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Characterization of climatic aridity in the groundnut basin, Senegal

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ABSTRACT/RESUME

Abstract: *Understanding of climate aridity is an important step towards assessing the availability of water in a given area. This understanding requires an appropriate analysis allowing monitoring the spatio-temporal evolution of the parameters which act on the availability of water. In this study, we used annual rainfall and temperatures from 5 synoptic stations in the groundnut basin over the period 1965-2014. The study is essentially based on a quantitative and qualitative examination of the Lang, Martonne and hydrothermal indices. It is for us to extract information that can guide agricultural planning choices. The results obtained show that the groundnut basin actually experienced aridity phenomena during the study period. For the five regional stations, there are three degrees of aridity, namely semi-arid, arid and hyper-arid. In terms of duration and frequency, Louga stands out as the most affected and Kaolack the least affected by the aridity phenomenon. In terms of water balance, Fatick seems to be the most affected and Louga the least affected for the water deficit. In terms of heat balance, Louga stands out as the warmest and Thies the least hot. A comparison of the three indices has led to the conclusion that the Martonne aridity index remains very satisfactory for studies of a regional nature. These results thus highlight the great vulnerability of the area to drying up and global warming, especially from north to south. Indeed, an increasing decrease in precipitation and temperatures was observed during the period under review, which widened the gap between the amount of precipitation and the demand for water in agriculture.*

I. Introduction

Nowadays, tendency towards aridity is one of the most followed and studied phenomena, at the global and regional levels [1]. Globally, the term 'aridity' is, reflected in common textbook definitions of aridity, defined as a lack of moisture ('dry') not able to promote and sustain life [2]. It manifests itself above all by its edaphic, hydrological and geomorphological consequences [3]. Climatic aridity is characterized by an almost permanent rainfall deficit linked to high sunshine, high daytime temperatures, low air humidity and evapotranspiration which leads to water deficits for most of the year [4]. It is actually a spatial structural climatic phenomenon different from drought, a temporal phenomenon, which occurs in both arid and wetter environments [5]. Aridity is a complex concept that ideally requires a complete evaluation of the hydroclimatological and hydroecological variables to fully understand the anticipated changes [6]. Moreover, a region is considered to be arid when it is characterized by a serious lack of available water, which has the effect of slowing down, or even preventing, growth and development [5]. Thus, the only factor connecting to all arid zones is aridity, generally expressed as a function of precipitation and temperatures [7].According to [8], the increase in temperature and decrease in precipitation could cause an increase in aridity with severe consequences of water scarcity. [9] thinks that by considering the structural trends in climate aridity, the strengthening of its negative impact on both man and the environment can lead to significant disasters, particularly in arid and semi-arid regions. [10] reveal that these regions comprise almost 40% percent of the world's land surface and most of the inhabitants living in the developing countries are farmers. [11] add that crop and livestock production often are limited in these regions of infertile and erodible soils because of insufficient rainfall. The low and erratic precipitation pattern is the single most significant contributor for limiting crop production in semi-arid regions, although these areas have relatively ample water supplies for agriculture in presently prevailing climatic conditions [7,12]. According to [13], this situation constitutes a threat to food security, economic growth, poverty reduction, job creation and the fight against social disparities in countries where agriculture is mainly rain. Indeed [14], globally agriculture is the main source of food production and the main source of livelihood for 36% of the world's total workforce. Agriculture in sub-Saharan Africa remains the main source of activity and income for the majority of households. The importance of the agricultural sector is highlighted with its contribution to GDP (around 20%), its contribution of foreign exchange and its preponderance in the structure of employment with more than 65% of the active population [15]. In India, agriculture plays a vital role in its economy. It is our primary duty to increase the agricultural capacity as much we can; rural households depend on agriculture as their major means of livelihood [16]. Also according to the latter, agricultural export constitutes 10% of the country's exports and is the fourth-largest exported principal commodity. In Ethiopia, agriculture is the back bone of the entire economy which currently contributes about 42% to the GDP, employs more than 85% of the total population, and contributes around 90% of the national export [17,18]. In Burkina Faso, the agricultural sector plays an important role in the national economy as it generates more than 30% of the GDP. In addition, agriculture occupies nearly 86% of the population while providing 60% of the monetary income of rural households [19]. In short, although agriculture is predominantly almost extensive and rain-fed depending on climatic hazards, therefore subject to aridity, evidences show that whatever is happening in agriculture sector, the african country's economy would be profoundly affected not to say dead [20, 21].This is the reason why today, climate aridity is subject to an ongoing scientific debate all over the world [22,23]. It's through these meetings, to carry out a territorial analysis able to outline the overall national framework in terms of intensity, spatial distribution, and temporal evolution of water shortage caused by aridity also discussing the possible implications in the agricultural sector [24]. As aridity is a reliable indicator of potentially available water, assessing its changes in future climatic conditions is important for good water management [25]. This would, according to [26,27] , be a crucial condition for being able to conduct modern agriculture that is both ecologically balanced and economically profitable. So according to [2],a comprehensive assessment of aridity changes needs to consider the wealth of variables shaping the common perception of a 'dry' landscape, including hydroclimatological (precipitation, temperature, flow) and agroecological drivers (soil moisture, vegetation cover and productivity, etc.). A wealth of studies have suggested that global aridity will increase over the 21st century due to the thermodynamic response of a warming atmosphere [28,29,30,31,32]. The majority of these studies use indices developed in climatology literature as a reliable proxy for aridity [9]. These indices are generally based on the combination of precipitation, temperatures and the evaporative demand of the atmosphere. The best known are those of Lang, Emberger, d'Angström, Thornthwaite, Dubief, Gams, Capot-Rey, Angot, Moral, Transeau, Bagnouls-Gaussen et Birot etc [3]. These indices are generally calculated annually (sometimes monthly) and are above all usable at different scales. Aridity indices are quantitative indicators of the degree of water shortage at a given location. Depending on the extent of the water deficit, several degrees of aridity can be differentiated and are defined by conventional classes of aridity indices applicable to climate zoning. It is generally conventional to distinguish at least three degrees in aridity, namely the hyperarid or desert, the arid and the semi-arid, even if today this raises a lot of debate [5].This study aims to highlight the different aridity situations that the peanut basin went through during the study period and assess their duration, frequency and magnitude. This area is more or less bumpy, due to the existence of imperfect plains, raised towards the East and West in low plateaus covered with sand. Agriculture is the main source of livelihood and the main source of income for the majority of households [33].Like the country, this area has known for some time a climatic rupture which contributes continuously to decrease the quantity and the quality of water resources [34].This constitutes a serious obstacle for agricultural production not only for the groundnut basin, but also for many other country regions. This area which supplied most of the country's agricultural production yesterday, is today subject to a drastic decline [35,36]. Thus, in order to assess the situation in the area, we based our analysis on five representative weather stations (Louga, Thies, Diourbel, Fatick and Kaolack), with data sets comprising 5 decades of information (1965-2014) made available to us by the national agency for civil aviation and meteorology (ANACIM). Our choice is focused on the parameters which act directly on the availability of water, namely precipitation and temperatures. Our approach is based on the Lang, Martonne and hydrothermal indices defined on an annual time step. We first carried out a quantitative analysis expressed by these indices to assess atmospheric and climatic risk phenomena and then produced radar-type climatic diagrams for a quality interpretation of the rain-thermal characteristics. It seems to us in this regard that the identification of areas prone to aridity can prove to be a practical tool to find practical solutions intended to mitigate the impact of this phenomenon on local communities through agriculture and development in general.

