strategies for forecasting and sustainable water resources management. [11] reveals that rainfall plays a key role in the climate monitoring and these manifestations; particularly it contribute to the planning and management of sustainable water resources. According to [12,13], rainfall constitute the most used parameter in reliable diagnosis and analyzes of the climate and its evolution. [11,14] reveal that rainfall plays a key role in the planning and management of sustainable water resources, particularly as the fundamental design parameter for dam safety and flood risk analyses) and [15,16] to add that rainfall is the main source of water for crop production as irrigation covers only 5% of the cultivated land in many African countries. According to [17] most of the water resources projects are designed based on the water availability and demand, assuming constantly climatic behavior. So, any change in the climatic behavior has a big influence in the precipitation regimen [18,19]). In addition, the existence of an increasing or decreasing trend in hydrological time series can also be explained by the changes of the factors that influence the precipitation [20]. The adverse effect of climate fluctuations on rainfall and runoff are mainly reflected a decline in the quantity and frequency of rainfall in time and space a change in timing of occurrence [21,22], seasonal changes in rainfall changes in the response of a basin causing a rise in temperatures [23,24]. According to [25,26], future climate incidences on freshwater river networks will amplify problems caused by other constraints such as population growth changing economic activity changes in land use and urbanization and water needs (irrigation household consumption hydropower) will increase in the coming decades. [27] adds that these incidences would influence all characteristics of precipitation in terms of intensity, frequency and duration. Unfortunately, poor communities will be more vulnerable because of their limited adaptive capacity and high climate sensitivity with high resource dependency such as water resources and agricultural production systems [28]. The West Africa the poorest region of the continent will suffer more extreme events [29]. These disturbances are becoming more frequent intense and generate significant impacts on lifestyles and livelihoods of populations [30,31]. These impacts put people their development activities and become repetitive and their increasing vulnerability situation [32,33]**.** It is with this realization that the study on climate and its effects have caught the attention of researchers at the National, regional, and international levels [34, 35,36]. It is for these scientists to understand the dynamics of climate and to think in terms of reliable assessments of the impact of climate hazards on natural resources to develop coping strategies and appropriate to the new conditions forecast environmental [37,38]. In West Africa a lot of work in this direction and based on statistical tests have identified and characterized the magnitude of climate fluctuations from the rainfall series [39,40]. However[41] precise that to ensure the quality of the results on the study of climate change and variability and its impacts, the check for quality and reliability of data , is a priority and obligation; and must also robust and adequate approaches. It should also be noted thatnowadays, there are several methods and tools using the hydro climatic series to make statistical studies of the climate [41]. These require methodological rigor and should lead to conservative interpretation [42]. Therefore the choice must be made by identifying tools and/or methods capables accurately highlight all the events related to climate variability and change and their impact on water resources to ensure prediction [43]. This study focuses on the watershed of Bounkiling located in Lower Casamance in southern Senegal. Our mission through this study is to carry out frequency analysis and exploratory extreme hydro events in this agriculture-based Basin. We used rainfall data of Bounkiling station over the period 1975 to 2014. These data are from ANACIM (National Agency of Civil Aviation) is a national organization specializing in the collection of climate data. The goal through frequency analysis to identify the different situations experienced by the area Bounkiling in this column and extract all the information that can inform us about the climatic characteristics of this period; and through the exploratory analysis to highlight the distribution of general rain and see how the cycles of wet and dry periods have a spatial and temporal scale and an intensity varies. We initially process a frequency analysis to determine the distribution of rainfall and define the future occurrence probabilities. To this end the focus is on the calculation of the frequency of rain return periods and coefficient of irregularity. The Gumbel law and the law of Frechet that are most suited to annual rainfall of Bounkiling station are used. Our motivation at this level is to bring specific elements of knowledge about events in terms of variability and climate instability and its relationship to that of water resources. This would from development of different climate scenarios to help estimate and sustainable water resources management. The Hydracess software for such analysis was used to quickly make calculations. Secondly we proceeded with an exploratory analysis based on graphs to highlight the distribution of rainfall in terms of deficit and / or surplus. In this context we were interested to annual rainfall, maximum annual rainfall, monthly rainfall and monthly rainfall coefficient. This allowed us to have a clear idea on the distribution of rainfall on an annual basis, monthly and seasonal.

II. METHODS AND MATERIALS

1.1. Study area and data

The Bounkiling watershed is located in the lower Casamance southern Senegal between latitude 13 ° 08 N and longitude 15 ° 38 W (Fig. 1). It is bounded to the north and west by the Republic of Gambia the south by the municipalities of Inor and DiaroumeDiambati and to the east by the municipalities of Bourouco and Ndorma. It covers an area of 795.9 km2 in the rainfall station Bounkiling [44]. The climate is Sudano-Guinean type marked by alternating dry season from November to April and a wet season from May to October. August is the wettest month with an average around 300 mm. Annual rainfall revolves around 1000 mm. The lowest average monthly temperatures are recorded between December and January between 25 and 30 ° C the highest are rated between March and September with variations of 30 to 40 ° C [45]. The dry season is marked by the continental trade wind (or Harmattan) and the rainy season monsoon. The relief consists mainly of plateaus valleys and lowlands. Soil types encountered are mainly composed of ferruginous loamy clay soil and waterlogged soils. The vegetation is mainly characterized by rainfall human activities and the type of soil or rock. The plant formations are characterized by a predominance of woodland [46]. In this article we used rainfall data of Bounkiling station over the period 1975 to 2014. These data are from the ANACIM (National Agency of Civil Aviation) which is a national structure specialized in the climatic data collection.This structure guarantees the quality and the reliability of this time series.

