Journal of Materials and Environmental Science
ISSN : 2028-2508
CODEN : JMESCN

J. Mater. Environ. Sci., 2020, Volume 11, Issue 12, Page 2106-2122

http://www.jmaterenvironsci.com

Spatialization of the climate using aridity indices: case of agro ecological zone of peanut basin, Senegal

Vieux Boukhaly Traore[1,2*], Mamadou Lamine Ndiaye[2,3], Ramatoulaye Mbengue Ndiaye[2], Saïdou Diallo[4], Mariama Néné Koita[5], Amadou Tahirou Diaw [2], Aboubaker Chedikh Beye[1,6]

[1]*Hydraulics Laboratory and Fluid Mechanics, Cheikh Anta Diop University, Dakar, Senegal.*
[2]*Polytechnic High School's Geoinformation Laboratory, Cheikh Anta Diop University, Dakar, Senegal*
[3]*Ecological monitoring center (CSE), Dakar, Senegal*
[4]*Plasma Physics Laboratory and Interdisciplinary Research, Cheikh Anta Diop University, Dakar, Senegal*
[5]*Solar Energy Laboratory and Transfers, Cheikh Anta Diop University, Dakar, Senegal*
[6]*Solid Physics Laboratory and Materials Sciences, Cheikh Anta Diop University, Dakar, Senegal*

Received 22 July 2020,
Revised 21 Dec 2020,
Accepted 25 Dec 2020

Keywords
- ✓ *Climate aridity,*
- ✓ Climate map,
- ✓ GIS,
- ✓ DTM,
- ✓ Rainfed agriculture,
- ✓ Survival.

1vbtraore@gmail.com ; vieuxboukhalytraore@yahoo.fr
Phone: +221771056382;

Abstract

The main objective of this study is the identification of areas sensitive to the climate aridity in the groundnut basin. It is based on GIS mapping of Lang and Martonne indices on a decanal and global scale. In this sense, the spatialization is based on climatological data comprising 5 decades of information associated with digital terrain models to take into account the topography. Particular interest has been given to the analysis of the distribution of different plant species according to the climatic stages of the area. Our concern is to provide support allowing understanding the interactions in order to adopt valid standard methodologies for the prevention or mitigation of the phenomenon of aridity or desertification of vulnerable areas. At the end of this study, the results obtained highlighted the increasingly increasing aridity phenomena in the groundnut basin. According to the Lang index, the arid and semi-arid areas potentially affected by desertification represent 40 % to 100% and 0% to 60% of the territory studied. According to the Martonne index, they represent 0% to 20% and 80% to 100%. Thus, the Lang index gives more importance to arid areas than to semi-arid areas, unlike the Martonne index which favors semi-arid areas. The most arid regions are located in the far north and the least arid in the far south. In addition, the comparison of the two indices made it possible to adopt the Martonne index as the most satisfactory; its linear correlation with respect to the Lang index is more significant and is of the order of 0.995 on the decanal scale and 0.991 globally. It will therefore be used for regional and possibly national studies. In sum, the study also revealed a strong interdependence between temperatures, precipitation and the spatial distribution of plant formations. Overall, the expansion of the steppe to the detriment of the desert has become more significant. During the examined time period, growing reductions in rainfall and temperatures have been observed which have further widened the gap between precipitation amounts and water demand in agriculture and vegetation.

1. Introduction

It is now widely known that the climate of a region fluctuates, varies and changes with the years and the periods [1]. However, the very notion of climate is extremely complex [2]. Basically, [3, 4] defines it as the combination of the states of the atmosphere in a given place and over a defined period. According to [5], climatic events are mainly a blend of several factors that are natural and/or anthropogenic orders. [6] argue that the climate manifestations which are global phenomenon and occurring continuously since the earth came into existence are characterized by its change and its variability. Furthermore, according to [7] climate variability is an effect of natural conditions whereas climate change is due to natural conditions and human activities. The great variability of the climate is manifested by the relative increase in the frequency and intensity of extreme phenomena which have negative effects on the population and human activities [8]. Among these effects, the tendency to arid climate is one of the most followed and studied current climatic phenomena, at global and regional levels, especially because of the insidious long-term influences on human communities and on the economy [9]. Aridity is characterized by an almost permanent rainfall deficit which depends on the local climate and represents a permanent or seasonal condition. Contrary to drought that is a transitory phenomenon related to the meteorological variability and, as such, it can strike everywhere and at any time with levels of intensity and persistence which cannot be determined a priori [10]. [11] argue that the rainfall deficit is actually linked to high sunshine, high daytime temperatures, low air humidity and evapotranspiration, leading to water deficits during most of the year. According to [12], arid climate is a structural and spatial climatic phenomenon, while drought is a temporal phenomenon that occurs in both arid and wetter environments.

[12] add that arid regions are characterized by a severe lack of available water, which has the effect of slowing down, or even preventing, the growth and development of vegetation and the presence of animal life. Consequently, environments subject to arid climates are characterized by a scarcity of vegetation generally well adapted to the situation and desert. In these types of regions, water remains according to [13] the primary limiting factor for agricultural production. Rainfall is the main source of water [14]. To this end, it represents the most important climate factor for population, environment and ecosystems in underdeveloped countries, especially those in the Sahel where most crops require rain to optimize production [15]. According to [16], rain-fed based agriculture is predominantly the basis for developing and least developed countries livelihood and socio-economic system [17-19]. In the same vein, [20] claim that agriculture contributes to efforts to fight poverty, social and economic disparities, rural exodus, food insecurity and economic decline.

In Ethiopia for example, [21] states that 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. Evidences show that whatever is happening in agriculture sector, the country's economy would be profoundly affected [22, 23].

So, rainfall and temperature are the most important climatic factors that tend to affect the potential production of agricultural sector [21].Forexample, reports from [24] and [25] show that there was a decline in the contribution of agriculture and livestock sub-sector to GDP from 45.1% in 2000 to 26.7% in 2007 due to changes in climatic parameters and other non-climatic stressors. [26] also indicated that uneven and erratic rainfall during the last four decades makes a clear divergence of Ethiopian economy from the rest of the world. Therefore, the changing rainfall pattern in combination with the warming trends could make livestock and crop production severely affected resulting in decrease in food systems and security [7, 27]. African continent has been most vulnerable to the growing impact of climate manifestations because of low adaptive capacity and especially its dependence on natural resources [28,29]. Forexample, the noted impacts are fall in crop yield estimated at 10-20% by 2050, about 90% of people are prone to famine in the semiarid reside in Asia and Sub-Saharan Africa [30]. On another scale, [31] argue that drastic climatic constraints lead to human deaths, the decimation of livestock and considerable reductions in harvests; they also add that plant landscapes are disappearing on a large scale, arable land is being uprooted by erosion in the space of a few decades, threatening human existence. This explains why in recent decades, climate studies have caught the attention of scientists and researchers around the world and more particularly in West Africa [32]. All unanimous, the authors despite different approaches show that climate changes are a reality and constituent a serious threat to the well-being of populations and their ecosystems [33, 34]. Other recent studies estimate a further increase in climatic conditions due to the effect of global warming [9]. And considering, structural trends and the increasing frequency, the strengthening of their negative impact on both man and the environment can lead to desertification [35].