II. Materials and methods

II.1. Study area

The traditional Groundnut Basin (Figure 1) covers the west and center of the country and corresponds to the administrative regions of Louga, Thies, Diourbel, Fatick and Kaolack [37,38]. It lies between latitudes 13 ° and 15 ° 30 North and longitudes 13 ° and 16 ° 30 East [39,40]. It is bounded to the north by the Saint Louis region, to the south by The Gambia, to the west by the Dakar region and the Atlantic Ocean, to the east by the Tamba region [41]. It covers about a third of the area of Senegal and is home to about half of the population. Its population essentially rural (nearly 60%), is predominantly young, with a high density in the south (in the regions of Fatick and Kaolack) [42,43]. The population is predominantly Muslim and is made up of three ethnic groups: Sereres, Wolofs and Toucouleurs [44]. The climate is Sahelian in the North and Sahelo-Sudanian in the South marked by the inequality and the low rainfall which increases from the South to the North [45].Like the country, this area experiences a dry season from October to July and a rainy season from July to October between 400-500mm isohyets in the North and 800-900mm in the South. Average monthly temperatures are particularly high, especially in April, May and June when they are well above 30 ° C. Generally during the dry season the temperatures are on average higher, the air is dry and the lighting is important. Winds are very strong in this area and their effects are manifested by wind erosion which is often expressed by true sand winds [46]. The topography is more or less bumpy, due to the existence of imperfect plains, raised towards the East and West in low plateaus covered with sand. Hydrographically, three zones are identified: the western zone; the central zone and the eastern zone. The exploitation of water resources in deep aquifers is quite limited, unlike that of groundwater, the supply of which is dependent on rainfall and the nature of impermeable rocks [34,47].On the pedological level, one finds there ferruginous tropical soil little leached; and brown callimorphic soils located on depressions [48].The plant cover is mainly characterized by rainfall, anthropogenic activities and the nature of the soil. The plant formations are characterized by a predominance of tree savannah. The herbaceous carpet is composed of annual grasses. Natural vegetation is completely transformed or degraded by cultural practices, clandestine and abusive exploitation of forest products, bush fires and drought [34,38].The dominant activities are agriculture, trade, crafts and animal husbandry. The main speculations are: millet, peanut, cowpea sorghum, cassava watermelon and bissap. Groundnuts are the main cash crop that provides a large share of farmers' cash income. However, other crops such as cowpea, watermelon and especially cassava also contribute to increasing incomes [49,50]. Other products (vegetables, slaughter meat, poultry, forest products) provide relatively large benefits and constitute secondary activities in which farmers are increasingly involved in greater diversification of their sources of income [51,52]. In the past, this area supplied most of the country's agricultural production. Today, anthropogenic pressure and climatic disruption have contributed to accelerated degradation of ecosystems and induced profound changes in the production operating system [53].

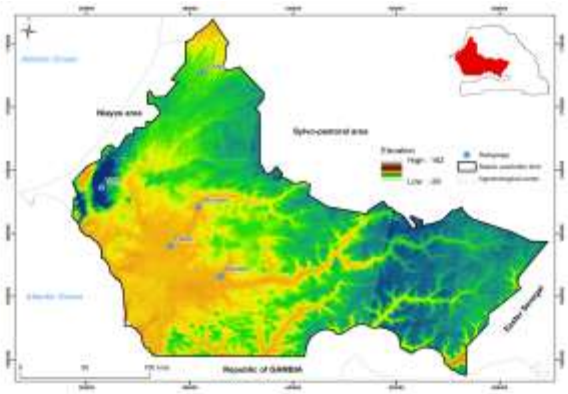

Figure 1. *Location of the study area*

II.2. Aridity indices used

Climatic aridity is assessed on the basis of indices generally calculated annually, sometimes monthly and usable on a small scale [3]. Aridity indices are quantitative indicators of the degree of water shortage at a given location [5]. Originally, a climate index is a combination of at least two variables describing the state of the atmosphere to characterize the climate of a place [54,55]. Over the past three decades, many authors have proposed formulas that generally combine precipitation and evaporation data [56]. According to [57], in the absence of precise evaporation data, it is the temperature that was most frequently used. So nowadays, the most used indices take as parameters rainfall and temperature [1]. These are quantified reports used to characterize the climate of a given region. In this article we have limited ourselves to the LANG and Martonne indices which use the fundamental climatic parameters acting on the availability of water, namely precipitation, temperatures. Their choice is justified by their robustness, suppleness, flexibility and their usability at all scales and all time steps.

