P-ISSN 2170-1318/ E-ISSN 2588-1949

DETECTION OF INHOMOGENEITIES AND BREAK POINTS IN ANNUAL RAINFALL SERIES OF SENEGAL REGIONS

TRAORE Vieux Boukhaly [1,2*], DIOUF Rokhaya [2,3], NDIAYE Mamadou Lamine [2], GODFROYD Ousman Rilengar [4], FAYE Moustapha [5], MALOMAR Giovani [4], SARR Joseph [5], DIAW Amadou Tahirou [2], BEYE Aboubaker Chedikh [1,4]

(1)Hydraulics Laboratory and Fluid Mechanics, University Cheikh Anta Diop (UCAD) Dakar, Senegal

(2)Geoinformation Laboratory, Polytechnic High School Cheikh Anta Diop University, Dakar, Senegal

(3)Environmental Sciences Laboratory, University Cheikh Anta Diop (UCAD), Dakar, Senegal

(4)Physics Solid and Sciences of Materials Laboratory, Cheikh Anta Diop University, Dakar, Senegal

(5)Fluid Mechanics and Applications Laboratory, University Cheikh Anta Diop (UCAD), Dakar, Senegal

Email: 1vbtraore@gmail.com/ vieuxboukhalytraore@yahoo.fr

(Received 29 May 2018– Accepted 2 June 2018)

Abstract.- *Annual rainfall data used in this study was provided by National Agency of Civil Aviation and Meteorology measured in 14 stations of 14 regions of Senegal. Standard normal homogeneity test was performed on these data to detect possible climatic accidents. Our main goal was to provide national decision-makers with plausible scenarios of climate change for all regions of the country. It is to equip them to: i) adapt their natural resource management strategies to climate change issues; and ii) strengthen the scientific base for their own benefit. For all 14 stations, the null hypothesis of no break is rejected at the 5% threshold and the break dates are between 1955 and 1971 depending on the region. The comparison of averages across the breaking point shows that this break is down for all 14 stations. The characterization of the mean amplitudes before and after rupture shows that this decrease did not have the same intensity in the 14 regions. Finally, the characterization of the wet and dry sequences shows that the temporal persistence of the drought is not at the same level for the 14 regions. In conclusion, the statistical analysis of the rainfall contributions confirms the dissymmetry and the general downward trend and therefore the low water level in Senegal. Such results suggest the need for water authorities to formulate effective water management policies according to the prevailing and future climatic conditions. Transitional, adaptive and urgent measures may be undertaken by priority according regions.*

Key words: *Homogeneity analysis, break points, droughts events, climate change, water availability, sustainable development, food security, agricultural policy.*

Introduction

For some time now, climate change and variability have been a concern for scientists and policymakers because of their immediate and long-term environmental consequences [1]. According to OUARDA *et al.* (1999), climate variability is an effect of natural conditions whereas climate change is due to natural conditions and human activities [2]. Drought is one of the most disturbing and insidious manifestations of climate in many countries in West Africa, particularly in sub-Saharan Africa [3]. It is characterized by a drastic decrease or a bad distribution, or an absence of rainfall in a given region for a period of time [4]. In any case, the rains become insufficient to meet the needs of the environment and human activities [5,6]. This situation has several consequences such as: the reduction of arable land, the yield of crops, the reduction of surface and underground water, the supply of drinking water, the soil moisture and the level of water stored in dams [7,8]. According to DIOUF *et al.* (2016) African and Asian countries are more concerned with their dependence on natural rainfall than for the production of irrigated land [9]. Since there are many relationships between climate instability, rainfall and demand, we have had a lot of attention to climate change in the regions of the world [10]. In Asia, a lot of work in this direction have identified and characterized the magnitude of climate fluctuations and its effects. GUO *et al.* (2002) studied the impact of climate change on water resources of the Hanjiang basin and their results showed that the precipitation change is the main factor for the change in runoff [11]; KAHYA and KALAYCI (2004) used precipitation, temperature and runoff data to analyze and assess the impact of climatic change on the water resources in China [12]; DHEEBAKARAN *et al.* (2015) investigated the impact of climate change on monsoon in Tamil nadu , they have identified shift in rainy season over the period from 1950 to 2010 and pre-monsoon sowing weeks at block level [13]. The World Bank (2013) has studied the large dependency of populations on the stability of monsoons. The results showed the disruption in monsoon regimen cause some serious threat on water and food resources; the incidence of climate change on subsistence crops and water seasonal availability may strongly hinder the sustainability and in many ways, complicate the multiple efforts related to drinkable water supply, irrigation, hydro-electric production and thermal power plants cooling systems [14]. In West Africa, many studies on climate variability have shown rainfall anomalies that have affected the flows of rivers, causing a considerable drop in their hydrological characteristics, degradation of vegetation cover (which has an influence on hydrological regimes) and many socio-economic problems whose effects are often difficult to reabsorb [15-17] characterized rainfall variability on a monthly and yearly scale, in the Mono-Couffo watershed in Cotonou, Benin; results shows general trend of rainfall decrease in Cotonou; PAETH and HENSE (2004) and PATUREL *et al.* (2010) showed that a drying trend was evident from the end of the 1960s confronting Ivory Coast to the water problem including a drying up of most surface water sources, many wells and therefore a significant drop in groundwater level tablecloths [18,19]; ROSINE *et al.* (2014) examined the impact of climate change on the evolution of N'zi River (main river of the Ivory Coast) [20]; OLIVRY *et al.* (1998) and MAHÉ *et al.* (2005) showed that beyond immediate response annual flow of rivers to deficit rainfall season, some sustainability deficit hydrological should be attributed to the cumulative effect of years of drought [21,22]. Other studies have been conducted by various researchers to assess the impact of climate variability on water resources and population dynamics: SAVANÉ *et al.* (2011) evaluated the impact of declining rainfall on aquifers in the region of Odienné [23]; GOULA *et al.* (2006) conducted a comparative study of the effect of drought on the watershed and that of N'zi N'zo [24]; BROU *et al.* (1998) studied the relationship between climate variability and human activities [25]; YAO *et al.* (2012) analyzes the interannual variability of rainfall and flows to assess the water availability in the basin of the Lobo in Ivory Coast [26]; AHOUSSI *et al.* (2013) studied the existence of climate variability in Côte d'Ivoire, specifically in the area of Abidjan-Agboville, and its impact on water resources supply [27]; PAYNE *et al.* (2004) and CHRISTENSEN *et al.* (2004) [28,29] showed that climate implications on those water resources are particularly strong), and affect, in turn, numerous activities sectors industries both economic development (agriculture, industry, hydropower) and for the future of the populations (health, drinking water supply, food security) [30,31]. In sub-Saharan Africa, many studies showed food production systems are more and more affected by climate change effects. CONWAY and SCHIPPER (2011) noted a sensitive reduction of crops productivity that created serious incidence on food security, with harmful impact on economic growth and poverty mitigation in Ethiopia [32]; DEMARÉE (1990) showed alternating wet and dry periods period in Mauritania [33]; CISSE *et al.* (2014) characterize the effect of climate variability and human actions (dams) on his regime and, subsequently, to shed light on the recent evolution of flows in the watershed River Senegal [34]; BIAZEN (2014) and RAM *et al.* (2015) showed significant changes in the composition of species and current ecosystems boundaries could have some negative incidence on rural populations livelihoods, on agricultural systems productivity and on food security [35,36]; the World Bank (2013) showed the impact of climate change on hydrologic resources may exert increasing pressure on energetic security: hydro-electric and thermal power plants stand as the two towering electric energy sources in developing countries, and both can be compromised by deficient water supply [14]; TRAORE *et al.* (2014) have highlighted the effect of climate change in the Gambia River Basin and its impacts on the availability of the water resources of this basin, The results showed negative effects and a general tendency to dry up [37]. BARRY *et al.* (2017) investigated temporal trends in annual rainfall and temperature, discontinuities in the time series; and assessed the Land Use/Land Cover Change in the Somone river basin, results clearly indicate that the impacts of climate change are exacerbated by rapid urbanization in the basin [38]. N'DIAYE *et al.* (2016) analyzed the consequences due to rainfall variability and urban dynamics in the Commune of Ouakam, results show rainfall is main causing flooding in the past two decades; the dynamics of land use is manifested by a conversion of crops areas into habitation areas [39]. These studies show that climate change is a reality and a serious threat to the well-being of populations and their ecosystems. This is why the manifestations of the climate have caught the attention of scientists, researchers and policy makers in recent decades. It should be noted, however, that climate is a regional phenomenon and each region has its own climatic characteristics [40]. Nowadays several methods are available in the literature to evaluate and supervise climatic events. In this study, we selected an absolute standard test homogeneous test (SNHT) to detect inhomogeneity, change points within the Senegalese record of rainfall series in 14 stations of the 14 regions over the period of 65 years from 1960 to 2015. Conscious that reliable measurements of climate data are the essential foundation for quantitative and qualitative climate analysis, we have taken the data from ANACIM (National Agency of Civil Aviation and Meteorology).). The choice of 14 stations in the 14 regions of Senegal is made on the basis of the duration and the quality of the available information. Mainly, apart from their easy accessibilities, the choice of rainfall among climatic variables, is due to the fact that it is a key variable in West Africa in the Sahel region such as Senegal where economies, livelihoods and food security is highly dependent essentially on agriculture and particularly rained agriculture. In this country, this agriculture contributes to employment creation, GDP and the majority of foreign exchange earnings [41]. This is for us to analyze the negative effects of climate events on the rainfall regime in the 14 regions of Senegal. This would contribute to a better understanding of the interactions between these effects of climate change and adaptation strategies for sustainable development. According to OUARDA *et al* (1999) LUBÈS-NIEL *et al.* (1998), the possible evolutions of rainfall can be reduced to the change in the average and the variance [2,42]. In that respect, homogeneity is an important method to detect the variability of the rainfall data even if we have to recognize that it is a hard task to deal such data because they are always subject to changes caused by measurement techniques and observational procedures, environment characteristics and structures, and location of stations [43]. The four absolute test methods commonly used to detect inhomogeneities in the meteorological time series are: the standard normal homogeneity test (SNHT), the Buishand range test, the Pettitt test and the Von Neumann ratio test [44]. These tests are often used instead of relative tests that require the presence of high positive correlation among investigated stations. In addition, these absolute tests were selected at the expense of relative tests on the basis of their different sensitivities [43]. However, among these four absolute tests, we have chosen SNHT to evaluate the homogeneity of precipitation series in Senegal regions. This choice is explained by the fact that this test is sensitive in detecting the breaks near the beginning and the end of the series; it is also insensitive to the eventual missing values.