This is why it is obvious today, with regard to water availability and its consequences, that the analysis of the spatial behavior of the climate is of paramount importance to be able to lead a modern agriculture at the same time ecologically balanced and economically profitable [1,36]. Based on these observations, this study assesses the aridity phenomena of the climate in the Senegal groundnut basin from a quantitative spatial analysis. Man has long been accused of being the source of increasing aridity in many parts of the world [37]. Indeed, the anthropic gradation of the plant carpet leads to an increase in the maximum temperatures and that of the soil, the decrease in water storage capacities: these two types of degradation combine according to [38], their effects for reinforce aridity of climatic origin. This suggests [39] (Floret and Pontanier, 1984) that aridity of climatic origin is accentuated or attenuated according to the types of soil and their use by humans. Over the past thirty years, most of the indices used to assess climatic aridity refer to precipitation, extreme temperatures and very often to the evaporative demand of the atmosphere [40]. These indices are generally calculated on an annual (sometimes monthly) scale in order to spatially delimit climatic zones and explain the geographic distribution of vegetation by the combination of different climatic factors [41]. Originally, a climate index is according to [42], a combination of at least two variables describing the state of the atmosphere. The indices used in this study involve rain and annual temperature because they are the parameters that directly affect the availability of water. It will be a question of examining how and to what extent the climatic effects of aridity can be accentuated or attenuated by the types of environment and their use by humans. To take account of the determinism of aridity linked in large part to the nature of the land and the action of man, it is obviously necessary to place oneself on scales larger than usual.

Therefore, for this study, we used meteorological data sets comprising 5 decades of information from the groundnut basin (1965-2014) made available by the national agency for civil aviation and meteorology (ANACIM). Our approach is based on the Lang and Martonne indices defined on an annual time step. The cartography under GIS of these indices using digital terrain models (DTM), represents a big step forward towards the provision of fine information through spatial distribution maps, necessary for the global understanding of the phenomenon and his evolution. It constitutes a necessary stage for studies of vocation and land management and development of the use of the territory in general. This study takes into account the topography, which should allow a representation of the different climatic parameters on spatial and temporal scales more and more compatible with forest management. Our objective is to produce, through the use of GIS associated with Digital Terrain Models, as well as meteorological databases, synthetic spatialized indices aimed at identifying sensitive areas, defining useful indicators that can respond to the problems posed with a view to proposing concepts of monitoring and management of these areas, insofar as our study area is known for its high interannual variability in the rainfall regime and temperatures due to its vulnerable geo-climatic position as well as other constraints to the development of productive activities.

2. Material and Methods

2.1. Study area

The Groundnut Basin (Figure 1) is one of three agro-ecological zones in Senegal [43]. It stretches 200 km from east to west and 220 km from north to south. It traditionally corresponds to the administrative regions of Louga, Thies, Diourbel, Fatick and Kaolack [44]. The groundnut basin is between latitudes 13 ° and 15 ° 30 North and longitudes 13 ° and 16 ° 30 east; that is, north of the equator and east of the Greenwich meridian [45]. 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 atlantic ocean, to the east by the Tamba region [46]. The traditional groundnut basin covers a total area of 46,387 km², or about a third of the area of Senegal. Its population essentially rural (almost 60%), is estimated at more than 2,100,000 inhabitants, mostly young, with a high density in the south (in the regions of Fatick and Kaolack) and 82% of the rural population in 2007 [47, 48]. This predominantly Muslim population is made up of three ethnic groups: the Sereres, the Wolofs (the largest groups) and the Toucouleurs [49]. 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 [50]. Like the country, this area has a dry season from October to July, favorable for fruit crops, market gardening and animal production and a rainy season from July to October where the area is between 400-500mm isohyets at North and 800-900mm to the South, favorable for cereal, groundnut and legume crops. 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 [51]. 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. On the hydrographic level, three zones are identified: the western zone where the static level of the water table is 25 to 40m, flows from 75 to 100m3 / h are obtained by drilling at depths varying between 50 and 100m; the central zone which is almost devoid of groundwater resources in sufficient quantity and quality and the eastern zone covered by the Maestrichtien aquifer which is 200 to 250m deep, but where the quality of the water is fairly good. 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 [52].

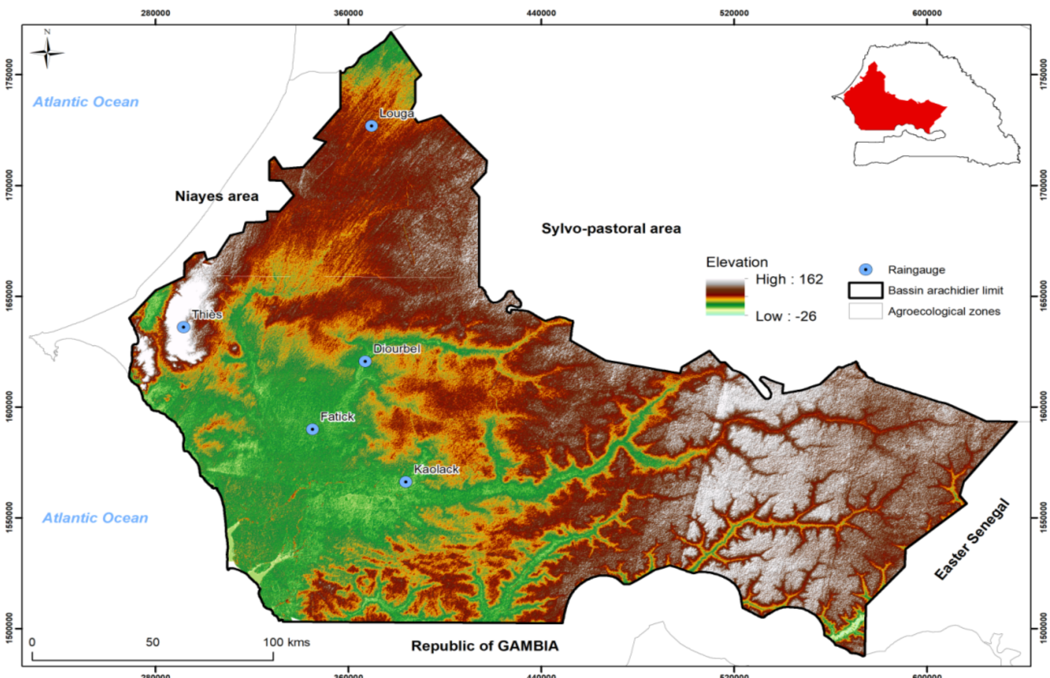

Figure 1: Study area location.