II.2.1. LANG index

Lang could be considered the first scientist to propose an index combining precipitation (in mm) and average monthly or annual temperatures (in ° C) to characterize the climate of the area and determine "humidity-aridity at regional scale, given by relation (1) [58]. The concept of the Lang rain factor is based on the increase in temperature which influences the water deficit and makes the soil sufficiently recharged by precipitation [59]. Based on this ratio, LANG proposed four classes according to the values of the annual index to characterize the climate of a given area (Table 1)

$$I_L = \frac{P}{T} \qquad (1)$$

Where P: annual precipitation (mm) and T: annual temperature (° C)

Table 1. *Climate classification with the LANG index [56]*

Index value	Climate types
$I_L < 20$	Arid
$20 < I_L < 40$	Semi-arid
$40 < I_L < 70$	Semi-humid
$70 < I_L < 100$	humid
$I_L > 100$	Per-humid

II.2. 2. Hydrothermal index

Like the majority of climatic indices, the hydrothermal index highlights the different level of evolution of the 2 fundamental climatic elements (temperature and precipitation) to assess the level of drying and drought in the analyzed territory [60]. It is calculated as the product of the average annual air temperature and the annual water depth divided by 1000 indicated by equation (2). According to [1], this index has the same characteristics as the Lang rain factor (see table 1)

$$I_h = \frac{T * P}{1000} \qquad (2)$$

Where P: annual water depth (mm) and T: annual average temperature (° C)

II.2.3. Martonne index

Based on essentially geographic considerations, Martonne defined the aridity of the climate on an annual scale by the quotient (3) [61]. It allows you to assess the annual aridity level of any station. The method is widely used for climatological, agricultural and hydrological studies [57]

$$I_M = \frac{P}{T+10} \qquad (3)$$

Where P: annual precipitation (mm) and T: annual temperature (° C)
According to [43], this index makes it possible to characterize the absorbing and evaporating power of air from temperature; it is all the lower since the climate is arid At the global level, Martonne proposed at the regional scale six main types of according to the values of the annual index given in table (2) [58].

Table 2. *Climate classification with the Martonne index [27]*

Index value	Climate types
$I_M < 5$	Per-arid
$5 < I_M < 10$	Arid
$10 < I_M < 20$	Semi-arid

$20 < I_M < 30$	Semi-humid
$30 < I_M < 40$	humid
$I_M > 40$	Per-humid

II. 3. Data and Application

Studies relating to the characterization of the aridity of the climate are necessary to assess the constraints linked to the different types of climate with regard to water availability and its consequences on agriculture and development in general. This study relates to the groundnut basin, in particular the center west of the country which corresponds to the administrative regions of Louga, Thies, Diourbel, Fatick and Kaolack. It is based on annual rain and temperature data from synoptic stations in the five regions for the period 1965-2014. They come from ANACIM (national agency of civil aviation and meteorology) which is a reliable national structure and specialized in the collection of quality climatic data. The choice of these parameters is justified by the fact that they can induce a water shortage. Our approach is essentially based on the quantitative analysis expressed by the Lang, Martonne and hydrothermal and qualitative indices through climate diagrams of the radar type. This is an essential step to identify climatic zones, quantify the degree of water shortage and characterize the type of station uniformly throughout the study area. To do this, after calculating the indices on an annual scale, we used them using radar diagrams for the five regional stations. Using reference tables 1 and 2, we have highlighted the different "moisture-moisture" situations experienced by the groundnut basin during this period. We also evaluated the probability of occurrence of each of the situations encountered and made a thermal and water balance for each of the regions. We finally compared the 3 indices on the same diagram to see the two indices which corroborate best. They will thus be chosen as the best suited for such area studies and possibly throughout the territory. Finally, this study is intended to be a starting point for the implementation of water conservation measures, prevention or mitigation of the phenomenon of aridity in vulnerable areas.

III. Results and discussion

III.1. LANG index

Figs. 2a, 2b, 2c, 2d and 2e illustrate the distribution in radar form of the LANG index respectively at Louga (fig.2a), Thies (fig.2b), Diourbel (fig.2c), Fatick (fig .2d) and Kaolack (fig.2e) for the period 1965-2014. Analysis of the results obtained over the study period shows that: for Louga (fig.2a), 98% of the years are arid and 2% semi-arid; for Thies (fig.2b), 67% of the years are arid and 33% semi-arid; for Diourbel (fig. 2c), 61% of the years are arid and 19% semi-arid; for Fatick (fig.2d), 53% of the years are arid and 47% semi-arid; for Kaolack (fig. 2e), 49% of the years are arid and 51% semi-arid. It appears that the arid years are more extensive in space and persistent in time than the semi-arid ones. 1997 emerged as the driest year and 1969 as the least arid for Louga; for Thies 1972 is the driest year and 1969 the least arid; for Diourbel and Fatick 1983 is the driest year and 1967 the least arid; and for Kaolack 1983 was the driest year and 1966 the least arid. The probability of occurrences of the arid climate is 96% in Louga; 66% in Thies; 60% in Diourbel; 50% to Fatick and; 44% in Kaolack. The probability of semi-arid occurrences is 2% in Louga; 32% in Thies; 38% in Diourbel; 44% in Fatick and; 46% in Kaolack. We note here that Louga seems to be the most exposed and Kaolack the least to the phenomenon of aridity. In terms of water balance, Louga recorded a loss of (-449.4 mm); Thies (-591.3 mm); Diourbel (-524.5mm); Fatick (-704.2mm) and Kaolack (-601.1mm). For the heat balance, Louga recorded an increase of (+ 2.8 ° C); Diourbel (+ 2.4 ° C); Fatick (+ 1.5 ° C); Kaolack (+ 1.2 ° C) and Thies a decrease of (-1.7 ° C). According to the water balance, the lack of water seems much more remarkable in Fatick than in Kaolack, Thies, Diourbel and Louga. In terms of warmth, Louga seems the warmest and Thies the least warm. This result index highlights the great vulnerability and drying and warming experienced by the groundnut basin during the period 1965-2014.