1.- Material and Methods

1.1.- Study Area

Senegal (fig. 1) is a West African country bordered on the west by the Atlantic Ocean on 700 km of coastline. It is surrounded by Mauritania to the north, Mali to the east and Guinea-Conakry and Guinea Bissau to the south. The Gambia forms an enclave 300 kilometers long and 60 kilometers wide and separates the Casamance region from the rest of the country [45,46]. The Senegalese territory is between 12° 8 and 16° 41 north latitude and 11° 21 and 17° 32 west longitude and covers an area of 196 722 km^2. Senegal is composed of 14 administrative regions and 45 departments with a total population estimated at 13.5 million 2013, 55% of which are rural [47]. The climate is tropical (Sahelian zone, Sudan zone, Sahelo-Sudan zone, Guinean zone and Sudano-Guinean zone) marked by the alternation of a rainy season (wintering) from June to October and a dry season of November to June. The duration of wintering decreases from south to north: six months in the south, four months in the center, two months in the north while the duration of the dry season goes on: six months in the south, eight months in the center, ten months North. The rainy season is characterized by the monsoon coming from the ocean while the dry season is characterized by the continental trade wind of the north and eastern Harmattan [48]. Annual rainfall ranges from 250mm in the north to 1,500mm in the south. The highest temperatures are observed in summer, during the rainy season. The lowest in winter during the dry season, are in January-February. The highest temperatures are around 45° (in the center and east of the country) and the lowest temperatures can drop below 10° (on the coast) [49]. Topographically, Senegal is a vast plain monotonous relief whose altitude rarely exceeds 100 meters. We can distinguish: dunes, hills, Massif and cliffs. The soil is sandy, lateritic and granitic. Except in the south where it is luxuriant, the vegetation has a distinctly Sahelian character as a whole. The bush is thin and the thorny dominate [50]. On the hydrographic level, four lazy rivers: Senegal, Gambia, Casamance and Sine and Saloum, flow into the ocean, making Senegal a country where rivers, deltas and bolongs (arms), lakes and backwaters. Salt water and freshwater are the domain of pirogues and fishermen and bird paradise [51]. Dams of circumstances are also erected to try to strengthen the hydraucity of the country. The Agriculture sector is an important economic sector; it contributes 14% of GDP and employs about 50% of the labor force. Despite this, more than half of rural people, usually very small subsistence farmers live below the poverty line and 30% of them are affected by food insecurity [52]. Agriculture is based on both cash crops (groundnuts, cotton, sugar cane, horticultural products) and food crops mainly cereals (rice, millet, maize and sorghum) [41,53]. The cultivated lands are 50% occupied by cereals, 30% by groundnuts and 20% by other crops each year. Most of these are seasonal and rain-fed, centered on the wintering period. But irrigated areas, which represent only 5% of the UAA, and off-season production, tend to develop. The country is not self sufficient in cereals. Imports are strong, particularly in years with low rainfall, as it is rainfed [54]. In spite of the many agricultural policies initiated by the public authorities: NEPAD's Comprehensive Program for African Agriculture Development (CAADP) (New Partnership for Africa's Development), the Senegalese Agricultural Acceleration Program

(PRACAS) of the PSE (Emerging Senegal Plan), West Africa in general and Senegal in particular have still not achieved food sovereignty [55,56]. In 2011, FAO estimates that the average food consumption of a Senegalese is around 370 kg per year. In terms of quantity, Senegalese eat half as much as Westerners. For the 2014-2016 periods, FAO estimates that there were 1.7 million undernourished people, which corresponds to 11.7% of the population. In 2014, 19.4 per cent of children under 5 were stunted [57]. Climatic hazards, declining soil fertility and pest attacks have a strong impact on production. Senegal remains a net importer of food products; the cereal bill is particularly high [58].