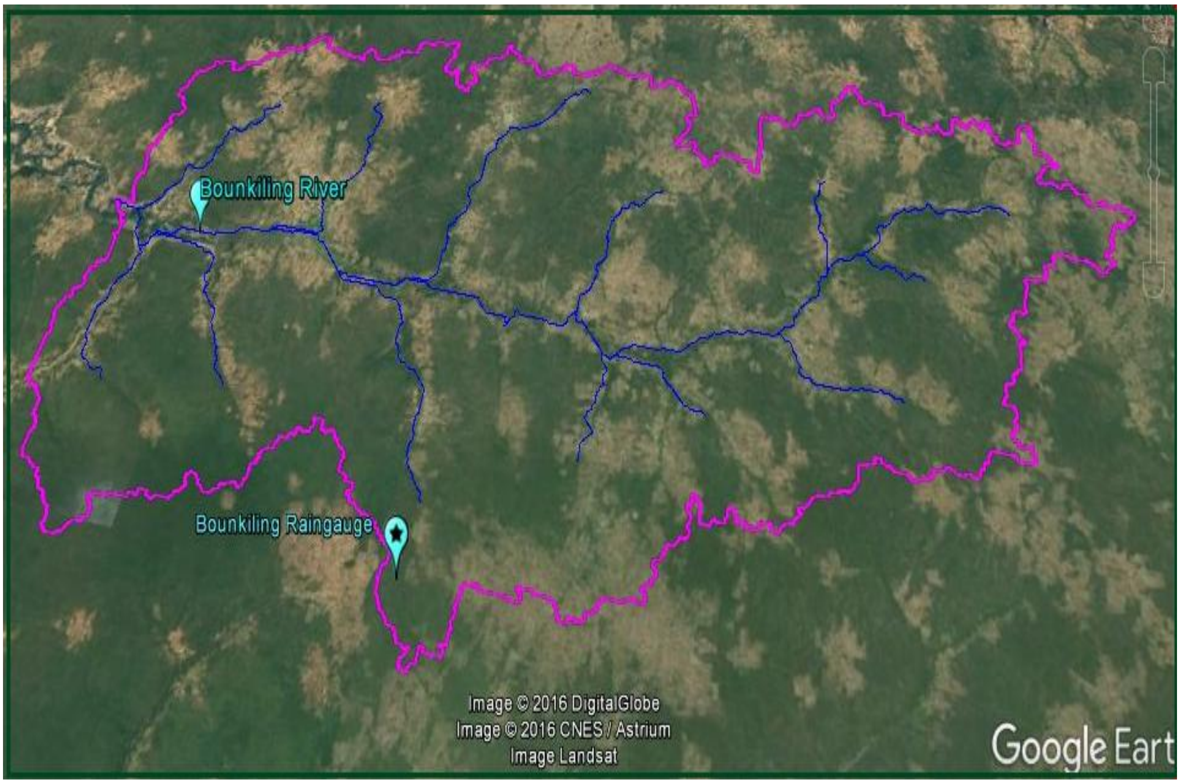

Fig.1. Localisation of study area

1.2. Frequency analysis

It is a statistical prediction method of studying past events characteristics of a given process (hydrological or other) in order to define the future occurrence probabilities [47]. This prediction is based on the definition and implementation of a frequency model which is an equation describing the statistical behavior of a process. These models describe the probability of a given value of event. Frequency analysis uses various statistical techniques and is a complex industry that should be treated very rigorously. Its various steps can be summarized very simply according to the diagram (Fig. 2). The validity of the results of a frequency analysis of the frequency depends on the choice model and especially its type [1]. Various avenues can help facilitate this choice but unfortunately there is no universal and infallible method. Several statistical laws such as laws Gumbel Pearson Frechet Goodrich Normal and Log-normal .are used in frequency analysis [48]. Those that fit best with the values of the variable used would be retained. From a methodological standpoint this characteristic frequency study begins with the arrangement of the variable values in ascending order by giving each variable rank in the series then by calculating the frequency of return periods extraction and rainy days etc., weather events [49].