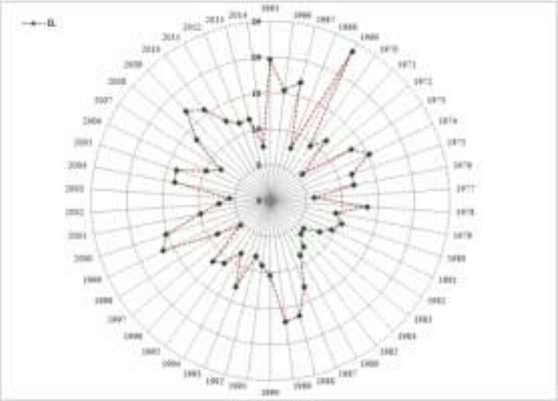

Figure 2a. *Radar distribution of LANG index at Louga*

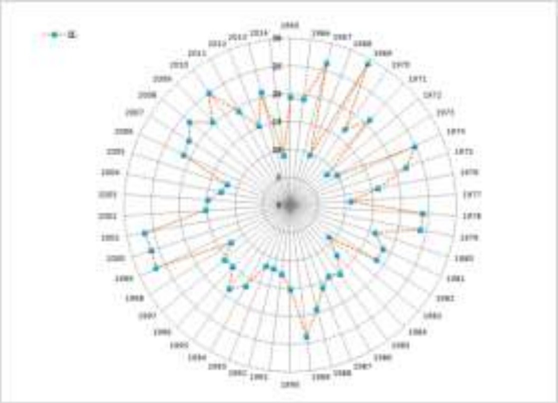

Figure 2b. *Radar distribution of LANG index at Thies*

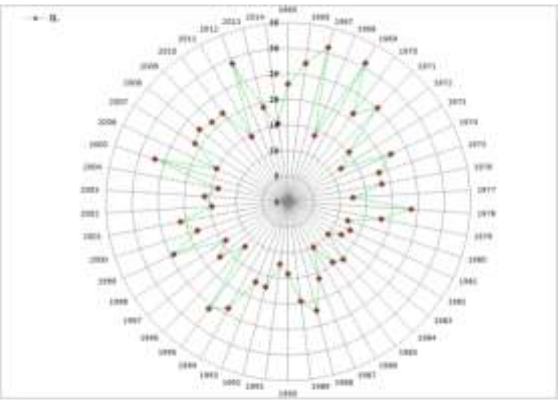

Figure 2c. *Radar distribution of LANG index at Diourbel*

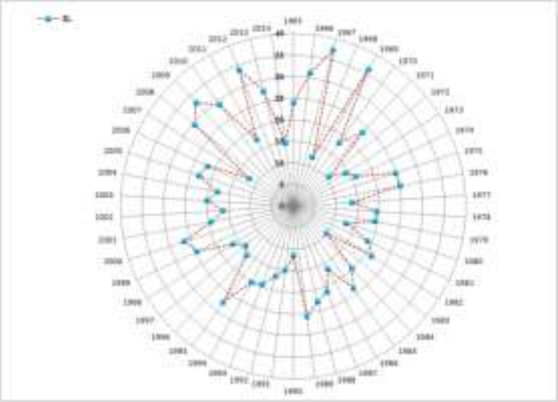

Figure 2d. *Radar distribution of LANG index at Fatick*

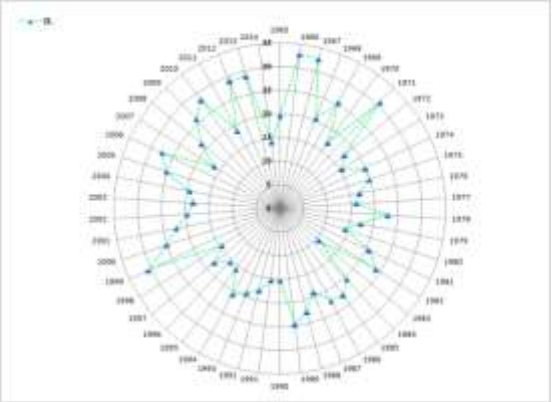

Figure 2e. *Radar distribution of LANG index in Kaolack*

III. 2. Hydrothermal index

Figs. 3a, 3b, 3c, 3d and 3e show the evolution in radar form of the hydrothermal index respectively at Louga (fig.3a), Thies (fig.3b), Diourbel (fig.3c), Fatick (fig .3d) and Kaolack (fig.3e) over the period 1965-2014. Analysis of the diagrams gave the following results: for Louga (fig. 3a), 100% of the years in the study period are arid; for Thies (fig.3b), we have 98% arid and 2% semi-arid; for Diourbel (fig. 3c), 96% are arid and 4% semi-arid; for Fatick (fig.3d), 82% are arid and 18% semi-arid; for Kaolack (fig. 3e), 73% are arid years and 27% are semi-arid. In short, the arid years are more extensive in space and persistent in time than the semi-arid ones. For Louga and Thies, 1972 appears to be the driest year and 1969 the least arid; for Diourbel 1986 is the driest year and 1969 the least arid; for Fatick, 1983 was the driest year and 1967 the least arid and for Kaolack 1983 was the driest year and 2010 was the least arid. According to this index, the arid climate occupies a probability of occurrences of 100% in Louga; 98% in Thies; 92% in Diourbel; 80% to Fatick and; 72% in Kaolack. That relating to the semi-arid is estimated at 0% in Louga; 2% in Thies; 4% in Diourbel; 18% in Fatick and 26% in Kaolack. Louga again stands out as being the most exposed and likewise Kaolack as the least exposed to the phenomenon of aridity. The water loss recorded at Louga is of the order of (-442.6mm); in Thies it of (-591.3mm); Diourbel (-589.2mm); Fatick of (-704.2mm) and Kaolack (-548mm). The increase in heat noted in Louga is (+1.7 ° C); Fatick (+ 1.5 ° C); and for Kaolack, Diourbel and Thies, there is a decrease of (-1.3 ° C), (-0.2 ° C) and (-1.7 ° C) respectively. According to the water balance, the drop in rainfall due to its intensity seems much more significant in Fatick than in Thies, Diourbel, Kaolack and Louga. In thermal terms, Louga seems the warmest and Thies the least hot. These results corroborate well with previous ones to the vulnerability of the area to drying out and warming during the period 1965-2014.