On the pedological level, we find there ferruginous tropical soils little leached which are sandy and very permeable: the common characteristic for these soils is their low clay and organic matter content; and brown callimorphic soils located on the depressions. They are sandy with 3 to 8% clay, have a humiferous horizon, are better structured than the first but are less widespread [53]. The vegetal 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 composed of Acacia Senegal, Balanites aegyptiaca, Zizyphus mauritiana and Adansonia digitata. The herbaceous carpet is made up of annual grasses dominated by Cenchrus biflorus. The natural vegetation is completely transformed by agricultural activities. This results in the disappearance of several species. Only Acacia albida remains the best protected species in the area due to its multiple uses on the farm. The state of degradation of this vegetation is mainly due to the clandestine and abusive exploitation of forest products, bush fires, drought and cultural practices [44, 52]. The dominant activity is agriculture, followed by trade, crafts and animal husbandry. Considering the area planted, the main speculations are: millet, peanuts, cowpeas, sorghum, cassava, watermelon and bissap. The main cash crop is peanuts, which provide a large part of farmers' cash income. However, other crops such as cowpea, watermelon and especially cassava also contribute to increasing incomes [54, 55]. Other products (vegetables, slaughter meat, poultry, and forest products) provide relatively large profits and constitute secondary activities in which farmers are investing more and more for a greater diversification of their sources of income [56]. Anthropogenic pressure and climate change have contributed to accelerated degradation of ecosystems and induced profound changes in the farming system [57]. Today this area is that of Sahelian agro-pastoral production systems. It is currently facing the depletion of land assets both in terms of soil fertility and that of wood resources [58].

2.2. Choice of Groundnut Basin

The Groundnut Basin has a long tradition of food crops and groundnuts in the rain on tropical ferruginous soils. This area provides most of the agricultural production with groundnuts as the main crop [59]. In 1995, it represented 65% of the total rural population of the country and 62% of the useful agricultural surface (UAA) in 1998. The production of groundnuts there was largely promoted by the government and, in the 1960s; this production could represent up to 60% of gross agricultural income and 80% of export income. Groundnut production peaked in 1976 at 1,435,000 tonnes. However, from 1980, we are witnessing a very sharp decrease in the area planted with peanuts, which went from 1,300,000 ha in 1982-1983 to 600,000 ha in 2002-2003, production also stood at 260,500 tonnes on the same date [60]. The reasons for this development are twofold: agro-climatic and economic. First, with demographic pressure, the reduction in fallow time (or even the abandonment of fallow crop cycles) and the insufficiency or even the absence of land fertilization, the soils are becoming poorer and are very vulnerable to erosion due to the destruction of plant cover [50,61]. This area also faces problems with the drying up of water points and the salinization of groundwater. It has a central position which puts it close to consumer markets with functional road axes [50]. However, it is facing a real climatic rupture (translated by a reduction in rainfall) leading to the denudation of soils and their erosion, to a strong degradation of natural resources, to the insufficiency of agricultural infrastructure and equipment, to a high land pressure and low livestock carrying capacity. Then, the production and marketing of peanuts is no longer strongly supervised by the State as it once was [62]. This being the case, the choice of the Groundnut Basin is motivated by its important historic place in the national economy, its significant demographic weight, without forgetting the intensity of the mutations observed in agricultural holdings and village communities following the groundnut crisis which has affected 'now the area. Given the great variability of the climate, manifested by the relative increase in the frequency and intensity of extreme phenomena in this region, the study oriented towards the use of climate data, spatialization using GIS techniques and studying the distribution of different plant species can be a very good tool for people and human activities, in the sense that it will allow the identification and delimitation of vulnerable areas.

2.3. Aridity indices used

Aridity manifests itself above all by its edaphic consequences (extreme deprivation of vegetation, rarefaction and adaptation of living beings); hydrological (weakness and extreme irregularity of flows, functional degradation of hydrographic networks); and geomorphological (specific erosion and accumulation processes, soil poverty ...) [39]. According to [40], to identify and / or analyze arid and semi-arid regions, there is extreme confusion in the conventions, the definitions issued, the terms used, the use of indices and established formulas. Originally, a climate index is a combination of at least two variables describing the state of the atmosphere to assess the degree of aridity [63]. As such, many authors have proposed different formulas generally combining precipitation data and an estimator of the evaporating power of the atmosphere [40]. According to [64], in the absence of precise data on evaporation or even the deficit in air saturation, it is the temperature that was most frequently used. Thus, the most used indices take as parameters rainfall and temperature [65]. These are quantified reports used to characterize the climate of a given region. Some of these indices are useful for decision-makers and investors because they are correlated with the distribution of land and forest species; which gives us an idea of the forms of morphological and physiological adaptation of plants [40].In this article we have limited ourselves to the Lang and Martonne indices which use two fundamental climatic elements (temperature and precipitation). Their choice is justified by their robustness, suppleness, flexibility and their usability at all scales and all time steps. The mapping of these indices using spatial analysis tools and geographic information systems aims to generate spatial aridity distribution maps and analyze the distribution of vegetation in relation to the different biophysical parameters (topography, exposure, altitude, precipitation, temperature, etc.).

2.3.1. Lang index

Lang measured average annual rainfall with temperature and defined the ratio "rainfall factor" given by relation (1) [66]. Lang could be considered the first scientist to propose an index combining precipitation (in mm) and average monthly or annual temperatures (in ° C) to determine “humidity-aridity on a regional scale. The concept of Lang's rain factor is based on the increase in temperature which influences the water deficit and makes the soil sufficiently recharged by precipitation [67]. On the basis of this ratio, Lang proposed five classes according to the values of the annual index to characterize the climate of an area given by the table (1).

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

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

Table 2: Climate classification according to Lang

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

2.3.2. Martonne index

Martonne's annual aridity index is used to calculate the annual aridity level of any station. Based on essentially geographic considerations, Martonne defined the aridity of the climate on an annual scale by the quotient (2) [68]. The method is widely used for climatological, agricultural and hydrological studies [66].

$$I_M = \frac{P}{T+10} \qquad (1)$$

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

This index is a useful indicator to characterize the aridity phenomenon by expressing the restrictive nature for certain plant formations. It characterizes the absorbing and evaporating power of air from temperature; the lower the climate is arid [48]. Low aridity corresponding to heavy rain and / or low temperatures [12]. At the global level, Martonne proposed at the regional scale six main types of macroclimates ranging from arid desert zones to wetlands with predominant forest according to the values of the annual index given in table (2).

3. Data and application

Nowadays, several methodologies have been developed to identify areas sensitive to arid climates, to define useful indicators making it possible to respond to the problems posed on a temporal and spatial scale, and finally with a view to proposing concepts of monitoring and management of these areas. Thus, this study focuses on the groundnut basin, especially the western center of the country which corresponds to the administrative regions of Louga, Thies, Diourbel, Fatick and Kaolack. This area has a long tradition of food crops, groundnuts and pulses in the rain on tropical ferruginous soils. It provided most of the agricultural production with peanuts as the main speculation and occupies its important historic place in the national economy. This during these last decades, the zone is confronted with a real climatic rupture and anthropic effect which drastically affected biodiversity as well as the well-being of populations and ecosystems.