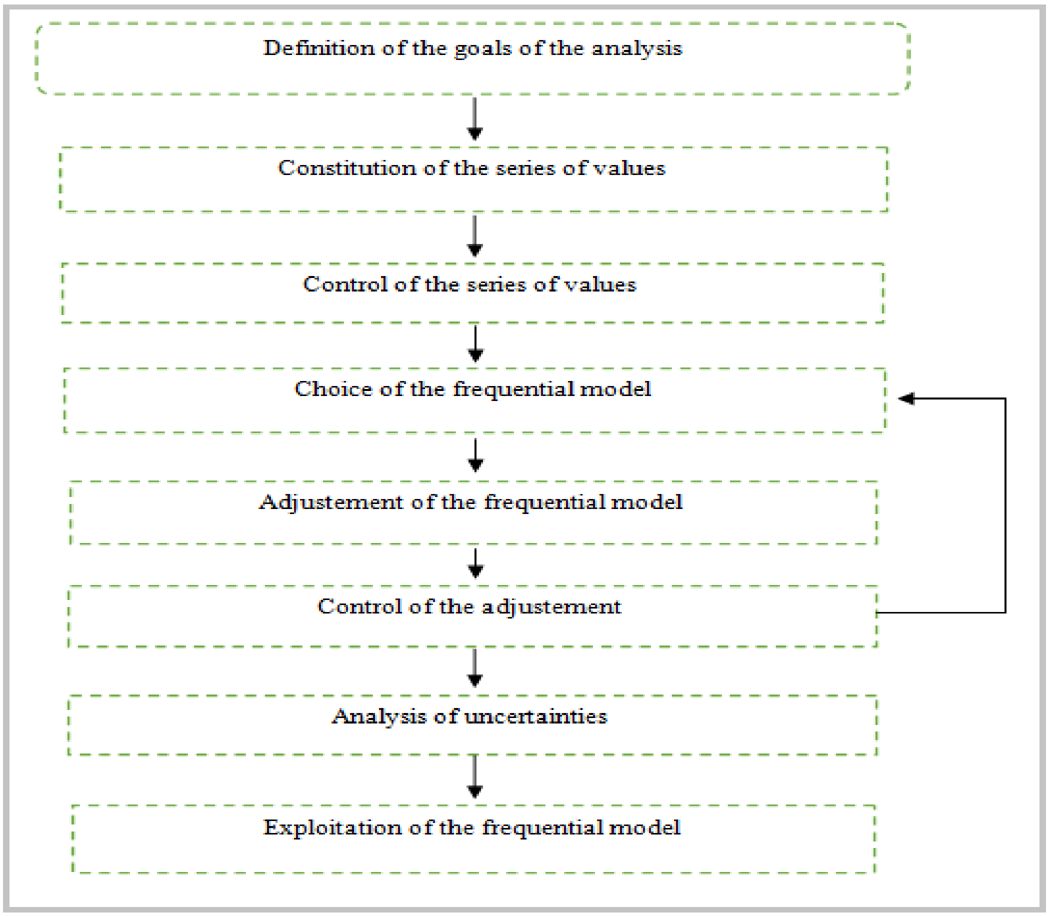

Fig.2. Procédures frequency analysis, adapted of [1]

1.3. Exploratory analysis

The exploratory analysis is a technique to highlight certain factors explaining the correlation and dependency between the variables. It starts data and is based on a logical observation [7]. The explorer with a well stocked toolbox will look its data in all facets try to highlight structures and where appropriate make plausible assumptions. It does not give great importance to the "optimality" of his tool that it behaves "well" in most situations it is sufficient [50]. Climate parameters such as rainfall temperature . on an annual scale decadal and interannual monthly are often exploited. This method is a graphical representation of all comments to visually define their evolution during the study period. A judicious and rigorous interpretation of results provides a global vision and possibly detects forms of irregularities.

III. APPLICATION

We used rainfall data of Bounkiling station over the period from 1975 to 2014.Ces data come from the ANACIM (National Agency of Civil Aviation) which guarantee the quality and reliability of this time series. We initially process a frequency analysis to determine the distribution of rainfall and define the future occurrence probabilities. To this end the focus is on the calculation of the frequency of rain return periods and coefficient of irregularity. The Gumbel law and the law of Frechet that are most suited to annual rainfall of Bounkiling station are used. Our motivation at this level is to identify the various extreme situations experienced by the area Bounkiling in this column and also retrieve all the information that can inform us about the climatic characteristics of this period. The Hydracess software for such analysis was used to quickly make calculations. Secondly we proceeded with an exploratory analysis based on graphs to highlight the distribution of rainfall in terms of deficit and / or surplus. In this context we were interested to annual rainfall maximum annual precipitation average monthly precipitation and monthly precipitation coefficient. This allowed us to have a clear idea on the distribution of rainfall on an annual basis monthly and seasonal.

IV. RESULTS AND DISCUSSION

1.1. Frequency analysis

1.1.1.Repartition of annual rainfall

The goal through this analysis is to try to categorize years of the study period according to their rainfall. Thus Figure 3 shows the distribution of annual precipitation Bounkiling over the period 1975-2014 through the frequencies calculated by the ln-normal distribution. The analysis of this figure compared with the median frequency value leaves appear two years classes Class 1 representing all wet years and 2 class symbolizing dry years. The analysis of class 1 compared to their average, gives two blocks of wet years: bloc_a that brings together years (2009, 2006, 2012, 2008, 2003, 2011 et 2005) characterized by very strong rainfall values and bloc_b that brings together years (1982, 1987,1996, 1978 ,1994, 1981 ,2004 ,2007 et 2010) characterized by heavy rainfall values. Similarly analysis of Class 2 in relation to their average, gives two blocks of dry years: bloc_a that brings together years (2013,1998,1984,2002,1993,2000,2001,1986,1990 , 1997et .1976) characterized by average rainfall values and bloc_b that brings together years (1980, 1977, 1983 ,1995, 1992, 1991, 1985, 2014.1979) characterized by low rainfall values. Ultimately the rainfall of Bounkiling is organized into four blocks.