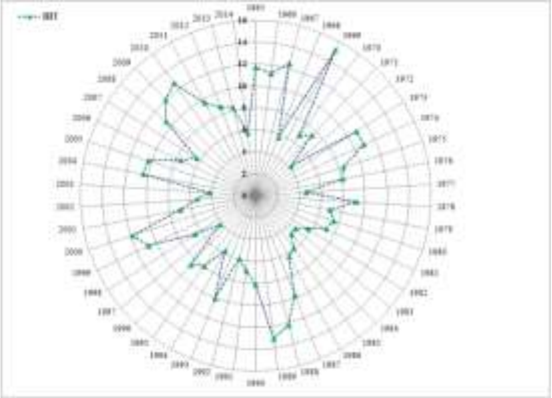

Figure 3a. *Radar distribution of hydrothermal index at Louga*

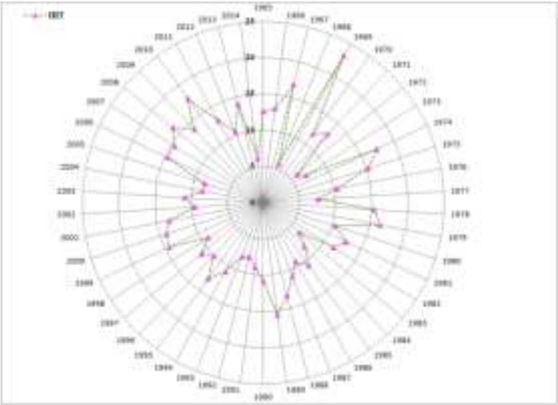

Figure 3b. *Radar distribution of hydrothermal index at Thies*

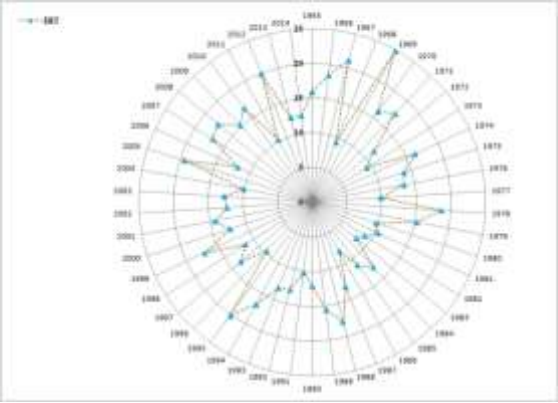

Figure 3c. *Radar distribution of hydrothermal index at Diourbel*

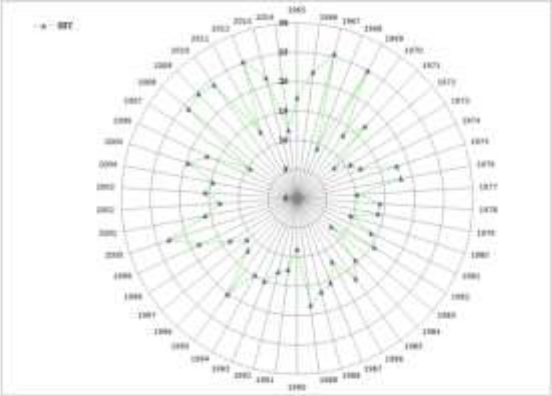

Figure 3d.*Radar distribution of hydrothermal index at Fatick*

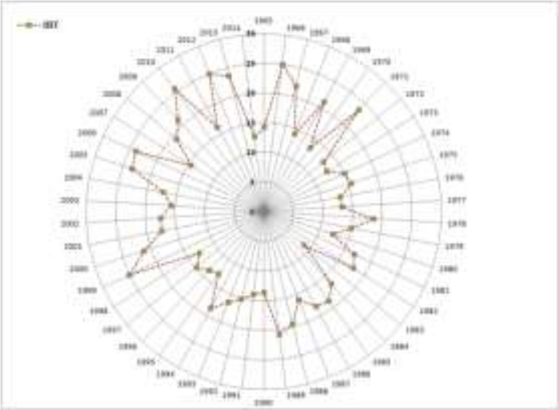

Figure 3e. *Radar evolution of hydrothermal index at Kaolack*

III. 3. Martonne index

We present in fig.4a, 4b, 4c 4d and 4e the distribution of the Martonne index respectively to Louga (fig.4a), Thies (fig.4b), Diourbel (fig.4c), Fatick (fig.4d) and Kaolack (fig. 4e) over the period 1965-2014. According to this index, for Louga (fig.4a), 10% of the years have a per-arid climate, 60% an arid climate and 23% a semi-arid climate; for Thies (fig.4b), 27% of the years are arid, 73% are semi-arid and 2 semi-humid; for Diourbel (fig. 4c), 18% are arid, 75% semi-arid and 7% semi-humid; for Fatick (fig.4d), 13% are arid and 71% semi-arid and 16% semi-humid and finally for Kaolack (fig.4e), 2% are arid, 82% semi-arid and 16% semi-humid . We note here that the semi-arid years are more extensive in space and persistent in time than the arid and semi-humid years. 1997 emerged as the driest year and 1969 as the least arid for Louga; for Thies 1972 is the driest year and 1969 the least arid; for Diourbel 1983 is the driest year and 1969 the least arid; for Fatick 1983 is the driest year and 1967 the least arid and for Kaolack 1983 is the driest year and 1966 the least arid. The probability of occurrences of the per-arid climate is 8% in Louga and 0% in Thies, Diourbel, Fatick and Kaolack. That of the arid is 52% in Louga; 26% in Thies; 16% in Diourbel; 12% at Fatick and 2% at Kaolack. The probability of occurrences of the semi-arid climate is 22% in Louga and 70% in Thies, 66% in Diourbel, 64% in Fatick and 82% in Kaolack. For the semi-humid climate, this probability is 0% in Louga and 2% in Thies, 6% in Diourbel, 14% in Fatick and 16% in Kaolack. Louga seems to be the most exposed and Kaolack the least to the aridity phenomenon. In terms of water balance, the loss is estimated at (-449.4mm) in Louga; (-591.3mm) at Thies; (-590.4 mm) at Diourbel; (-704.2 mm) at Fatick and (-601.1mm) at Kaolack. For the heat balance, Louga recorded an increase of (+ 2.8 ° C); Diourbel (+ 0.5 ° C); Fatick