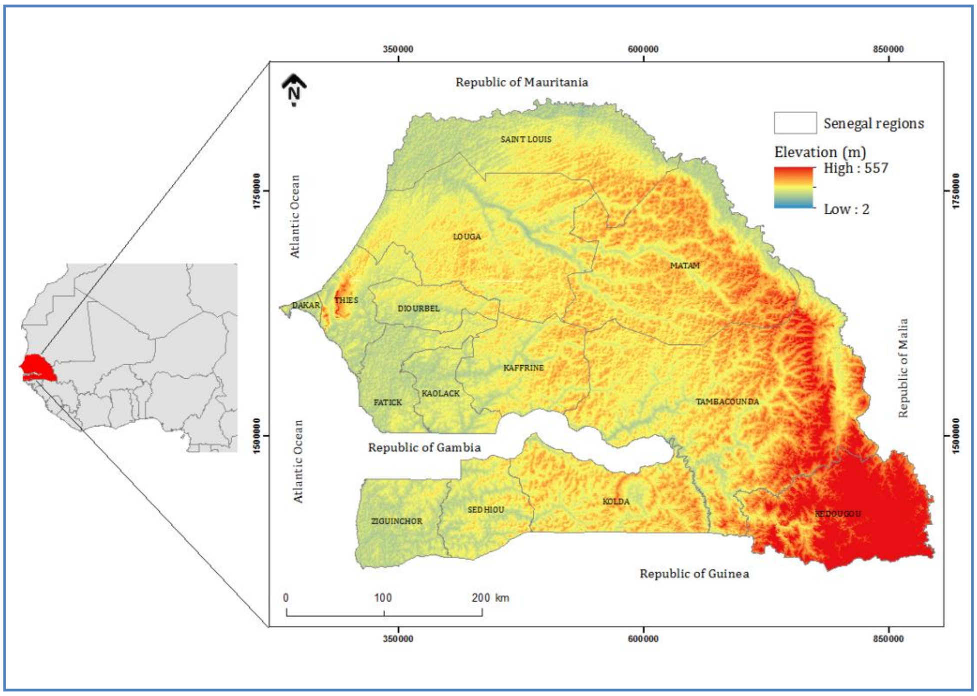


Figure 1.- Study area Location

1.2.- Statistical test of homogeneity

A same is said to be homogeneous if it present no breaks. A break can be generally defined as an abrupt change in the probability law of the series at a given time, usually unknown. It corresponds to a trend reversal of the time series [37]. Before perform homogeneity analysis, a quality analysis of data is requested. The quality control procedure is aimed to identify errors related to data processing and outliers. It is also useful to check the procedures and instruments of observation, environment characteristics, formulas, etc. [59]. Data we used in this study have been validated by ANACIM which guarantees their quality and reliability. In general when the data is homogeneous, it means that the measurements of the data are taken at a time with the same instruments and environments [43]. From a statistical point view, if times series is homogeneous and no change point/trend are detected, then it can be treated as stationary. In presence of one or more change points a series can be stationary between two consecutive change points. If a trend is detected, non-stationary extreme value theory should be applied or the assumption of “slow” variation of the processes can be done [60]. In statistical analysis of homogeneity, a time series can be absolutely homogeneous, i.e. the time series is temporally homogeneous with respect to itself, or relatively homogeneous, i.e. the time series is homogeneous with respect to a reference time series or to a neighbour station. The absolute test methods commonly used to detect inhomogeneities in the meteorological time series are: the standard normal homogeneity test (SNHT), the Buishand range test, the Pettitt test and the Von Neumann ratio test [44]. The absolute homogeneity can always be tested while the relative homogeneity requires the existence of one more time series collected in the same period in a different location. In addition, the absolute tests were frequently selected relative to relative tests on the basis of their different sensitivities where the break is likely to be expected. Furthermore, it should be noted that with the absolute tests there are no effects or the effects of homogeneity tests [43]. This is why in this study our choice is focused on one of them, especially the standard normal homogeneity test (SNHT).

1.2.1.- Standard Normal Homogeneity test

SNHT is sensitive in detecting the breaks near the beginning and the end of the series; it is also insensitive to the eventual missing values [43]. In addition, according to BEAULIEU *et al.* (2008), one often uses SNHT because of its simplicity and relative good performance compared to other tests [61]. This is why our choice is focused on SNHT among the absolute best known test to evaluate the homogeneity of precipitation series in Senegal regions. The SNHT is based on the ratio T (k) defined by equation (1) that compares the mean of the first observations with the mean of the remaining (n - k) observations [62].

$$T_k = k * \bar{Y}_1^2 + (n-k) * \bar{Y}_2^2 \qquad k = 1, 2, 3, ..., n$$

Where Y_1 and Y_2 are variables defined by equations (2) and (3)

$$\bar{Y}_1 = \frac{1}{k} \sum_{i=1}^{k} \frac{(X_i - \bar{X})}{\sigma} \qquad (2)$$

$$\bar{Y}_2 = \frac{1}{n-k} \sum_{i=k+1}^{n} \frac{(X_i - \bar{X})}{\sigma} \qquad (3)$$

Where Xi (i is the year from 1 to n) is the testing variable; X is the mean; s is the standard deviation, n is the sample size (in this case it is equal to 65). Under null hypothesis, the series are considered as homogeneous. Meanwhile under alternative hypothesis, the series consisted of break in the mean and considered as inhomogeneous [43]. The break occurs when T(k) is localized around the observation that maximizes the variable T and the null hypothesis is rejected if the test statistic T0 = max(T(k) which depends on the sample size n, exceeds the critical value given by VEZZOLI *et al.*(2012) [63].

1.2.2.- Data and Application

In this study, we used annual rainfall data from 14 stations in 14 regions of Senegal. The data were made available to us by the National Agency of Civil Aviation and Meteorology (ANACIM). The choice of rainfall stations in these regions was dictated by the need for good quality data over a long identical period for all 14 regions. Thus, the period 1951 to 2015 was selected for this study. There are several reasons to justify the choice of rain among climatic variables: i) it represents the most important climate factor for population, environment and ecosystems and it is the most accessible measure in various parts of the world ; ii) it constitute according to many authors, the most important parameter in reliable assessment and monitoring climate manifestations ; iii) it is the most important climate variables directly affecting the availability of water resources; iv) it 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) ; v) it is the main source of water for crop production as irrigation covers only 5% of the cultivated land and vi) it is a key variable in West Africa in general and more specifically over the Sahel region and especially in Senegal where economies, livelihoods and food security are highly dependent on rained agriculture. The purpose of this study is to detect for each station the possible occurrence of a climatic accident. In view of the increased vulnerability of sectors such as agriculture, food security, water supply and ecosystems, it is important to take into account and, where appropriate, adjust the concepts of sustainable development and sustainable development strategies development. From a statistical point of view, the climatic fluctuation is marked at a given date by a break or a change of average within the time series. Our approach is essentially based on the T variable of the test and is structured as follows: First, we calculated the values of this variable and identified the maximum value T0 for each of the 14 regions. The value T0 is then compared to the reference value TR. This led us to reject the null hypothesis of no break in the series and consequently to give the date of this break for each of the 14 stations. We then subdivided the series into two sub-series on either side of the breaking point. For each sub-series, we calculated the mean of the T variable of the test and noted TBR the mean before rupture and TAR the average after rupture. The average before breaking being greater than that after the break for all 14 stations, we deduce the direction of the break which is decreasing. We then calculated the amplitude D given by the difference between the averages TBR and TAR for all 14 regions; these amplitudes are compared with respect to their average Dm; which led us to decide on the magnitude or extent of this decline. This showed that the phenomenon did not have the same intensity (severity or brutality) everywhere. Moreover, it allowed classifying the 14 regions according to the severity of the drought in the space. In order to classify the regions according to the persistence of the drought over time, we counted for each region the number of wet years (given here by the years before the break) and the number of dry years (given here by the years after the break). The difference between these two categories of years made it possible to see clearly by comparison with the average difference. A synthesis was made to identify the region's most affected, vulnerable or affected by climate instability. Transitional and adaptive urgent measures can thus be prioritized and undertaken by the authorities according to the regions.