Table 2: Correlation study between index, type of climate and vegetation according to Martonne

Index value	Climate types	Vegetation types	Meaning
$I_M < 5$	Per-arid	Absolute desert	no cultivation
$5 < I_M < 10$	Arid	Desert	no cultivation without irrigation
$10 < I_M < 20$	Semi-arid	Steppe or savannah	irrigation required for crops requiring moisture
$20 < I_M < 30$	Semi-humid	Natural meadow	irrigation generally not necessary
$30 < I_M < 40$	Humid	Forest	Trees are playing an increasingly important role in the landscape.
$I_M > 40$	Per-humid	Predominant forest	cereal crops tend to be replaced by grassland

Faced with this new situation, a good mastery of decision support tools as well as a better knowledge of these phenomena become essential to be able to develop strategies taking into account current and future climate and anthropogenic risks. It is in this context that this contribution analyzes the spatial extension and the geographic location of arid zones through the use of simple, robust and accessible indices to process climate data. Good use of these climatic formulas can facilitate spatialization through decision support tools such as Geographic Information Systems. This study is based on annual rain and temperature data from synoptic stations in the five regions over the period 1965-2014 associated with

Digital Terrain Models. Climate data comes from ANACIM (National Agency for Civil Aviation and Meteorology) which is a reliable national structure specialized in the collection of quality climate data. Our approach is essentially structured according to 2 components: a component relating to index calculation and their exploitation and then a component relating to the spatial examination of the climate through a GIS mapping of these indices. The calculation of these data enriches the panel of digital indices available to the manager, and maps them from the DEM with good resolution for local use. The advantage here is to be able to produce synthetic indices integrating climate and topography and providing information at any point of the territory studied which will allow the degree of aridity to be quantified. Particular interest has been given to the distribution of different vegetation species according to the Martonne climatic index. This will make it possible to analyze the distribution of vegetation in relation to the various biophysical parameters (topography, precipitation, temperature, altitude, etc.). In addition, knowing the relationships between climatic variability and vegetation makes it possible to better establish policies for adapting to the aggressiveness of meteorological agents. Finally, this study is intended to be a support ensuring the understanding of the problem, the identification and delimitation of the areas affected in order to better establish prevention policies if not reliable and sustainable adaptation. Such initiatives constitute a preliminary step necessary for studies of vocation and land management and development of the use of the territory in general.

3.1. Component 1

For this section, we first calculated the Lang and Martonne indices over the entire study period of the five synoptic stations used. We then divided this study period into five sub-decanal periods; and for each decade, we calculated the average of the indices. The decanal mean values of Lang (I_L) and Martonne (IM) thus calculated for each station are shown in table (3). We then calculated the average of the indices over the entire study period for the five stations used. The values obtained from Lang (I_L) and Martonne (I_M) indices are shown in table (4).

Table 3: Decanal mean values of the LANG and Martonne indices

	Louga		**Thies**		**Diourbel**		**Fatick**		**Kaolack**	
	I_L	I_M	I_L	I_M	I_L	I_M	I_L	I_M	I_L	I_M
1965-1974	14	10	19	13	22	16	22	16	23	17
1975-1984	9	7	17	12	15	11	19	14	18	14
1985-1994	11	8	16	11	17	12	19	14	20	15
1995-2004	10	8	18	13	18	13	20	15	20	15
2005-2014	12	9	19	14	21	15	24	18	24	18

Table 4: Average values of the LANG and Martonne indices over the study period

	Louga		**Thies**		**Diourbel**		**Fatick**		**Kaolack**	
	I_L	I_M	I_L	I_M	I_L	I_M	I_L	I_M	I_L	I_M
1965-2014	11	8	18	13	19	14	21	15	21	16

3.2. Component 2

We first mapped separately the decanal mean values of the Lang) and Martonne indices represented in Tables (5) and (6) respectively. Then, we mapped the average of these same indices calculated over the entire period for the five the stations used represented respectively in tables (7) and (8). This cartography, based on the digital terrain models (DTM), was made possible thanks to ArcGIS software which is a high performance GIS tool recognized worldwide. Our analysis was oriented towards the identification of the degrees of aridity applicable to climatic zoning and the distribution of vegetation in relation to the different biophysical parameters. This is a big step towards providing expert information on climate factors to assist national and regional initiatives useful to living things. In general, GIS tools allow a representation of the space and the interactions occurring within it as well as an update of the structure to guarantee the sustainability of the data.

Table 5: Decanal mean values of the LANG index

	Louga	Thies	Diourbel	Fatick	Kaolack
1965-1974	10	13	16	16	17
1975-1984	7	12	11	14	14
1985-1994	8	11	12	14	15
1995-2004	8	13	13	15	15
2005-2014	9	14	15	18	18

Table 6: Decanal mean values of the Martonne index

	Louga	Thies	Diourbel	Fatick	Kaolack
1965-1974	14	19	22	22	23
1975-1984	9	17	15	19	18
1985-1994	11	16	17	19	20
1995-2004	10	18	18	20	20
2005-2014	12	19	21	24	24

Table 7: Average values of the LANG index over the study period

	Louga	Thies	Diourbel	Fatick	Kaolack
1965-2014	11	18	19	21	21

Table 8: Average values of the Martonne index over the entire study period

	Louga	Thies	Diourbel	Fatick	Kaolack
1965-2014	8	13	14	15	16

Finally, we compared the 2 indices through linear regressions, to conclude which of the two gives a fairly good estimate of the aridity. This will be retained as the most suitable for regional studies. To this end, we have correlated the index of Martonne with that of Lang and vice versa for all of the decades and for the entire period. The polynomial trend which gave the most significant correlation coefficients for the two-way indices on both the decanal and global scales has been implemented.

4. Results and discussion

4.1. Spatialization of Lang's index

Fig. 2 shows the decanal spatial distribution of the Lang index for the whole groundnut basin. Analysis of the maps relating to the different decades and to the global scale shows that, on the basis of Table 1, the arid climate occupies the total area during the decades: (1975-1984); (1985-1994) and (1995-2004). During the decades (2005-2014) and (1965-1974), the semi-arid climate occupied 60% of the total area followed by the arid climate with around 40%. Similarly for the global scale (1965-2014), the arid climate occupies 60% of the area while the semi-arid extends over 40%. Overall, the Lang index gives more importance to the arid climate at the expense of the semi-arid climate. In addition, the most arid areas are located in the extreme north of the zone with values of the order of 9 and the least arid regions are located in the extreme south with values up to 24. This index has highlighted the need for irrigation for crops.