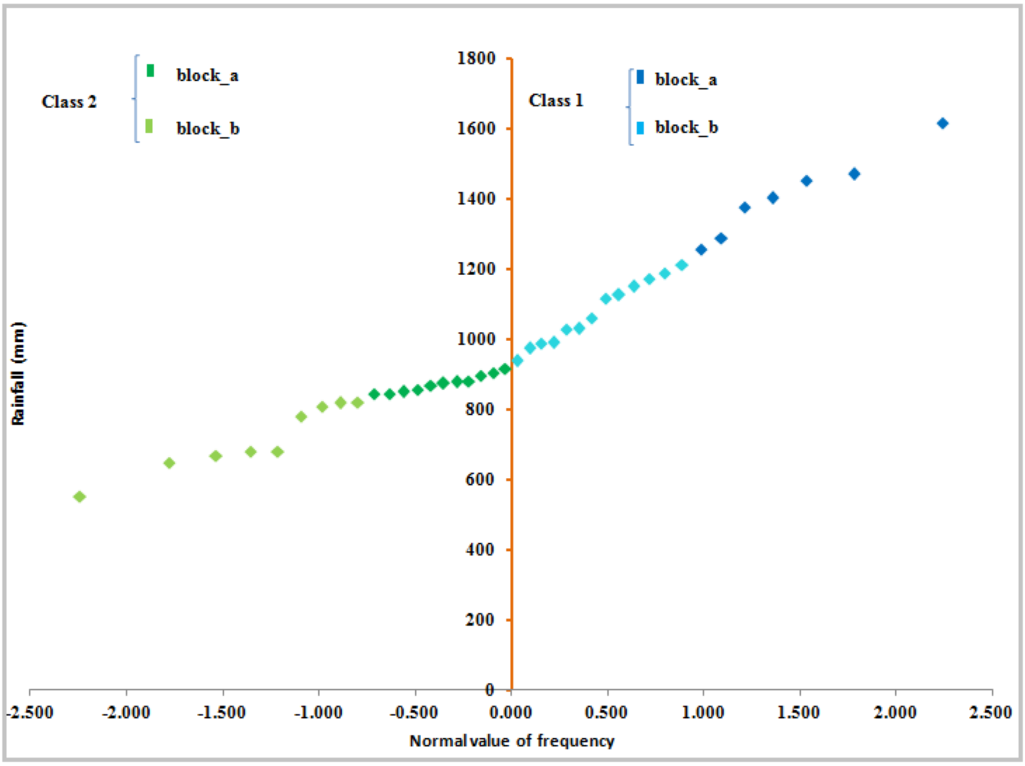

Fig.3. Organizationof Bounkiling rainfall over the period (1975-2014)

1.1.2. Calculation of return periods

The return period (or recurrence) defines the time between occurrences of a natural event of a given intensity. This time allows characterizing natural hazards [51]. We present in Table 1 the values obtained by the laws of Gumbel and Frechet that are most suited to annual rainfall of Bounkiling station. Fig. 4 illustrates the adjustment of the precipitation Gumbel and Frechet. Operation of the table shows that the average study period (959.6 mm with Gumbel and Frechet with 945.7mm) corresponds to the 1/2 median frequency (recurrence or 2 years). The lowest value of the chronic (570.6 mm with Gumbel and Frechet with 587.7mm in 1980) corresponds to a frequency of 1/100 (or recurrence of 100 years). The greatest value of the chronic (1819.5 mm with Gumbel and Frechet with 2065.7mm in 2005) also corresponds to a frequency of 1/100 (or recurrence of 100 years). The analysis of this table shows It shows that either with the Gumbel distribution or Frechet the rainfall difference between a wet year and a dry year with the same frequency increases with recurrences. The figure is graphic illustration of the table; it shows that in reality, the Gumbel distribution is even better suited to Bounkiling precipitation than that of Frechet.

Table1. Return periods for Bounkiling rainfall according the laws of Gumbel and Frechet

	Récurrences sèches					Médiane	Récurrences humides				
Récurrence	100 ans	50 ans	20 ans	10 ans	5 ans	2 ans	5 ans	10 ans	20 ans	50 ans	100 ans
Gumbel	570,6	603,9	658,3	**711,9**	784,9	**956,6**	1187,6	**1340,6**	1487,3	1677,2	1819,5
Frechet	587,7	615,7	662,7	**710,4**	777,4	**945,7**	1197,6	**1382,0**	1573,4	1844,2	2065,7