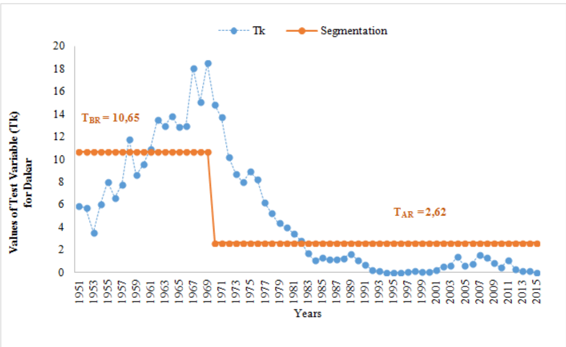
2.- Results and discussion

✓ - Related to SNHT

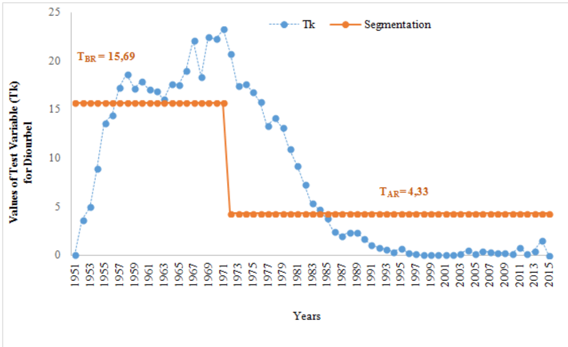
Table I below presents the values of the T0 statistic of the 14 regions and the critical value Tc at the 5% threshold to distinguish the real climate variation under the null hypothesis of absence of break. The (fig. 2a to n) highlight the graphical aspect of the test results. Reading the table shows that the T0 value of the test exceeds the critical value for each of the regions. This leads us to reject the null hypothesis for the 14 regions. As result, SNHT found these stations rainfall time series as inhomogeneous at 5% probability level. The break dates are between 1955 and 1971 according to the region as indicated in the table and corresponding to the maximums in the figures. The analysis of the figures shows the average before break (TBR) is greater than that after (TAR) for all 14 regions, indicating a break down as shown in the figures. In the end, there is a downward trend for the 14 regions. Senegal has known at least since 1955 a so-called meteorological drought.

Tableau I.- Résultats du test d'homogénéité at 5% significance level

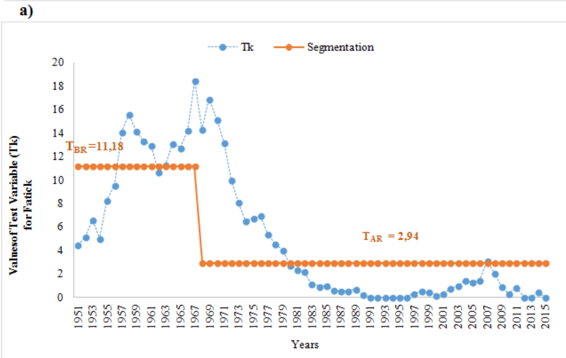
Regions	T0	Tc	H0	shift Years	T_{BR}	T_{AR}	Direction of shift
Dakar	18,49	8,70	Rejected	1969	10,65	2,62	Downward
Diourbel	23,26	8,70	Rejected	1971	15,69	4,33	Downward
Fatick	18,45	8,70	Rejected	1967	11,18	2,94	Downward
Kaffrine	14,62	8,70	Rejected	1958	7,14	3,82	Downward
Kaolack	24,81	8,70	Rejected	1958	13,89	8,09	Downward
Kedougou	9,67	8,70	Rejected	1966	5,43	1,65	Downward
Kolda	13,44	8,70	Rejected	1958	4,42	4,08	Downward
Louga	24,43	8,70	Rejected	1955	18,13	6,99	Downward
Matam	20,30	8,70	Rejected	1966	9,91	3,09	Downward
Saint louis	10,64	8,70	Rejected	1969	4,56	1,60	Downward
Sedhiou	22,96	8,70	Rejected	1969	11,45	5,04	Downward
Tamba	18,50	8,70	Rejected	1966	7,35	4,84	Downward
Thies	22,33	8,70	Rejected	1964	14,65	5,66	Downward
Ziguinchor	13,91	8,70	Rejected	1967	6,51	2,79	Downward



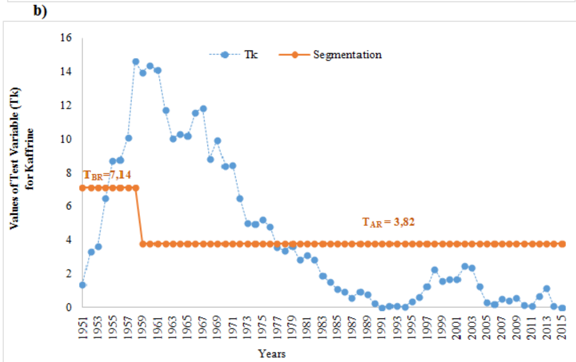
a)



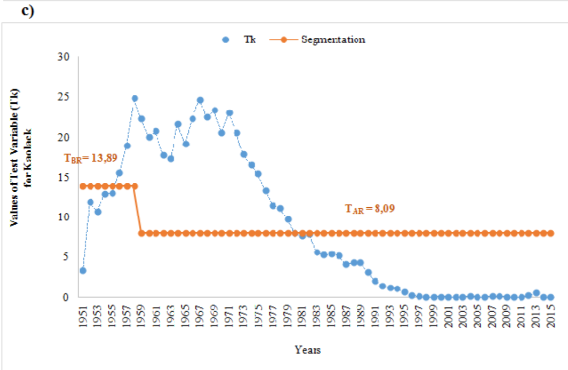
b)



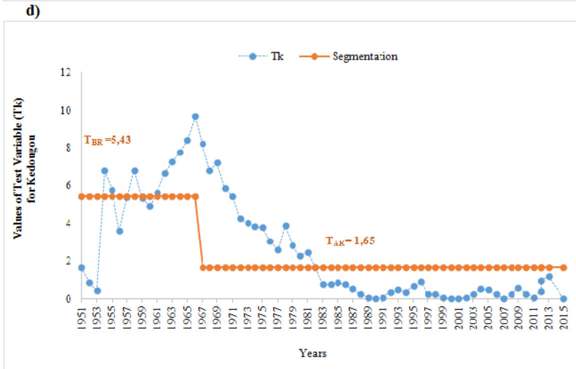
c)



d)



e)



f)

