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Impacts of Climate Change on Agroclimatic Indicators in West Africa: Case Study of the N'zi (Bandama) Watershed in Côte d'Ivoire

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In a context of climate change observed in West Africa for several decades, knowledge of agroclimatic indices is essential in order to analyze and predict the potential impacts of climate change on agriculture with a view to adaptation. This study aims to analyze the impacts of climate change on agroclimatic indicators such as agricultural humidity index, agricultural water stress index and agricultural water need satisfaction index within the main Ivorian climatic regimes across the N'zi (Bandama) watershed. The study was based on an interannual analysis of the agroclimatic indicators selected for the vegetative period in general and the spring and summer periods in particular, during the current normal reference period (1991-2020). The interannual analysis showed that the potential evapotranspiration (PET) observed over the whole of the current normal reference period 1991-2020 during the vegetative period as well as during the spring and summer periods, experienced an increase over all the climatic zones with the pre-eminence of the spring period over the summer period. However, the actual evapotranspiration (AET), although characterized by a general upward trend regardless of the climatic zone, sometimes experiences divergent trends in the PET. The interannual evolution of the water balance expressed by the water humidity index during the different cropping periods highlights a predominance of deficit years. The N'zi watershed was marked by water stress varying between the low level and the high level during the period 1991-2020. A deterioration in the rate of satisfaction of agricultural water needs was also highlighted, going from a very satisfactory level to a weakly satisfactory level. However, the evolution of agroclimatic indicators differs according to climatic zones and cropping seasons (crop season, spring and summer). The results obtained constitute a series of important indicators for the economic development of a country with an agricultural vocation such as Côte d'Ivoire. The study of the evolution of these indicators on a seasonal scale would constitute a metric for an analysis in the short (horizon 2030), medium (horizon 2050) and long term (horizon 2100) and will provide information on risks and/or opportunities for the development of certain crops (cereals, etc.).

Keywords: Climate change; agroclimatic indices; N'zi watershed (Bandama); Côte d'Ivoire.

1. INTRODUCTION

Climate change increases the uncertainty associated with agricultural activities because it constitutes a hazard that adds to the many environmental factors on which agriculture depends. Indeed, of all human activities, agriculture remains the sector most influenced by climate and its variations [1]. Indeed, agriculture holds a special place as a sector that is very sensitive to climatic hazards in West African countries. In these regions, rain-fed agriculture plays a key role in national economies and production systems (agriculture, livestock) are dependent on the climate [2]. However, according to the Fourth Assessment Report (AR4) of Working Group II of the Intergovernmental Panel on Climate Change (IPCC), climate change will, to varying degrees, have many impacts on crops and livestock. Currently, about 40% of the land area is managed as cropland or pasture. Furthermore, it is estimated that the livelihoods of about 450 million people in developing regions are entirely dependent on managed ecosystems, reflecting the scale of importance of the human well-being issue. Many studies document the implications of climate change for agriculture and also show that it is a significant threat to sustainable development. Indeed, meteorological droughts accentuate agronomic droughts, resulting in lower yields. This agronomic drought results in a deterioration of the balance between water loss through transpiration and water uptake from the soil by plant roots [3]. During this period of drought, plants are likely to be in a state of water stress. This is an environment that causes the amount of water transpired by the plant to be greater than the amount it absorbs. Water stress slows down the growth of plants and affects their productivity even more than other stresses (nitrogen, parasites). Some xerophilic crops are naturally able to withstand prolonged water stress. However, cereals, which contribute 70% of the daily diet of Burkinabe, are the most sensitive to water deficit [4], especially maize. Burkina Faso focuses mainly on cereal production, with the aim of rapidly achieving complete food self-sufficiency for its population. Thus, most of its cultivated land is devoted to cereal production. Moreover, it is a predominantly rain-fed agriculture and is therefore dependent on agro-edoclimatic conditions. As a result, the quantity and yield of cereals vary from year to year, depending on rainfall, temperature and soil moisture. For example, a lack of water at the flowering stage of maize leads to grain abortion. This disruption can lead to a drop of more than 60% in cereal production, thus hindering socio-economic development [5]. In a context of climate change, knowledge of agroclimatic indices is essential in order to predict the impacts of these changes on agriculture. Stakeholders and agricultural producers will thus be able to adapt to the advantages and disadvantages of these changes. Indeed, the use of agroclimatic indices as working tools in the agricultural sector is relatively recent [6]. An agroclimatic index makes it possible to express the relationship between climate and agricultural production in a simple way. Thus, the distribution, development and yields of crops can be correlated with these indices such as heat accumulation and rainfall. More recently, the evolution of technology, the improvement of instruments for measuring and acquiring meteorological data and the arrival of more powerful computers have contributed to the increasingly common use of these indices. The main indices used in Quebec in the agricultural field are related to temperature (thermal indices and cumulus) or water [6].