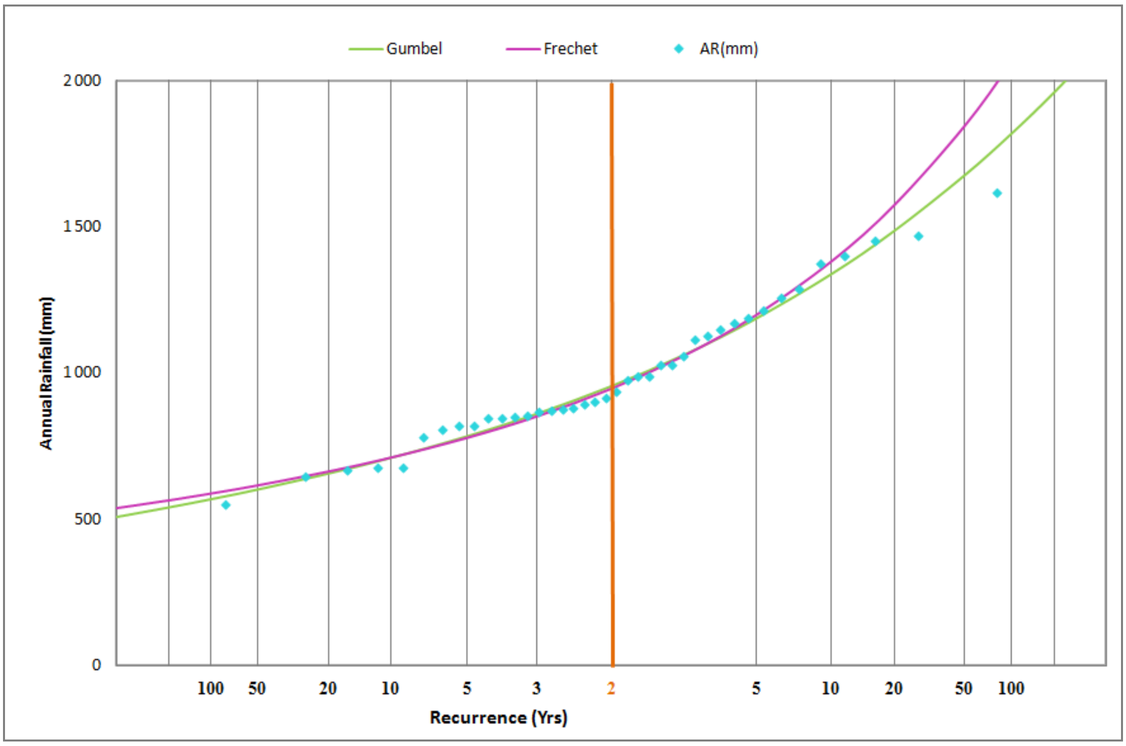

Fig. 4. Adjustment of Bounkiling rainfall to Gumbel and Frechet laws.

1.1.3. Coefficients of irregularity and severity

Gumbel and Frechet's laws fit better to our data. They have therefore been used in calculating the irregularity coefficient (Ki) which allows appreciating the transition of wet and dry periods and severity coefficient (Ks) which allows appreciating the extent of the deficit years. The first is defined by the ratio of the wet decennial induction on the dry decennial recurrence [52] and the second by the ratio of the dry decennial recurrence on the median [53]. The results are presented in Table 2. The analysis of the coefficient (K) indicates that the rainfall station Bounkiling receive decennial wet year about double the expected precipitation in dry decennial year. The analysis of coefficient (Ks) shows that Bounkiling precipitation is regular.

Table 2. Values of the coefficients of irregularity and severity

	Coefficient of irregularityKi (%)	Coefficient of severityKs (%)
Gumbel	1.88	74.4
Frechet	1.94	75.1

1.2. Exploratory analysis

1.2.1. Annual rainfall

We present in Figure 5a were leaving the annual rains Bounkiling station over a period of (1975-2014). This is to make the development of annual rainfall characteristics of Bounkiling watershed through its rainfall station. The year is in deficit when the rain is below average and surplus when the average is exceeded. The years may be very deficient or very excess. A large deficit is a year that received rainfall below the average deficit years and a very surplus year is a year that received above average precipitation surplus years. We present the figure5b distribution of annual rainfall from the average and figure5c the distribution of annual rainfall over ADY and ASY. Of the 40 years of the study period (fig. 5a) we counted 16 wet years dry years and 22 two intervening years. Annual rainfall of Bounkiling experiencing strong interannual variability the difference between the maximum (1616.6 mm) and minimum (551.1mm) reached 1065.5 mm which explains the large rainfall contrast. Furthermore analysis of the fig. 5b brings up very wet years (with higher rainfall than the upper limit) and very dry years (with lower rainfall in the lower limit). 2005 appears as the wettest year 1980 and the driest year. Ultimately we see an organization rainfall amounts of Bounkiling into four categories (very humid wet very dry and dry) as shown in fig. 5c. This corroborates with the results of the frequency analysis.