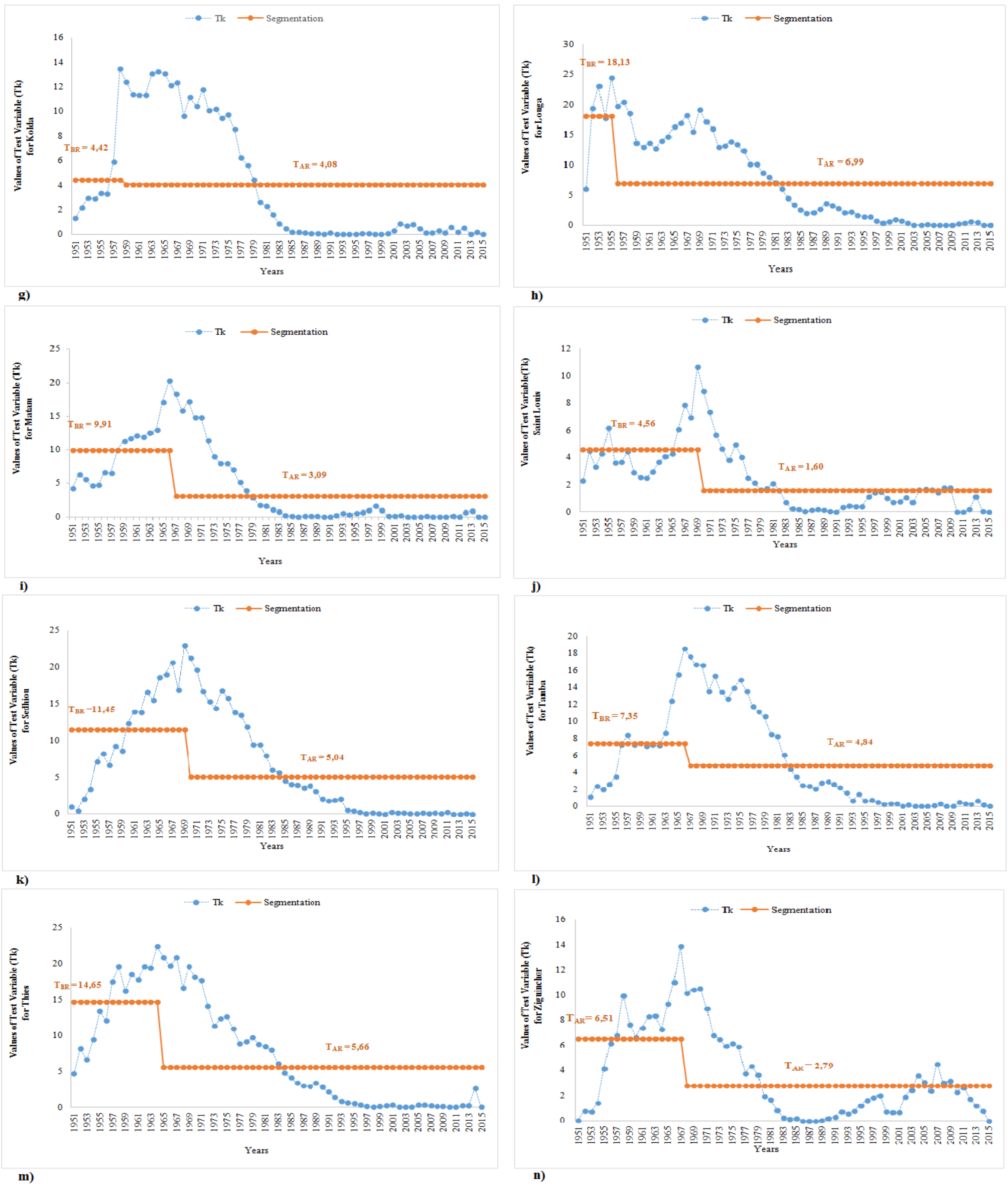


Figure 2.- Graphic results of the test at 5% probability level
(a: Dakar; b: Diourbel; c: Fatick; d: Kaffrine; e: Kaolack; f: Kédougou; g: Kolda;
h: Louga; i: Matam; j: Saint Louis; k: Sedhiou; l: Tambacounda; m: Thiès; n: Ziguinchor)

✓ - Results on the extent and persistence of drought

Tables II and III respectively analyze the magnitude (or intensity) of the drought in space and its persistence over time for the 14 regions. Figures 3 and 4 respectively illustrate the classifications of regions according to the extent and persistence of the phenomenon. The analysis in table II highlights two categories of regions: those whose spatial extent is significant and those of which it is not. Figure 3 shows the distribution in relation to the average. It is thus possible to undertake a classification of the regions according to the gravity of the phenomenon in space as shown in table II and diagrammatically shown in FIG. In sum, Diourbel is the most affected region and Kolda the least affected region. Similarly for table II, the analysis also gives two groups of regions: those whose persistence of the phenomenon over time is significant and those of which it is not. A classification according to the intensity of temporal persistence of the phenomenon is presented in table III. This classification places Louga as the most affected region and Diourbel the least affected region as shown in fig. 4.

Table II.-Analysis of the spatial extent of drought

Regions	T_{BR}	T_{AR}	Amplitude	Extent	Order.1
Dakar	10,65	2,62	8,02	brutal	5
Diourbel	15,69	4,33	11,36	brutal	1
Fatick	11,18	2,94	8,24	brutal	4
Kaffrine	7,14	3,82	3,32	No brutal	11
Kaolack	13,89	8,09	5,80	No brutal	8
Kedougou	5,43	1,65	3,78	No brutal	9
Kolda	4,42	4,08	0,35	No brutal	14
Louga	18,13	6,99	11,14	brutal	2
Matam	9,91	3,09	6,82	brutal	6
Saint louis	4,56	1,60	2,96	No brutal	12
Sedhiou	11,45	5,04	6,41	brutal	7
Tamba	7,35	4,84	2,52	No brutal	13
Thies	14,65	5,66	8,99	brutal	3
Ziguinchor	6,51	2,79	3,71	No brutal	10

Table III.- Analysis of the intensity of temporal persistence of drought

Regions	BR	AR	gap	Severity	Ordre2
Dakar	19	46	27	No brutal	6
Diourbel	21	44	23	No brutal	7
Fatick	17	48	31	No brutal	5
Kaffrine	8	57	49	brutal	2
Kaolack	8	57	49	brutal	2
Kedougou	16	49	33	No brutal	4
Kolda	8	57	49	brutal	2
Louga	5	60	55	brutal	1
Matam	16	49	33	No brutal	4
Saint louis	19	46	27	No brutal	6
Sedhiou	19	46	27	No brutal	6
tambacounda	16	49	33	No brutal	4
thies	14	51	37	brutal	3
ziguinchor	17	48	31	No brutal	5