(+ 1.5 ° C); Kaolack (+ 1.2 ° C) and Thies a decrease of (-1.7 ° C). According to the water balance, the water deficit seems much more remarkable in Fatick than in Kaolack, Thies, Diourbel and Louga. In terms of warmth, Louga seems the warmest and Thies the least warm. These results corroborate well with the previous ones.

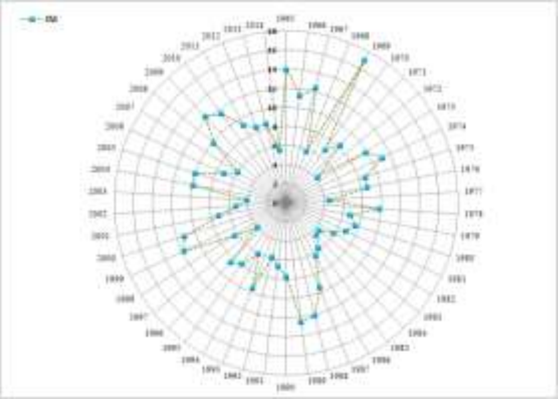

Figure 4a. *Radar distribution of Martonne index at Louga*

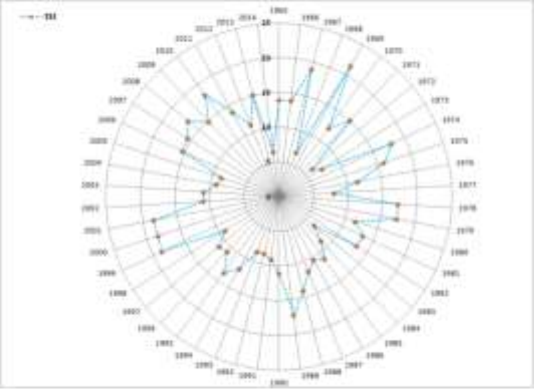

Figure 4b. *Radar distribution of Martonne index at Thiès*

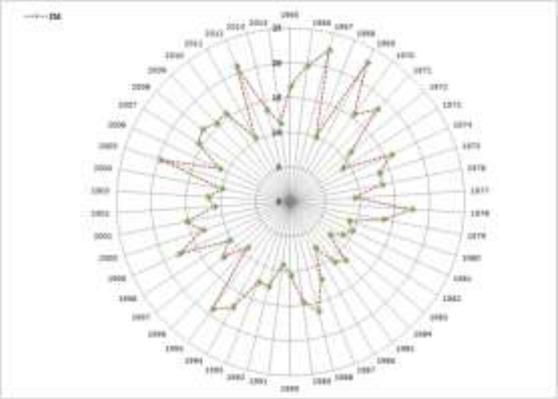

Figure 4c. *Radar distribution of Martonne showing at Diourbel*

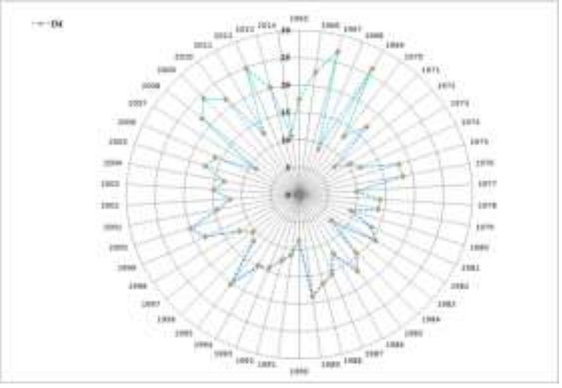

Figure 4d. *Radar distribution of Martonne to Fatick index*

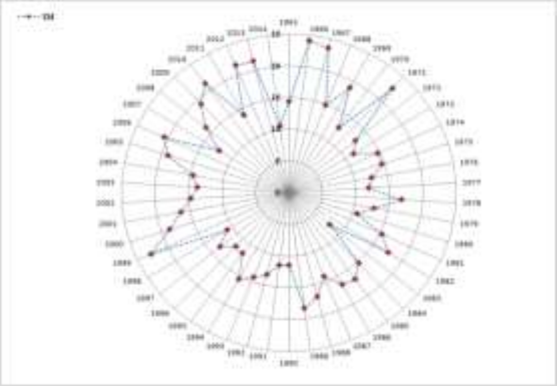

Figure 4e. *Radar distribution of Martonne showing at Kaolack*

III. 4. Comparison of different indices

Figs. 5a, 5b, 5c, 5d and 5e describe the comparative analysis of the three indices respectively at Louga (fig.5a), Thies (fig.5b), Diourbel (fig.5c), Fatick (fig.5d) and Kaolack (fig .5e) over the period 1965-2014. It is a question of identifying among these indices the most suitable for regional studies. The principle consists in identifying on the radar the indices which will have practically identical paces and these will be retained. Analysis of the various diagrams clearly shows that the hydrothermal index and that of Martonne are in perfect agreement. They are therefore seen as the most suitable. In addition, the Martonne index, which is easy to calculate and above all which describes the climate as a whole, going from per-arid zones to per-humid zones will be retained.