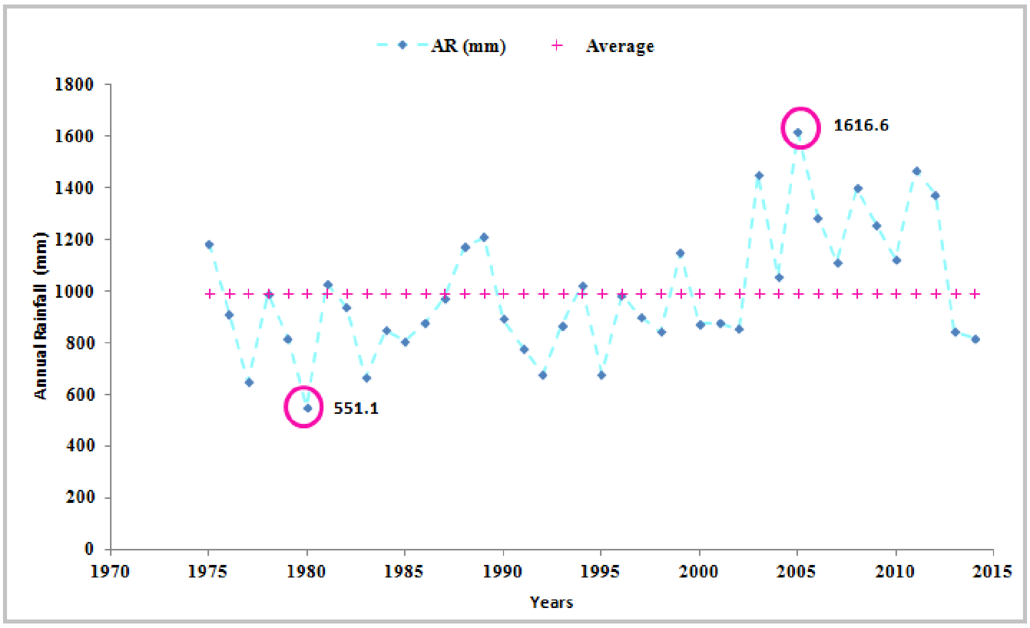

Fig.5a. Distribution of annual rainfall compared to the average

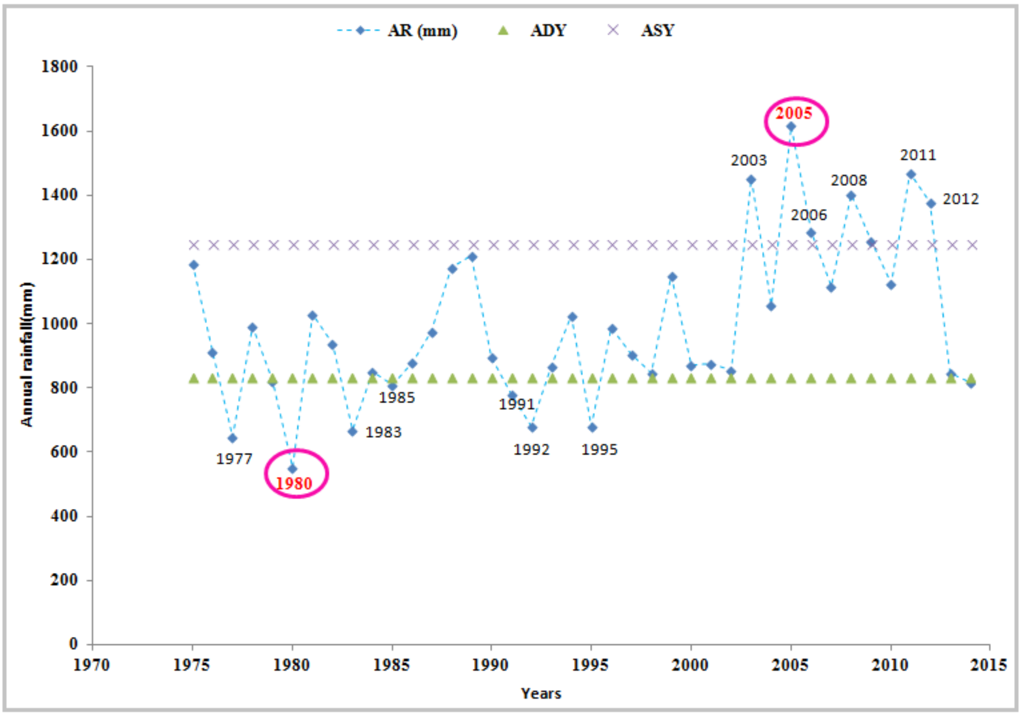

Fig.5b. Repartition of annual rainfall compared to ADY and ASY

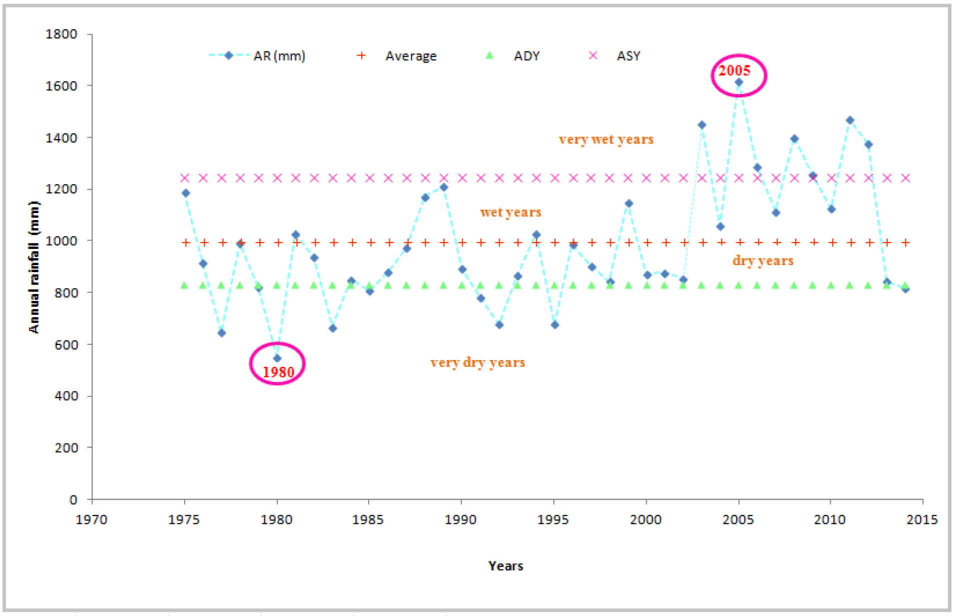

Fig.5c. Categorizing of Bounkiling rainfall over the periods (1975-2014)

1.2.2. Deviation from mean

The deviation from mean (DM) is the difference between annual rainfall and annual average of rainfall. It allows visualizing and determining the number of loss-making years and succession [54]. The year is called wet if the difference is positive and dryer if it is negative. If the difference is greater than the average wet years (rated upper limit) then the year is said to very wet. Similarly if the difference is less than the average of dry years (rated lower limit) then the year is said to very dry [55]. We present in fig. 6 the distribution of deviation from the mean calculated on an annual basis. The direct analysis shows surplus 16 years 22 years and 2 intermediate deficit years. Furthermore the analysis compared to limit values reveals very surplus years 6 and 7 very lean years. In short, 2005 is the most surplus year and 1980 most deficit year.