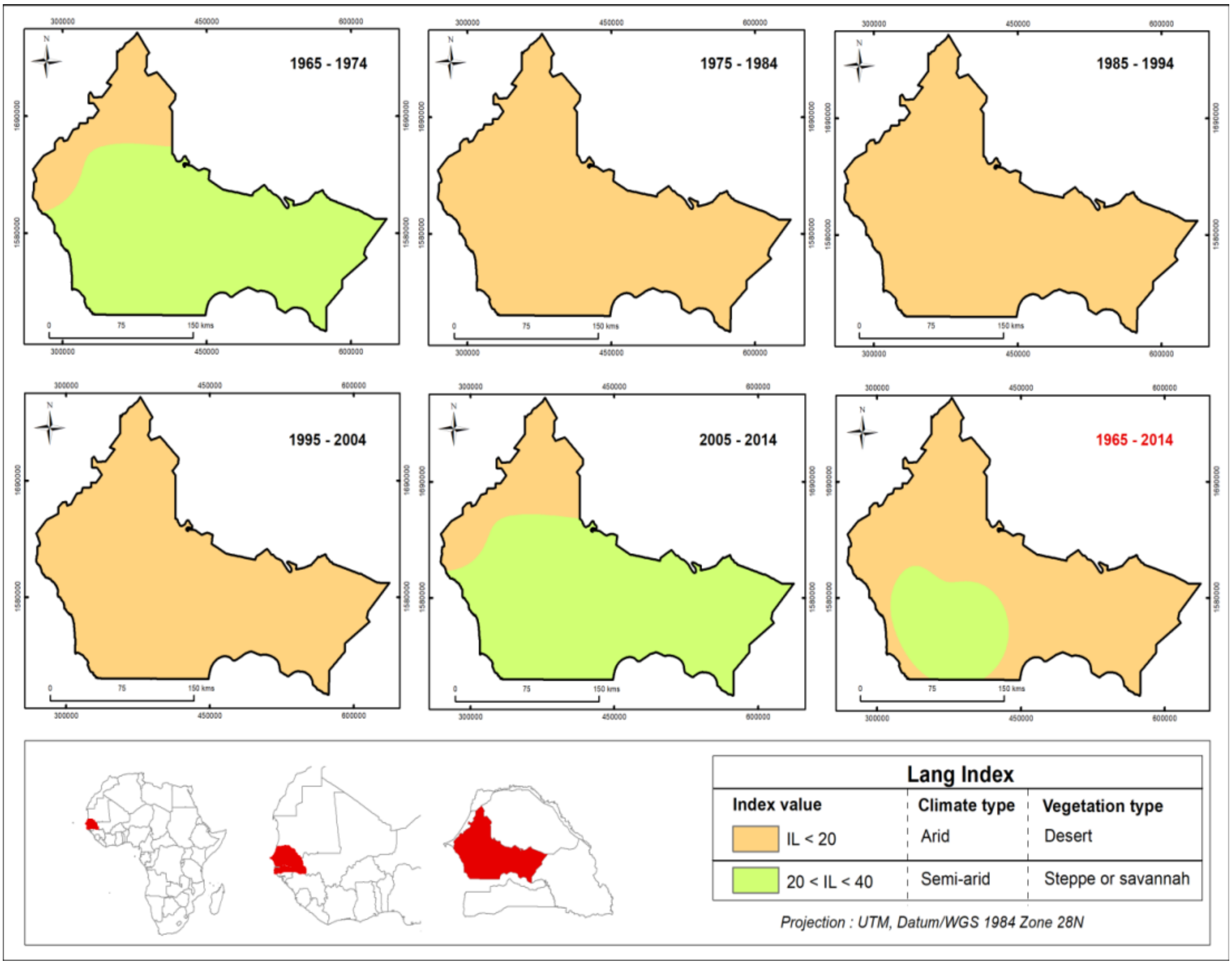

Figure 2: Spatial distribution of Lang's aridity index related to the decanal and global scale

4.2. Spatialization of the Martonne index

The spatial distribution maps of the Martonne index produced on a decanal and global scale for the entire groundnut basin are shown in fig. 3. Considering the classification standards defined in Table 2, the semi-arid climate occupies the entire area during the decade: (1975-1984). During the other four decades, the semi-arid climate is largely dominant followed by the arid climate. Thus, the semi-arid climate occupies 80% and the arid climate extends over approximately 20%. Similarly for the global scale (1965-2014), the semi-arid climate occupies 80% of the area while the arid climate extends over 20%. The Martonne index gives more importance to the semi-arid climate at the expense of the arid climate. In addition, the most arid areas are located in the extreme north with values on the order of 7 and the least arid are located in the extreme south with values up to 18. The results of analyzes performed on the basis plant formations, show that the study area is more savannah (or steppe) than desert with 80% of the area, affected by the semi-arid climate. The concordance of the results of all the decades and the whole of the study period seems to indicate a priori that this index is possibly the best suited to our area. From an agricultural point of view, irrigation is essential for crops requiring moisture.

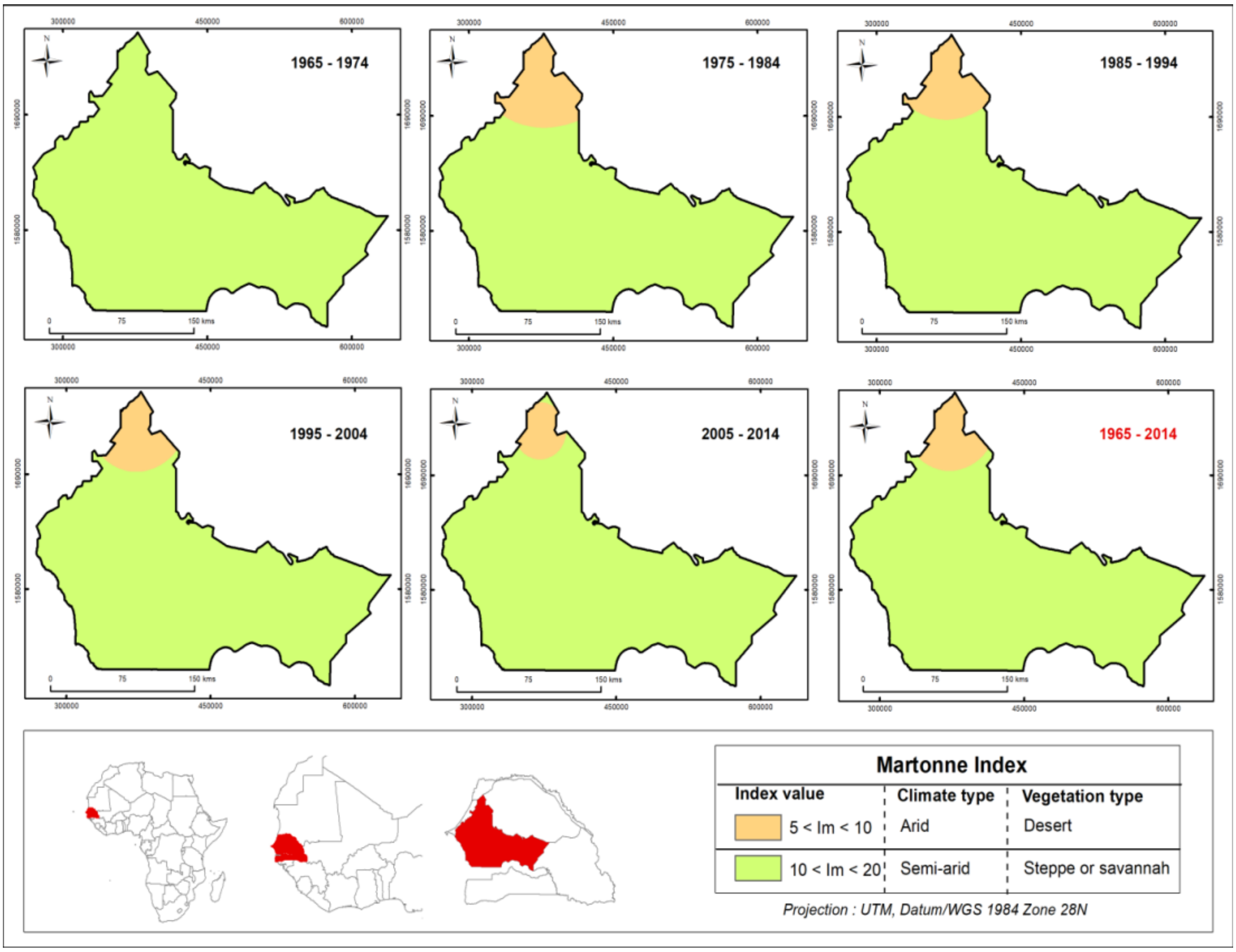

Figure 3: Spatial distribution of Martonne's aridity index related to the decanal and global scale