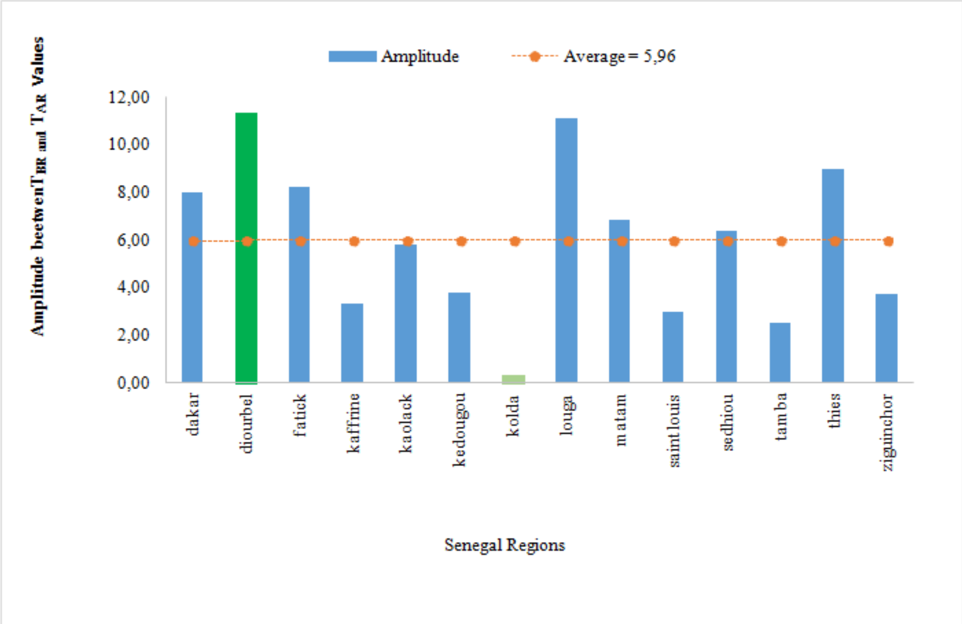


Figure 3.- Classification of regions according to spatial extent of drought

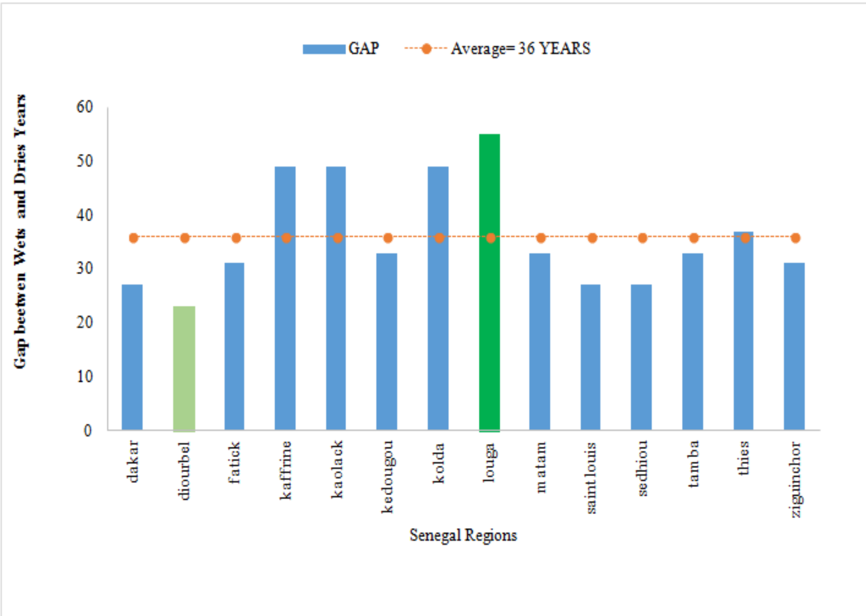


Figure 4.- Classification of regions according to the intensity of temporal persistence of drought

✓ **- Synthesis results**

Table IV is a synthesis of tables II and III. It aims to classify the 14 regions in terms of priority intervention to mitigate the disturbances induced by the instability of the climate on the rains regime. The analysis of this table provides the public authorities with a tool to help decision-making on new agricultural policies to reduce the benefits of dependence on rainfed agriculture. In this sense, Louga is the region with the highest priority and Kolda the least priority in this sense.

Table IV.- Priority intervention analysis

Regions	Classification according to spatial extent (order 1)	Classification according to temporal persistence (order 2)	Priority intervention order
Dakar	5	6	Priority 7
Diourbel	1	7	Priority 3
Fatick	4	5	Priority 4
Kaffrine	11	2	Priority 11
Kaolack	8	2	Priority 6
Kedougou	9	4	Priority 9
Kolda	14	2	Priority 14
Louga	2	1	Priority 1
Matam	6	4	Priority 5
Saint Louis	12	6	Priority 12
Sedhiou	7	6	Priority 8
Tamba	13	4	Priority 13
Thies	3	3	Priority 2
Ziguinchor	10	5	Priority 10

Conclusion

The African continent presents an increased risk of vulnerability to disturbances induced by climate change. In view of the increased vulnerability of sectors such as agriculture, food security, water supply and ecosystems, it is important to take into account and, where appropriate, adjust the concepts of sustainable development and sustainable development strategies development. It is in this context that this study is aimed at making plausible scenarios of climate change available to national and sub-regional decision-makers for all regions in order to understand the elements affecting water availability and to offset the negative impacts of rainfall variability. This study is based on annual rainfall data from 14 stations in Senegal's 14 regions. They were made available to us by the National Agency of Civil Aviation and Meteorology (ANACIM). The choice of rainfall stations in these regions was dictated by the need for good quality data over a long identical period for all 14 regions. Thus, the period 1951 to 2015 was selected for this study. Our methodological approach is essentially based on standard normal homogeneity test and the exploitation of its basic variable. The aim here is to detect the break, its date, direction and magnitude and also to estimate the temporal persistence of the drought. The results obtained are on the whole consistent and revealing. The test showed the existence of a downward break for all the rainfall stations in the 14 regions. Reading the table shows that the T0 value of the test exceeds the critical value for each of the regions. This leads us to reject the null hypothesis for the 14 regions at 5% probability level. Therefore, the time series of rainfall used in this study are inhomogeneous. The break dates are between 1955 and 1971 depending on the region. Senegal has therefore known at least since 1955 a so-called meteorological drought, particularly in Louga. The analysis of the magnitude (or intensity) of this drought in space has highlighted two categories of regions: those of which it is significant and those of which it is not. In this sense, Diourbel stands out as the most affected region and Kolda as the least affected. The analysis related to the persistence over time of the phenomenon has also highlighted two groups of regions: those whose persistence is significant and those of which it is not. This analysis places Louga as the most affected region and Diourbel as the least affected. A synthesis based on these two analyzes made it possible to classify the 14 regions in terms of priority intervention to mitigate the disturbances induced by the instability of the climate on the rains regime. The purpose of this analysis is to provide governments with a tool for decision-making on new agricultural policies to reduce the dependence on rainfed agriculture. Thus the region of Louga appears as the highest priority and Kolda the least priority in terms of reversal to offset the rainfall deficit by water control policies, for application to agriculture. The results of this study should indeed be a source of reflection for the authorities to undertake clear, structured and well-oriented agricultural policies. It is true that many agricultural policies of circumstance were initiated by the authorities for the self-sufficient in cereals but the battle is still not won. According to the World Bank, Senegal remains a net importer of food products; the cereal fracture being particularly high. FAO, for its part, estimates that 11.7% of the Senegalese population was in a state of under-nutrition. The causes and responsibilities of this situation must therefore be located. Is it a problem of vision or political will or both? In any case, the problem is and there and very real. Short and long-term solutions in the mobilization and development of water resources must be found for a revitalization of agriculture. Otherwise, local food self-sufficiency long advocated by the authorities will never be achieved.