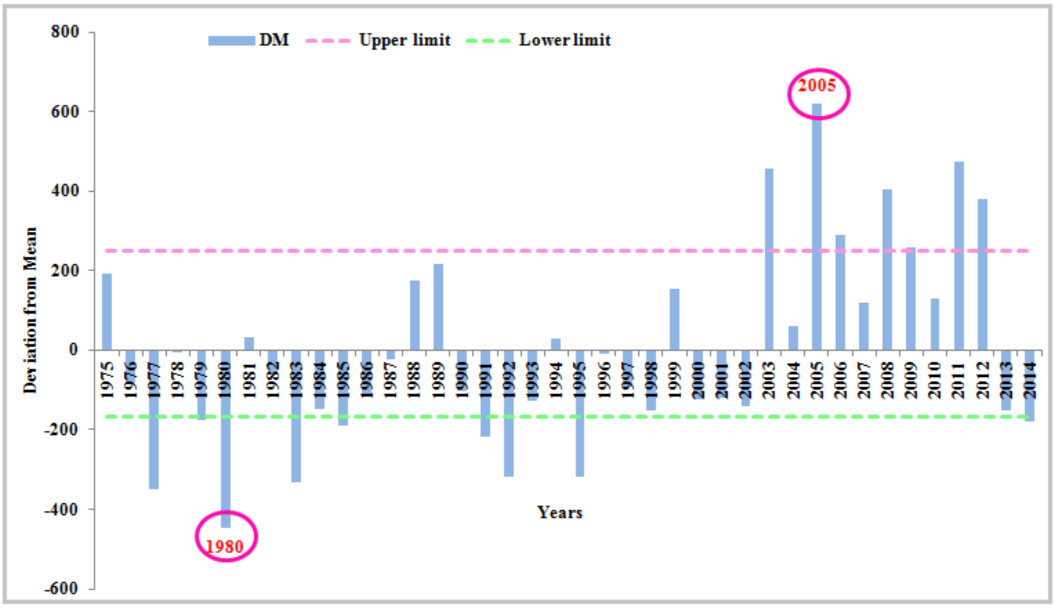

Fig.6. Evolution of the deviation from the mean at annual scale

1.2.3. Maximum annual rainfall

The fig. 7 presents the maximums annual rainfall inputs along the study period. The analysis of the figure shows that the maximum rainfall inputs are at the level of the years (2005, 2009, 1975, 1988 and 2011). The maximum of these rainfall values reached 538.6 mm recorded in 2005 and the minimum values reached 199.6 mm recorded in 1980.

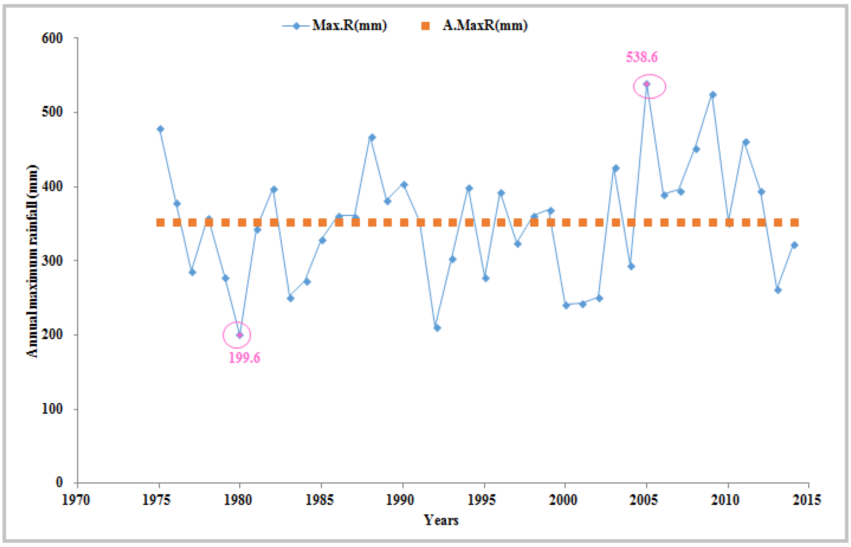

Fig. 7. Repartition of maximums annual rainfall over the periods (1975-2014)

1.2.4. Monthly rainfall average

It is to have an idea on the distribution of rainfall at interannual monthly scale. In fact, the analysis on the monthly variation of rainfall allows bettering understanding the temporal distribution of inputs of Watershed of Bounkiling. The Fig. 8 shows the distribution of monthly rainfall regime at Bounkilingraingauge. The analysis of the figure shows strong monthly rainfall variability, so the gap between maximum (304.4mm) and minimum (7.1mm) reached 297.3 mm. Indeed, the rainy months can be classified into two distinct phases that contrast sharply in terms of precipitation: July, August and September are months with high rainfall and May, June and October months of low rainfall. Aout corresponding to the middle of the rainy season is the wettest month of May and the beginning of the rainy season is the least rainy months. October meanwhile corresponds to the end of the rainy season.