4.3. Comparison of aridity indices

The spatial distribution maps of the different aridity indices have highlighted two types of climate according to the different classes selected by each of the indices: it is the arid climate and the semi-arid climate. According to Lang's index, the arid climate varies from 40% to 100% and the semi-arid climate from 0% to 60%. Similarly for the Martonne index, the arid climate varies from 0% to 20% and the semi-arid climate from 80% to 100%. According to the different results, the Lang index gives more importance to the arid climate at the expense of the semi-arid climate. On the other hand, the Martonne index is more favorable to the semi-arid climate than to the arid climate. Faced with this tension, it becomes necessary to decide between them. In this context, we compared the 2 indices through linear regressions, to conclude which of the two gives a fairly good estimate of the aridity. This will be considered the most suitable for regional studies. To this end, we have correlated the index of Martonne with that of Lang and vice versa for all of the decades and for the overall period for the five regional stations. The polynomial trend gave correlation coefficients for the two-way indices on both the decanal and global scales. Thus, the linear correlation of the Martonne index with that of Lang for the different decades is between 0.977 to 1 depending on the decade, an average of 0.995. Conversely for the Lang index, the correlation coefficients range from 0.987 to 0.997, an average of 0.992. On a global scale, Martonne's linear correlation is around 0.991 and vice versa for Lang, it is 0.889. Thus on the basis of these results relating to the most significant coefficient, it is normal to adopt the Martonne index as the most satisfactory for the monitoring and management of arid and therefore desert areas of studies at regional and national scale.

Conclusion

Given the changing structure of the climate, manifested by the relative increase in the frequency and intensity of extreme phenomena in the groundnut basin, mapping GIS of climate indices is of paramount importance to better understand the spatial variability of the climate and the distribution of different plant species in relation to biophysical parameters. This constitutes a preliminary step necessary for the establishment of adaptation and prevention policies aiming at revaluing agriculture economically and ecologically for a better quality of life and subsistence of populations and ecosystems. It is in this context that this study was conducted in the groundnut basin, known for its vulnerable geo-climatic position. This study is based on annual temperature and precipitation data from the synoptic stations of Louga, Thies, Diourbel, Fatick and Kaolack associated with Digital Terrain Models (DTM). It is based on the calculation of the Lang and Martonne indices and their mapping under GIS. It is for us to extract information integrating the climate and the topography at any point of the territory studied. So this study is intended to be a support allowing the understanding of the problem, the identification and the delimitation of the affected areas, which is necessary for studies of vocation and land management and development of the use of the territory studied. At the end of the study, the results obtained are on the whole convincing, meaningful and promising. Analysis of the spatial distribution maps of the Lang index shows that during the decades (1975-1984); (1985-1994) and (1995-2004), the arid areas extend over the entire area; during the decades (2005-2014) and (1965-1974), they occupied 40% and those semi-arid 60%; unlike the global scale (1965-2014), 60% of the area is arid and 40% semi-arid. Overall, the Lang index gives more importance to the arid climate at the expense of the semi-arid climate. In addition, the most arid regions are located in the extreme north of the zone with values on the order of 9 and the least arid are located in the extreme south with values up to 24. the Martonne index, the analysis of its spatial distribution maps, 100% of the areas were semi-arid during the decade (1975-1984); during the other four decades, semi-arid areas occupy 80% and arid ones extend over 20%; on a global scale (1965-2014), semi-arid areas also occupy 80% and arid areas 20%. The Martonne index gives much more importance to the semi-arid climate at the expense of the arid climate. In addition, the most arid areas are located in the extreme north with values on the order of 7 and the least arid are located in the extreme south with values up to 18. Analysis of this same relatively index with plant formations, show that the study area is more savannah than desert with 80% of the total area, affected by the semi-arid climate. The concordance of the results of all the decades and the whole of the study period seems to indicate a priori that this index is possibly the best suited to our area. This assertion is confirmed by comparing the two indices by correlation with polynomial tendency. Thus, the linear correlation of the Martonne index with that of Lang for the different decades is between 0.977 to 1, an average of 0.995. Conversely for the Lang index, the correlation coefficients range from 0.987 to 0.997, an average of 0.992. On a global scale, Martonne's linear correlation is around 0.991 and vice versa for Lang, it is 0.889. Thus on the basis of the most significant correlation coefficients, we have adopted the Martonne index as the most satisfactory for the monitoring and management of arid and therefore desert areas for studies at the regional and national scales. These results show, in a convergent way that the magnitude of the risk of arid expansion or desertification is real in the area, especially from North to South. Given that an arid region is characterized by a serious lack of available water, which has the consequence of slowing down, or even preventing, the growth and development of vegetation and the presence of animal life, this study aims to be a alert the authorities to 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 yield for each crop. Indeed, even if our study area is not yet concerned by the critical phase of the phenomenon, taking into account the risk is essential to reason about the agriculture of the future, in particular for food production: irrigation for crops with high water requirements.

In short, it emerges from this study that the cartography under GIS of climate indices has real advantages in that it makes available to the practitioner important information (or data) allowing them to :

- ✓ characterize potential aridity levels;
- ✓ model the distribution or fertility of forest species;
- ✓ adjust the choice of species or type of forestry to adopt;
- ✓ characterize the type of forest station uniformly throughout the study area;
- ✓ study the stations' sensitivity to climate change ;
- ✓ assess the potential impact of warming on species or forest stations;
- ✓ understanding the levels of aridity in the context of ecological studies or forest management; etc ...

However, despite its merits, it is important to remember that the present study inevitably has shortcomings. It was based on climate and topography data. The effect of the soil was not taken into account. So to give this study all its quintessence, it would be important to use geographic information systems (GIS) associated with digital terrain models (DTM), climactic and soil data. This should make it possible to produce synthetic indices integrating climate, topography and soil. All of this would make it possible to better establish policies to adapt to the aridity and aggressiveness of meteorological agents, which constitute an obstacle to food and feed sovereignty.

Acknowledgements

We would like to thank sincerely the National Agency of Civil Aviation and Meteorology (ANACIM) for their determining support through putting reliable data at our disposal within the framework of this study. Special thanks are given to the reviewers who were kind enough to share their expertise through the evaluation of this document. We are truly honored.