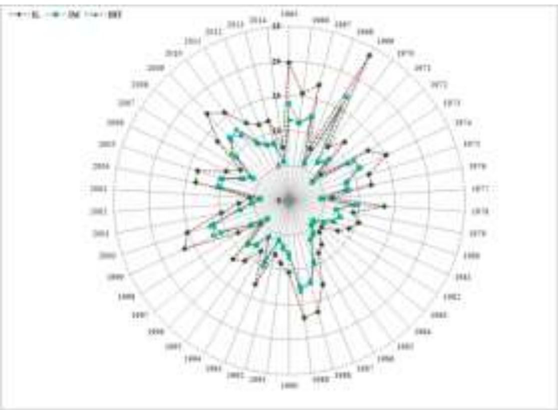

Figure 5a. *Comparative study of the three indices at Louga*

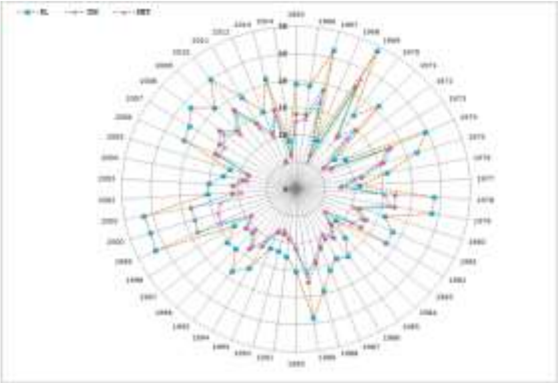

Figure 5b. *Comparative study of the three indices at Thies*

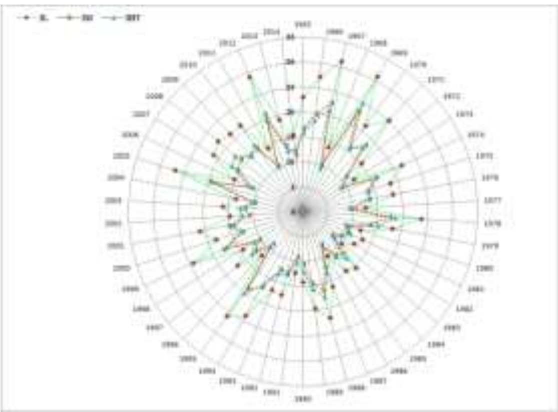

Figure 5c. *Comparative study of the three indices at Diourbel*

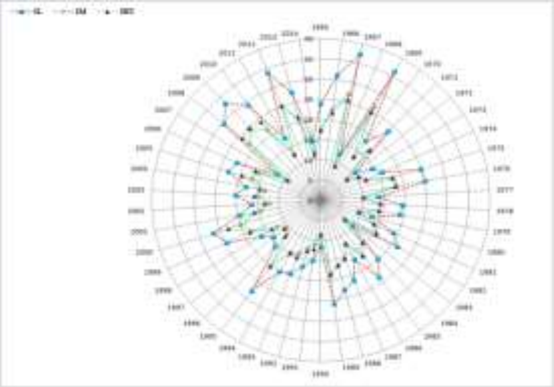

Figure 5d. *Comparative study of the three indices at Fatick*

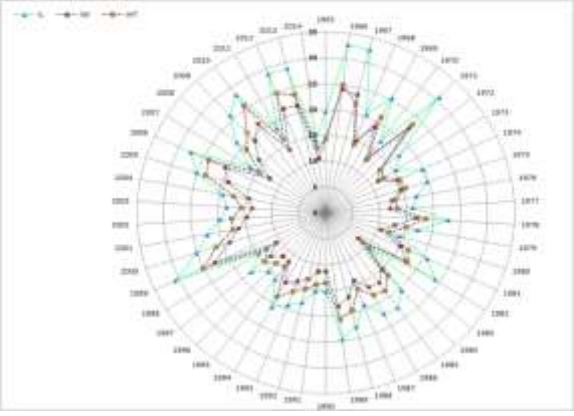

Figure 5e. *Comparative study of the three indices at Kaolack*

IV. Conclusion

The analysis of climatic indices and climatic diagrams is relevant for assessing atmospheric and climatic risk phenomena. It is a fundamental step towards a synthesis of climatic factors of particular importance for living beings. This study relates to the traditional groundnut basin which corresponds to the administrative regions of Louga, Thies, Diourbel, Fatick and Kaolack. It is based on annual rain and temperature data from synoptic stations in the five regions for the period 1965-2014. Our approach is essentially based on quantitative and qualitative analysis of the Lang, Martonne and hydrothermal indices. At this level, our concern is to provide decision-makers with indicators that can enable them to quantify the degree of water shortage and to put in place adequate measures to reduce and combat climate impacts. This would be a prerequisite for upgrading agriculture economically and ecologically for a better quality of life and subsistence for populations and ecosystems like the groundnut basin due to its vulnerable geo-climatic position. At the end of this study, the results obtained are on the whole convincing, meaningful and promising. The Lang index analysis showed that for Louga 98% of the years are arid and 2% semi-arid; for Thies, there are 67% of arid years and 33% semi-arid; for Diourbel 61% are arid and 19% semi-arid; for Fatick we have 53% of arid years and 47% of semi-arid and for Kaolack, there are 49% of arid years and 51% of semi-arid. It appears with this index that the arid years are more extensive in space and persistent in time than those semi-arid. 1997 emerged as the driest year and 1969 as the least arid for Louga; for Thies 1972 is the driest year and 1969 the least arid; for Diourbel and Fatick 1983 is the driest year and 1967 the least arid; and for Kaolack 1983 was the driest year and 1966 the least arid. The probability of occurrences of the arid climate is 96% in Louga; 66% in Thies; 60% in Diourbel; 50% to Fatick and; 44% in Kaolack. The probability of semi-arid occurrences is 2% in Louga; 32% in Thies; 38% in Diourbel; 44% in Fatick and; 46% in Kaolack. We note here that Louga seems to be the most exposed and Kaolack the least to the phenomenon of aridity. In terms of water balance, Louga recorded a loss of (-449.4 mm); Thies (-591.3 mm); Diourbel (-524.5mm); Fatick (-704.2mm) and Kaolack (-601.1mm). For the heat balance, Louga recorded an increase of (+ 2.8 ° C); Diourbel (+ 2.4 ° C); Fatick (+ 1.5 ° C); Kaolack (+ 1.2 ° C) and Thies a decrease of (-1.7 ° C). According to the water balance, the lack of water seems much more remarkable in Fatick than in Kaolack, Thies, Diourbel and Louga. In terms of warmth, Louga seems the warmest and Thies the least warm. This index revealed the great vulnerability to drying and warming experienced by the groundnut basin during the study period. With regard to the hydrothermal index, analysis of the diagrams gave the following results: for Louga 100% of the years are arid; for Thies we have 98% arid and 2% semi-arid; for Diourbel 96% are arid and 4% semi-arid; for Fatick, 82% are arid and 18% semi-arid and for Kaolack, 73% are arid years and 27% are semi-arid. In short, the arid years are more extensive in space and persistent in time than the semi-arid ones. For Louga and Thies, 1972 appears to be the driest year and 1969 the least arid; for Diourbel 1986 is the driest year and 1969 the least arid; for Fatick, 1983 was the driest year and 1967 the least arid and for Kaolack 1983 was the driest year and 2010 was the least arid. According to this index, the arid climate occupies a probability of occurrences of 100% in Louga; 98% in Thies; 92% in Diourbel; 80% to Fatick and; 72% in Kaolack. That relating to the semi-arid is estimated at 0% in Louga; 2% in Thies; 4% in Diourbel; 18% in Fatick and 26% in Kaolack. Louga again stands out as being the most exposed and likewise Kaolack as the least exposed to the phenomenon of aridity. The water loss recorded at Louga is of the order of (-442.6mm); in Thies it of (-591.3mm); Diourbel (-589.2mm); Fatick of (-704.2mm) and Kaolack (-548mm). The increase in heat noted in Louga is (+1.7 ° C); Fatick (+ 1.5 ° C); and for Kaolack, Diourbel and Thies, there is a decrease of (-1.3 ° C), (-0.2 ° C) and (-1.7 ° C) respectively. According to the water balance, the drop in rainfall due to its intensity seems much more significant in Fatick than in Thies, Diourbel, Kaolack and Louga. In thermal terms, Louga seems the warmest and Thies the least hot. This finding corroborates well with the previous one on the vulnerability of the area to drying and warming during the study period. As for the Martonne index, for Louga 10% of the years have a per-arid climate, 60% an arid climate and 23% a semi-arid climate; for Thies, 27% of the years are arid, 73% semi-arid and 2% semi-humid; for Diourbel, 18% are arid, 75% semi-arid and 7% semi-humid; for Fatick, 13% are arid and 71% semi-arid and 16% semi-wet and finally for Kaolack, 2% are arid, 82% semi-arid and 16% semi-humid. With this index, semi-arid years are more extensive in space and persistent in time than arid and semi-humid years. 1997 emerged as the driest year and 1969 as the least arid for Louga; for Thies 1972 is the driest year and 1969 the least arid; for Diourbel 1983 is the driest year and 1969 the least arid; for Fatick 1983 is the driest year and 1967 the least arid and for Kaolack 1983 is the driest year and 1966 the least arid. The probability of occurrences of the per-arid climate is 8% in Louga and 0% in Thies, Diourbel, Fatick and Kaolack. That of the arid is 52% in Louga; 26% in Thies; 16% in Diourbel; 12% at Fatick and 2% at Kaolack. The probability of occurrences of the semi-arid climate is 22% in Louga and 70% in Thies, 66% in Diourbel, 64% in Fatick and 82% in Kaolack. For the semi-humid climate, this probability is 0% in Louga and 2% in Thies, 6% in Diourbel, 14% in Fatick and 16% in Kaolack. Still, Louga seems to be the most exposed and Kaolack the least to the aridity phenomenon. In terms of water balance, the loss is estimated at (-449.4mm) in Louga; (-591.3mm) at Thies; (-590.4 mm) at Diourbel; (-704.2 mm) at Fatick and (-601.1mm) at Kaolack. For the heat balance, Louga recorded an increase of (+ 2.8 ° C); Diourbel (+ 0.5 ° C); Fatick (+ 1.5 ° C); Kaolack (+ 1.2 ° C) and Thies a decrease of (-1.7 ° C). According to the water balance, the water deficit seems much more remarkable in Fatick than in Kaolack, Thies, Diourbel and Louga. In terms of warmth, Louga seems the warmest and Thies the least warm. These results corroborate well with the previous ones. Finally, the comparison of the three indices shows that the Martonne aridity index remains the most satisfactory for studies of a regional nature and that it will be used for studies at national level. These results show, in a convergent way, that the risk of aridity expansion, by its duration, frequency and intensity, is significant in the area, especially from North to South. Thus, it should be noted that when the water deficiency period lasts longer, it can lead to a significant water imbalance, which leads to crop losses or restrictions on water consumption, thus causing a number of economic problems. This study is therefore intended to be an alert to the authorities on the necessity and urgency of having a better water management system to prevent or reduce effects on crops in order to obtain a minimum economic return for each culture. However, despite its merits, it is important to remember that this study undeniably has its limits. This was based solely on the use of data from weather stations. The effect of topography was not taken into account, since the weather stations are often located in a flat area. In addition, the relief is often very variable on a forest scale, and there was no data to estimate its diversity, while the importance of topography is often recognized in the typologies of stations. To give this study all its quintessence, it would be important to use geographic information systems (GIS) associated with digital terrain models (DTM) and meteorological data. This should allow the production of spatialized synthetic indices integrating climate and topography.

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Notation

DPS	Forecast and Statistics Department
IEDA	Innovation Environment Development Africa
ISRA	Senegalese Institute for Agricultural Research
ENDA	Third World Environment and Development
DEMSG	Directorate of General Secondary Education
NMA	National Meteorology Agency

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