The aim of this study is to investigate the influence of climate change on agroclimatic indicators in the N'zi (Bandama) watershed in Côte d'Ivoire through the study of the degree of vulnerability to agricultural water stress in the N'zi watershed in order to propose a tool to assist in the management of rainfed agriculture. Indeed, the N'zi (Bandama) watershed, stretched in latitude, is a transition zone between different climates. Indeed, the basin straddles three climatic zones (subtropical or Sudanese climate in the North, humid tropical or Baoulean climate in the center and subequatorial or Attiean climate in the South). This basin is therefore representative of the major climatic zones of Côte d'Ivoire. This work is based on the hypothesis that climate change affects agroclimatic indicators. Thus, the application of agroclimatic indices over the vegetative period, including the spring and summer periods, from the current normal reference period (1991-2020) made it possible to analyze the impacts of climate change on agroclimatic indicators in the N'zi watershed in Côte d'Ivoire.

2. MATERIALS AND METHODS

2.1 Presentation of the Study Area

The study area is the N'zi watershed (Fig. 1), a sub-basin of the Bandama River watershed. It lies between longitudes 3°49' and 5°22' west and latitudes 6° and 9°26' north. The N'zi-Bandama watershed covers an area of 35,500 km2. Due to its elongated geographical configuration, the N'zi watershed is representative of the major climatic zones of Côte d'Ivoire. The study area extends over different climatic regions ranging from the savanna region in the north to the forest zone in the south of the basin (Fig. 1). The subtropical regime (Sudanese climate) is characterized by two seasons, a rainy season from April to October and a dry season from November to March which is accentuated by the Harmattan. This climate corresponds to the transitional tropical climate. August and September are the rainiest months. This regime characterizes the northern part of the basin and is located north of the 8th parallel north. It is characterized by an average annual rainfall (1951-2000) of less than 1200 mm. The humid tropical regime (Baoulean climate) is located in the center of the basin. There is a four-season climate regime: a long rainy season from March to June, a short dry season from July to August, a short rainy season starting in September and ending in October and a long dry season from November to February. This type of climate makes the transition between the subtropical and the subequatorial climate. This climate is close to the sub-equatorial climate in terms of the abundance of rainfall. It is characterized by an average annual rainfall (1951-2000) varying between 1200 mm and 1600 mm. The sub-equatorial regime (Attiean climate) which is characterized by four seasons; the main rainy season occurs between March and June followed by a break of short dry season between July and August. The short rainy season occurs in September and ends in November. The months of November, December, January and February constitute the long dry season. This regime characterizes the southern part of the basin below the 7th parallel north. It is characterized by an average annual rainfall (1951-2000) of over 1600 mm.