Conflicts of interest

We hereby declare that this paper has no conflicts of interest. It is our original work

References

1. S. Anouar. Agro-climatic potentials of the Zenata and Maghnia region. Study of a long climatic series. Dissertation for Graduation in Engineering, Abou-Bekr Belkaid University - Tlemcen, (2014), 227p.
2. UNESCO Ecological study of the Mediterranean area: Bioclimatic map of the Mediterranean area; Explanatory note, (1963), 63p.
3. A.M. Kouassi, K.F. Kouamé, Y.B. Koffi, B.K. Dje, J.E. Paturel and S. Oulare. Analysis of climate variability and its influences on seasonal rainfall patterns in West Africa: the case of the N'zi watershed (Bandama) in Côte d'Ivoire, *European Journal of Geography* [Online] environment, Nature, Landscape, Document 513, put online December 7 (2010), accessed July 18, (2016).
4. F. Lebourgeois (2010). Bioclimatology course for foresters, AgroPariTech , 250p.
5. R. Diouf, V.B. Traore, M. L. Ndiaye, H. Sambou, N. Ngargoto, B. Cisse, Y. Lo, B. Sambou, A.T.D. Diaw and A.C. Beye. Spatial and temporal distribution of rainfall in agro-climatic zone of Fatick region, Senegal, *Journal of Scientific and Engineering Research*, 5(1), (2018), 50-62.
6. R. Diouf, H. Sambou, V. B. Traore, M. L. Ndiaye, A. Chaibo, B. Sambou, A. T. Diaw, A. C. Beye. Frequency Analysis and Exploratory of Rainfall Variability in Bounkiling River Basin in a Context of Climate Change and Variability, *American Journal of Engineering Research*, 5 (2016) 82-93.

7. V.B. Traore, S. Diallo, M.L. Sow, M.L. Ndiaye, R. Diouf, J. Sarr, A.T. Diaw and A.C. Beye, Characterization of meteorological drought level in oriental Senegal, *Int. Res. J. Environmental Sci.*, 7(11) (2018) 22-36.
8. G. M. Henry, J. M. Milline, P. M. Faustin. Innovative pathways for enhancing climate change and variability resilience among agro-pastoral communities in semi-arid areas of Kiteto and Kilindi Districts, Tanzania, *African Journal of Environmental Science and Technology*, 13(5) (2019) 201-219
9. N. Ionac, E. Grigore and O.D.M. Constantin. Assessment of the phenomena of drying and drought in the continental zone of the southern Dobroudja plateau. XXVIIIth Symposium of the International Association of Climatology, Liège, (2015), 269-274.
10. E. R. Cook, C. A. Woodhouse, Eakin C. M., D. H. Meko and D. W. Stahle. Long-term aridity changes in the western United States, *Science*, 306(5698) (2004) 1015–1018.
11. H. Mongi et al. Vulnerability and adaptation of rain fed agriculture to climate change and variability in semi-arid Tanzania, *African Journal of Environmental Science and Technology*, 4(6) (2010) 371-381.
12. N. Mokhtari, R. Mrabet, P. Lebailly and L. Bock. Spatialization of bioclimates, aridity and vegetation stages of Morocco, *Rev. Mar. Sci. Agron. Vét*., 2 (1) (2014) 50-66
13. M.H.J.P. Gunarathna and M.K.N. Kumari. Rainfall trends in Anuradhapura: Rainfall analysis for agricultural planning, *Gunaratne & Kumari. Rajarata University Journal*, 1 (2013) 38-44.
14. D. Ayalew, K. Tesfaye, G. Mamo, B. Yitaferu and W. Bayu.Variability of rainfall and its current trend in Amhara region, Ethiopia, *Afr. J. Agric. Res.,* 7(10) (2012) 1475-1486.
15. V.B. Traore, M.L. Ndiaye, C. Mbow, G. Malomar, J. Sarr, A.C Beye. and A.T. Diaw. Khronostat Model as Statistical Analysis Tools in Low Casamance River Basin, Senegal, *World Environment*, 7(1), (2017), 10-22.
16. E. Zewdu, G. Hadgu and N. Lisanework. Impacts of climate change on sorghum production in North Eastern Ethiopia, *African Journal of Environmental Science and Technology*, 14(2) 2020) 49-63.
17. J.H. Kotir. Climate change and variability in Sub-Saharan Africa: A review of current and future trends and impacts on agriculture and food security, *Environment, Development and Sustainability*, 13(3) (2011) 587-605.
18. M. Zacharias, S.N. Kumar, S.D. Singh, D.N.S. Rani and P.K. Aggarwal, Evaluation of a regional climate model for impact assessment of climate change on crop productivity in the tropics, *Current Science*, 3 (2015) 1119-1126.
19. I. Sene, A.N. Diene, V.B. Traore and D.T. Niane. Rainfall Analysis for Agricultural Purposes in Thies Region, Senegal, *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, 13(2) (2019) 30-39.
20. V. B. Traore, R. Diouf, M. L. Ndiaye, O. R. Godfroyd, M. Faye, G. Malomar, J. Sarr, A. T. Diaw and A. C. Beye, Detection of inhomogeneities and break points in annual rainfall series of Senegal regions, *Algerian Journal. of Arid Environment*, 8(1) (2018) 26-43.
21. Irish AID. Ethiopia Country Climate Risk Assessment Report. Irish AID, Resilience and Economic Inclusion Team, Policy Unit, (2018).
22. T. Gebrehiwot and V.D. A. Veen. Assessing the evidence of climate variability in the northern part of Ethiopia, *Journal of Development and Agricultural Economics*, 5(3) (2013) 104-119.
23. World Bank. Action Plan on Climate Change Adaptation and Resilience: Managing risks for a more resilient future, Washington DC, USA, (2019).

24. World Bank. Rainfed agriculture. http://water.worldbank. Org/topics agricultural-water-management/rainfed-agriculture, (2015), Accessed 13 January 2015.
25. FAO. Regional Overview of Food Insecurity Africa. Food and Agricultural Organization, (2014), Accra 2015
26. A.E. Aragie. Climate change, growth and poverty in Ethiopia. Volume 3, (2013).
27. N. Y. Barry, V. B. Traore, M. L. Ndiaye, O. Isimemen, H. Celestin and B. Sambou. Assessment of Climate Trends and Land Cover/Use Dynamics within the Somone River Basin, Senegal, *American Journal of Climate Change,* 6 (2017) 513-538.
28. B. Sarr, S. Atta and L. Kafando. Review of climatic indices used in index agricultural insurance systems in Africa, *Drought*, 23, 2 (2012) 55-60.
29. M.L. Ndiaye, V.B. Traore, M. A. Toure, A.T. Diaw and A.C. Beye. Contribution of Remote Sensing to the study of spatiotemporal evolution of rainfall in Senegal: Exploitation of TRMM 3B43 Low Spatial Resolution, *Journal of Multidisciplinary Engineering*, 2(7) (2016) 1-6.
30. P.G. Jones and P.K. Thornton. The Potential Impacts of Climate Change on Maize Production in Africa and Latin America in 2055, *Global Environmental Change*, 13 (2003) 51-59.
31. E. M. Tossou, M. L. Ndiaye, V. B. Traore, H. Sambou, C. K. Nelly, B. A. Sy and A.T. Diaw. Characterization and Analysis of Rainfall Variability in the Mono-Couffo River Watershed Complex, Benin (West Africa), *Resources and Environment*, 7 (2017) 13-29.
32. M.N.F. Rosine, S. Nagnin, V.B Traore., L. Théophile, S. Soussou and S. Tanina . Climate variability and its impact on surface water resources: the case of stations of Bocanda and Dimbokro, east-central of Ivory Coast in West Africa, *Africa Science*, 10 (4) (2014) 118 – 134.
33. G. Hadgu, K. Tesfaye, G. Mamo and B. Kassa. Trend and variability of rainfall in Tigray, Northern Ethiopia: Analysis of meteorological data and farmers' perception, *Acad. J. Environ. Sci.*, 1(8) (2013) 159-171.
34. N. Pareek. Climate Change Impact on Soils: Adaptation and Mitigation, *MOJ Eco Environ. Sci.,* 26(3) (2017) 1-4.
35. S. Luca, Z. Marco, D. B. Rosanna and P. Luigi. Climate Aridity under Changing Conditions and Implications for the Agricultural Sector: Italy as a Case Study, *Geography Journal*, 2013, (2012),7p.
36. N.S. Christensen, A.W. Wood, N. Voisin, D.P. Lettenmaier and R.N. Palmer. Effects of Climate Change on the Hydrology and Water Resources of the Colorado River Basin, *Clim. Change*, 62(1-3) (2004) 337-363.
37. ONESCO. Bioclimatic and phytoecological considerations on the arid zones of Morocco. notebooks of agricultural research, Rabat, 19 (1965) 1-69.
38. C. Floret and R. Pontanier. The aridity in pre-Saharan Tunisia. Climate, soil, vegetation and planning. Thesis dissertation. Works and documents of the O.R.S.T.O.M., Paris, 150, (1982),544 p.
39. C. Floret and R. Pontanier (Climatic aridity, edaphic aridity. *Bull. Soc. Bot. Fr.,* 131, *Actual. Bot.,* 2/3/4, (1984), 265-275.
40. IEDA. Aridity and semi-aridity: meanings, contents and developments: Promoting the Resilience of Economies in Semi-Arid Zones at IED-Afrique, (2019).
41. R. Gavilan. The use of climatic parameters and indices in vegetation distribution. A case of the Spanish Sistema Central, *Int. J. Biometeorol*, 50 (2005) 111-120. https://doi.org/10.1007/s00484-005-0271-5
42. A. Tiscovschi, G. Manea, O. Cocos, I. Vijulie and R. Cuculici. Characteristics of aridity conditions in Sout Dobroudja. Riscuri si catastrofe, Casa Cărţii de Ştiinţă, Cluj-Napoca, XII, 12, (2013), 57-65.