Acknowledgment

We would like to express our deep gratitude and sincere thanks to the Direction of National Agency of Civil Aviation and Meteorology (ANACIM) for putting reliable and qualitative data at our disposal within the framework of this study.

References

[1].- Jouilil I., Bitar K., Salama H. A., Mokssit A, Tahiri M., 2013.- Meteorological drought hydraulic basin of OUM ER RBIA during the last decades. Larhyss Journal, 12: 109-127

[2].- Ouarda T. B. M. J., Rasmussen P. F., Cantin J. F., Bobée B., Laurence R., Hoang V. D., Barabé G., 1999.- Identification of a hydrometric network for monitoring climate change in the province of Quebec. Journal of Science of Eau, 12: 425-448.

[3].- Hadgu G., Tesfaye K., Mamo G., Kassa B., 2013.- Trend and variability of rainfall in Tigray, Northern Ethiopia: Analysis of meteorological data and farmers' perception. Acad. J. Environ. Sci., 1(8): 159-171.

[4].- Bootsma A., Boisvert J. B., De Jong R., Baier W., 1996.- Drought and Canadian Agriculture: A Review of Ways of Action. Drought,.7: 277-285.

[5].- Ardoin, S., Lubes-Niel, H., Servat, E., Dezetter, A., Boyer, J. F., Mahé, G. and Paturel, J. E., 2003.- Analysis of the persistence of drought in West Africa: Characterization of the situation of the 1990s; IAHS publ., n°.278: 223-228..

[6].- WMO, 2012.- Standardized Precipitation Index User Guide (Mr Svoboda, Mr Hayes and D. Wood) (WMO-No. 1090) World Meteorological Organization, Geneva, 16p.

[7].- Bergaoui M., 2001.- Characterization of meteorological and hydrological drought:

case of the Siliana watershed in Tunisia. Science and Global Change / Drought .12: 205-213

[8].- Elbouqdaoui K., Haida S., AboulabbesO., Benaabidat L., Zahraoui M., Ozer A., 2006.- Evolution of the pluviometric and hydrometric mode of the drainage basin of Srou (Middle Atlas, Morocco). Geo-Eco. Trop., 30: 41-56.

[9].- Diouf R., Sambou H., Traore V. B., Ndiaye M. L., Chaibo A., Sambou B., Diaw A. T., Beye A. C., 2016.- Frequency Analysis and Exploratory of Rainfall Variability inBounkiling River Basin in a Context of Climate Changeand Variability. American Journal of Engineering Research. 5: 82-93.

[10].- Traore V. B., Ndiaye M. L., Mbow C., Malomar G., Sarr J., Beye A. C. and Diaw A.T., 2017.- Khronostat Model as Statistical Analysis Tools in Low Casamance River Basin, Senegal. World Environment, 1: 10-22.

[11].- Guo S. L., Wang J. X., Xiong L. H., Ying A. W., 2002.- A macro-scaleand semi-distributed monthly water balance model to predict climate change impacts in China. J. Hydrol, 268: 1-15.

[12].- Kahya E., Kalayci S., 2004.- Trend analysis of stream flow in Turkey. J. Hydrol.289: 128-144.

[13].- Dheebakaran G. A., Jagannathan R., Paulpandi V. K., Kokilavani S., 2015.- Impact of climate change on monsoon onset over Tamil Nadu. International Journal of Current Research, 7: 23818-23820

[14].- WB, 2013, Turn down the Heat: climate extremes, regional and advocacy impacts for adaptation. International Bank for Reconstruction and Development. The World Bank, Washington, 39p. www.worldbank.org.

[15].- Servat E, Paturel J. E., Kouame B., Travagli M., Ouedraogo M., Boyer J. F., 1998.- Identification, characterization and consequences of hydrological variability in West and Central Africa. In: Water Resources Variability in Africa during the XXth Century, IAHS, 252: 323-337.

[16].- Doumouya F. R., Traore V. B., Sadio M., Sambou H., Issaka-Ali A. H., Diaw A. T., Sambou B., Beye A. C., 2016.- Rainfall Variability in Sine Saloum River Basin in a Context of Climate Change and Variability. Advances in Research, 6: 1-12.

[17].- Edjrogan M. T., Ndiaye M. L., Traore V. B., Sambou H., Nelly C. K., Sy B. A. and Diaw A.T., 2017.- Characterization and Analysis of Rainfall Variability in the Mono-Couffo River Watershed Complex, Benin (West Africa). Resources and Environment, 7: 13-29.

[18].- Paeth H., Hense S. S. T., 2004.- Versus climate change signals in West African rainfall: 20th-century variations and future projections. Climatic Change.65: 179-208.

[19].- Paturel J. E., Diawara A., Kong A. S., Talin L., Ferry E., Mahé G. F., et al ?????.,

2010.- Characterization of the hydropluviometric drought of Bani, the main tributary of the Niger River in Mali. In: Global change: Facing Risks and Threats to Water Resources. IAHS., 340: 661-667.

[20].- Rosine M. N. F., Nagnin S., Traore V. B., Théophile L., Soussou S., Tanina S. , 2014.- Climate variability and its impact on surface water resources: The case of stations of Bocanda and Dimbokro, eastcentral of Ivory Coast in West Africa. Africa Science, 10: 118-134.

[21].- Olivry J. C., Bricquet J. P., Mahé G., 1998.- Variability of the power of the flood of the great rivers of intertropical Africa and the impact of decrease of base flows in the last two decades. IAHS, 252: 189-197.

[22].- Mahé G., Olivry J. C., Servat E., 2005.- Sensitivity of West African watercourses to climate and environmental change: Extremes and paradoxes. IAHS, 296: 169-177.

[23].- Savané I., Coulibaly K. M., Gion P., 2011. Climate variability and groundwater resources in the semi-mountainous region of Man. Drought, 12: 231-237.

[24].- Goula B. T. A., Savané I., Konan B., Fadika V., Gnamien K. B., 2006.- Impact of climate variability on water resources and basins N'zo N'zi in Ivory Coast (tropical Africa). Vertigo, 7: 1-12.

[25] Brou T., Servat E., Paturel J. E., 1998.- Human activities and climate variability: A case of the Ivorian south forest. IAHS, 252: 365-373.

[26].- Yao A. B., Goula B. T. A., Kouadio Z. A., Kouakou K. E., Kane A., Sambou S., 2012.- Analysis of climate variability and quantification water resources in tropical wet zone: From watershed case of Lobo in Central West of Ivory Coast. Rev. Ivory. Sci. Technol., 19: 136-157.

[27].- Ahoussi K. E., Koffi Y. B., Kouassi A. M., Soro G., Soro N., Biémi J., 2013.- Study of hydroclimatic variability and its impact on water resources and agricultural forest South of Côte d'Ivoire: Case the region of Abidjan Agboville. Int. J. Pure App. Biosci., 1: 3 0-50.