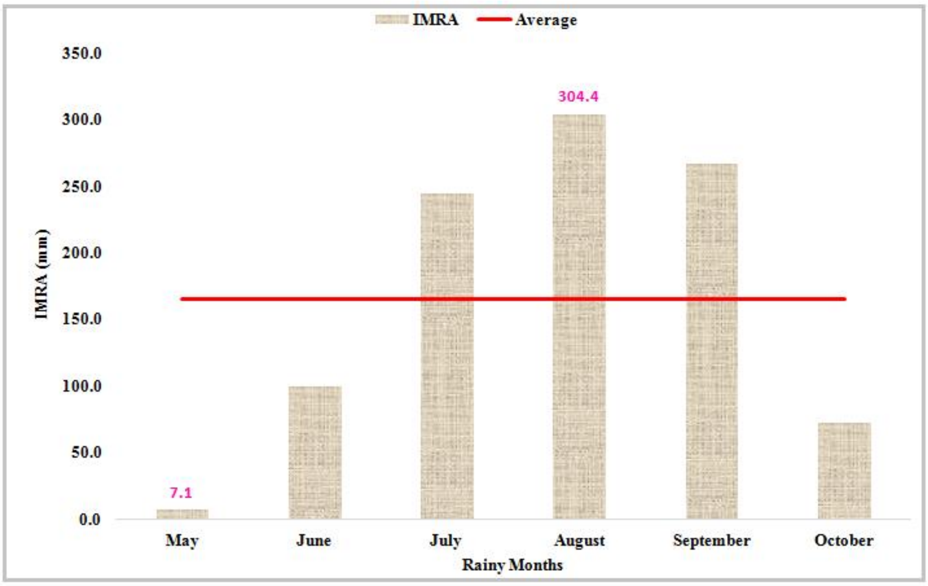

Fig.8. Repartition of the interannual monthly rainfall averages over the period (1975-2014)

1.2.5. Monthly rainfall coefficient

This coefficient allows for cutting a rainy month to determine the winter months (wettest) and summer (less water). It is defined by the ratio of average monthly values of the chronic [47]. Fig. 9 represents the variation coefficient of the monthly precipitation the Bounkiling station. The analysis of this figure brings up two stages in relation to the reference value a very watered phase from mid-June to mid-September; and less rainfall phase that begins May to mid-June (early winter) and from mid-September to November (end of the rainy season).

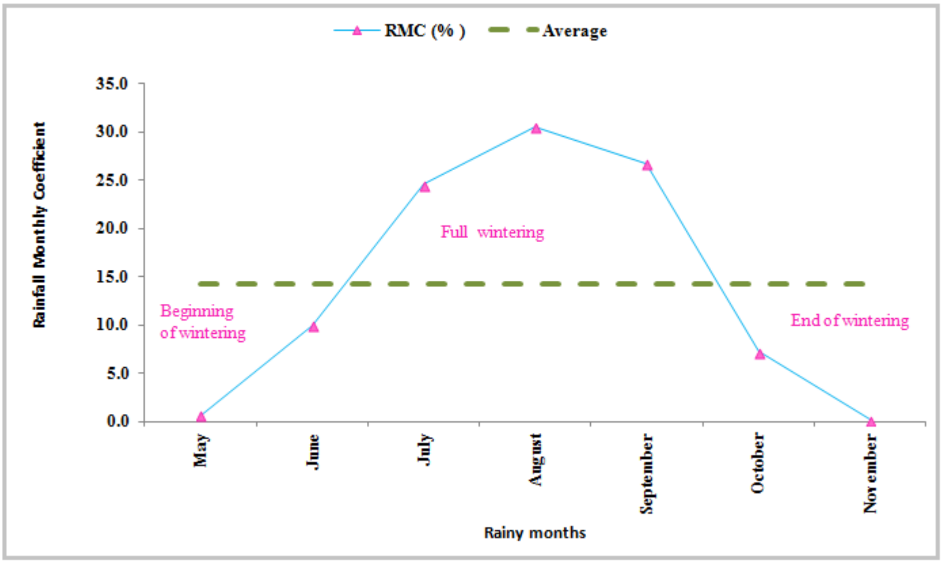

Fig.9. Evolution of monthly rainfall coefficient over the period (1975-2014

V. CONCLUSION

Frequency and exploratory analysis conducted at the station Bounkilingraingauge, was conducted using datacovering the period 1975-2014. Our aim through this study is to determine climate trends from the characterization of rainfall. Analysis of the results led to an organization of rainfall Bounkiling into four blocks (very heavy rainfall heavy rainfall low rainfall and very low rainfall). It also showed that the rainfall difference between a wet year and a dry year with the same frequency increases with recurrences. At the annual level the difference between the maximum and the minimum reached a very high proportion; annual rainfall varies quite considerably from one year to another in 2005 stands out as the most over-year in 1980 and the most deficit year. At the monthly level the analysis of class results in July August and September as months with high rainfall and May June and October months of low rainfall. August is the wettest and May the less rainy. These results are very important in the spatial and temporal characterization of climate Bounkiling watershed highlighting the differences that can occur between a wet year characterized by an excess of water and a dry year dominated by a deficit of water. In this sense this study provides interesting insights for managers of development. It is important to recognize that the characterization performed in this study is essentially limited to the analysis of the spatial structure of rainfall. It would then analyze the temporal variability of rainfall in order to reach a spatiotemporal characterization fuller rain. For this in the short term it is urgent to combine data collected on the ground by specialized services such as those addressed in this work and those obtained from satellite observations to parallel the spatial structure of rainfall on the ground and that systems convective altitude. This will help to place at the disposal of the decision makers, a very powerful tool for emergency programs

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