44. B. Stomal-Weigel. The recent and comparative evolution of the serer and Wolof production systems in two villages in the old peanut basin (Senegal), *Human Sciences notebook*, 24(1) (1988) 17-33.
45. B. Diop. Farmers in the groundnut basin. Living conditions and survival behaviors, *African Policy*, 45 (1992) 39-62.
46. B. Celine and S.S.J. Maam. Migration and diversification of local economic activities: study of the Senegal groundnut basin. De Boeck Superior | "*Developing worlds*, 164 (2013) 93-114.
43. ISRA. South peanut basin strategic plan. 3rd part: need for research ISRA _ Senegal, (1997).
47. M. Dione, O. Diop, P. N. Dieye and B. Ndao. Characterization and typology of family farms in Senegal, volume 3: Groundnut basin, Studies and Document vol. 8, ISRA, Dakar, Senegal, (2008).
48. D. D. Ba, P.M. Ndiaye and C. Faye. Rainfall variability and evolution of climate drought in the Senegal river valley, *Togolaise des Sciences Review*, 12(1) (2018) 57-71.
49. O. Mbengue. Socio-economic study of the practice of fallow forage in the Senegal groundnut basin. ENSA thesis, (2002), 69p.
50. D. Roquet. Leaving to last better: migration as a response to drought in Senegal? *Space populations Societies* , 1 (2008) 37-53.
51. J.M. S. Sakho. Food self-sufficiency through the diversification of activities: the case of agricultural households in the groundnut basin in Senegal, Doctoral thesis, Montpellier Supagro, (2009).
52. ISRA. Characterization and typology of family farms in Senegal. Research and Development Project: Understanding family farms to develop Agricultural Policies with peasants, Volume 3, groundnut basin, 8(3), (2008), 31p.
53. N. Badiane, M. Khouma and M. Sene. Management and transformation of organic matter. Synthesis of research work carried out in Senegal since 1945. Ed. ISRA, November (2000), 115 p.
54. A. Lericollais The peanut basin_In Senegal, atlas Jeune Afrique, Jeune Afrique Paris, (1980), 50-53.
55. D. Sow. Economic study of a quality test peanut production in the Peanut Basin (Paoskoto) in Senegal. Same. at the end of studies ENSA Thies Senegal, (2005), 55p.
56. DPS. Summary report of the Second Senegalese Household Survey (ESAM –II), Ministry of Economy and Finance, (2004), 253 p.
57. P. Fernandes, P. Silvie, G. Amadji, R. Belmin, B. A. Bocar, T. Brévault, A. Chailleux and al. Design of agro-ecological farming systems through agroecological management of pests and the use of organic residues (DIVECOSYS), (2019). project 2019-2024; 30 p.
58. N. Diouf, Typology of farms and profitability study of fodder crops in the production system of the Senegal groundnut basin. ENSA thesis, (2002), 84 p.
59. J. Roch, Economic migrations in the dry season in the Senegal groundnut basin, ORSTOM notebook*, Human Sciences series*, 12(1) (1975) 55-80.
60. J. Faye, C. O. Ba, P. N. Dieye and M. Dansoko. Structural changes in rural economies in globalization, Rural struc Phase 1 program: Senegal, Dakar, Agricultural and Rural Prospective Initiative, (2007).
61. M. M. M. Souradja. Study of the determining factors of the adoption of technologies relating to the production of Cowpea in the North Center of the Groundnut Basin, Same at the end of studies, ENSA-Thies, (2001).
62. ENDA. Report of the baseline study on seed management mechanisms Case of Senegal, report January, (2018), 41p.
63. T. Klein. Comparison of summer droughts of 1976 and 2003 in Western Europe using climate indices. *BSGLg,* 53 (2009) 75-86.

64. F. Lebourgeois and C. Piedallu, Understand the level of drought in the context of stationary studies and forest management based on bioclimatic indices, Rev. For. Fr. LVII, 4 (2005) 331-356.
65. A.E. Croitoru, A. Piticar, A. Imbroane and D. Burada. Spatiotemporal distribution of aridity indices based on temperature and precipitation in the extra-Carpathian regions of Romania, *Theo. and Applied Climatology,* (2012), DOI 10,1007/s00704-012-0755-2.
66. M.M. Nistor., K. R. Praveen, D. Vikas, N. M. Varun, P. Singh, A. Aman, K.K. Virendra and I.A. Carebia. Climate change effect on water resources in Varanasi district, India, *Meteorol. Appl.*, 27, (2020), 1 of 16,
67. C. Quan, S. Han, T. Utescher, C. Zhang and C.Y. S. Liu. Validation of temperature–precipitation-based aridity index: Paleoclimatic implications. Palaeogeography, Palaeoclimatology, Palaeoecology, 386, (2013), 86–95.
68. C. Piedallu, F. Lebourgeois, J.C. Gégout, I. Seynave, R. Vepierre, C. Cluzeau, T. Nedeltcheva, B. Éric and V. Badeau. Development, spatialization and validation of bioclimatic indices, (2013), 86p, HAL Id: hal-00835912 https://hal.archives-ouvertes.fr/hal-00835912