[28].- Payne J. T., Wood A. W., Hamlet A. F., Palmer R. N. , Lettenmaier D. P., 2004.- Mitigating the effects of climate change on the water resources of the Columbia River basin. Climatic Change, 62: 233-256.

[29].- Christensen N.S., Wood A.W., Voisin N., Lettenmaier D. P., Palmer R. N, 2004.- Effects of Climate Change on the Hydrology and Water Resources of the Colorado River Basin, Climatic Change, 62: 337-363.

[30].- Servat E., Paturel J. E., Lubès-Niel H., Kouamé B., Masson J. M., Travaglio M., Marieu B., 1999.- Different aspects of the rainfall variability in West Africa and Sahel Central not. Journal of Water Science, 12: 363-387.

[31].- Fulvie K., Saley M. B., Savane I.,2009.- Impacts of Climate Variability on Water Resources and Human Activities in Tropical Wetland: Case of Daoukro Region in

Ivory Coast. European Journal of Scientific Research, 26: 209-222.

[32].- Conway D., Schipper E. L. F., 2011.- Adaptation to climate change in Africa: Challenges and opportunities identified from Ethiopia. Global Environmental Change, 21: 227-237.

[33].- Demarée G. R., 1990. An indication of climatic change as seen from the rainfall data of a Mauritanian station. Theor. Appl. Clim., 42: 139-147.

[34].- Cisse M. T., Soussou S., Yaya D., Clement D., Mamadou B., 2014.- Analysis of flows in the river basin Senegal From 1960 TO 2008. Journal of Water Sciences, 27: 167-187.

[35].- Biazen M., 2014.- The Effect of Climate Change and Variability on the Livelihoods of Local Communities: In the Case of Central Rift Valley Region of Ethiopia. Open Access Library Journal, 1: 1-10.

[36].- Ram A., Suhas J., Wani P., Pathak P., Singh P., Kanwar L. S., Chander G. and Sudi R. S., 2015.- Evaluating Climate Change Mitigation andAdaptation Potential of Conservation Agriculturein Semi-arid Tropics of Southern India. British Journal of Environment & Climate Change, 5: 324-338.

[37].- Traore V. B., Soussou S., Cisse M. T., Seni T., Sidy F., Diaw A. T., Hyacinthe S., Malanda E. N., 2014.- Trends and shifts in time series of rainfall and runoff in the Gambia River watershed. International Journal of Environmental Protection and Policy, 2: 138-146.

[38].- Barry N. Y., Traore V. B., Ndiaye M. L., Isimemen O., Celestin H., Sambou B., 2017.- Assessment of Climate Trends and Land Cover/Use Dynamics within the Somone River Basin, Senegal. American Journal of Climate Change, 6: 513-538.

[39].- Ndiaye M. L., Ndiaye E. A. D., TraoreV. B., Diaw A. T., and Aboubacker C. B., 2016.- Impacts of Rainfall Variability and Urban Sprawl onthe Environment and the Population Well-being at Ouakam Commune, Dakar, Senegal.Archives of Current Research International, 6: 1-12.

[40].- WMO, 2003.- Guide lines on climate metadata and homogenization. Technical Report 53, World Meteorological Organization, Geneva, 24p.

[41].- ANSD, 2015.- Economic and social situation of Senegal in 2012 – National Agency for Statistics and Demography, R. of Senegal, 342.

[42].- Lubès-Niel H., Masson J. M., Paturel J. E., Servat E., 1998.- Climate variability and statistics. Simulating the power and robustness of some tests used to check the homogeneity of chronic. Journal of Water Sciences, 11(3): 383-408

[43].- Kang H. M.,Yusof F., 2012.- Homogeneity Tests on Daily Rainfall Series in Peninsular Malaysia. Int. J. Contemp. Math. Sciences, 7: 9-22.

[44].- Naoki M., Michael B. S., 2012.- Analysis of inconsistencies in multi-year gridded

quantitative precipitation estimate over complex terrain and its impact on hydrologic modeling". Journal of Hydrology, 428: 129-141.

[45].- Iba Der Thiam, Geography of Senegal, New African editions, EDICEF, 1981

[46].- Jean-Luc Piermay et Cheikh Sarr 2007.- The Senegalese city. An invention at the borders of the world, Paris, Karthala, 248 p.

[47].- ANSD, 2014.- RGPHAE - "Final Report", National Agency for Statistics and Demography. R. of Senegal, 307

[48].- WB, 2014.- "Presentation of Senegal" .World Bank . Africa Region. Senegal, 29p.

[49].- Diouf M, 2015.- Horticulture is the most successful sub-sector of Senegalese agriculture but ..., Lateranga.info.

[50].- Maya L., 2006.- Strategic management of the ecosystems of the Senegal River. International public actions and inactions. L'Harmattan, African Studies, 624 p.

[51].- Sall A, 2005.- Water in Senegal: the current challenges of privatization, Dakar and Kaolack: essay on social geography, thesis.

[52].- ANSD, 2015.- Foreign Trade Analysis Note - 2014 Edition .National Agency for Statistics and Demography.

[53].- MAER,2013.- Report of the final results of the 2012-2013 agricultural survey. Ministry of Agriculture and Rural Equipment, Senegal.

[54].- ANSD, 2016.- Senegal - Monthly Bulletin of Statistics. March 2016, Agri Senegal. National Agency of Statistics and Demography, Dakar, Sénégal.

[55].- Sénégal.com, 2015. Overview of Senegalese agriculture. http://www.au-senegal.com/l-agroalimentaire-au-senegal,3587.html?lang=fr

[56].- MAAF, 2015.- Agricultural Policies around the World - Country Brief - Senegal, 2015. Ministry of Agriculture, Agri-Food and Forestry, France.

[57].- FAO, 2012.- Rice Development Overview - "Senegal". Ed FAO, Rome.

[58].- WB, 2010.- "Local development, institutions and climate change in Senegal". World Bank, New York.

[59].- Sahin, S. ,Cigizoglu, H. K., 2010.- Homogeneity analysis of Turkish meteorological data set. Hydrol. Process,7534: 1-12.

[60].- Klein T. A. M. G., Zwiers F. W., Zhang X. ,2009.- Guidelines on analysis of extremes in a changing climate in support of informed decisions for adaptation. Technical Report 72, World Meteorological Organization

[61].- Beaulieu C. Ousmane S., Taha B. M. J. O., Xuebin Z., Gilles B., and Abderrahmane

Y., 2008.- Inter comparison of homogenization techniques for precipitation data. Water Resources Research, 44: 14-25. doi:10.1029/2006WR005615

[62].- Khaliq M. N., Ouarda T. B. M. J., 2007.- On the critical values of the standard normal homogeneity test (SNHT). International Journal of Climatology, 27 (5): 681-687.

[63].- Vezzoli R., Silvano P., Enrica Z., Fabrizio T., 2012.- Data analysis to detect inhomogeneity, change points, trends in observations: an application to Po river discharge extremes. CMCC (Euro-Mediterranean Center on Climate Change) Research Papers, Issue RP0138, Impact on Soil and Coasts Division (ISC).1 15.