2.2 Study Data

The past climate data used in this study concern rainfall and air temperature. They were collected from the national meteorological service (SODEXAM : Société d'Exploitation et de Développement Aéroportuaire, Aéronautique et Météorologique). The various data are on a monthly scale and cover the period 1991-2020. The rainfall data were collected at the stations of Tafiré, Niakaramandougou, Katiola, Dabakala,

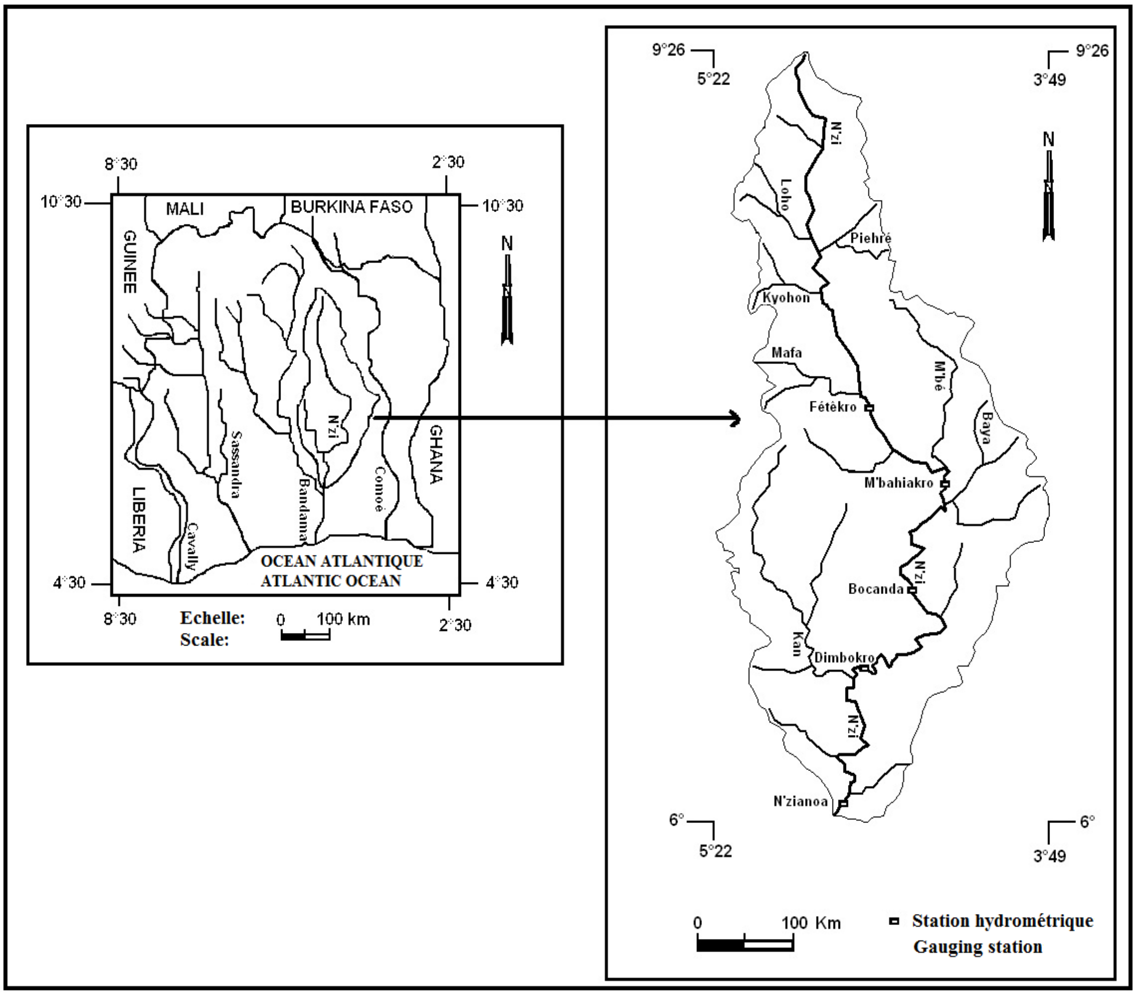

Fig. 1. Presentation of the N'zi (Bandama) watershed

Bouaké, Tiébissou, Bocanda, M'bahiakro, Daoukro, Bongouanou, Dimbokro and Tiassalé (Fig. 2). Temperatures were collected at the stations in Korhogo, Bouaké and Dimbokro.

2.3 Methods

The different climatic parameters (rainfall and temperature) were analyzed from the average value calculated (Thiessen polygon method) according to the climatic zones crossed by the N'zi watershed based on the work of Kouao et al. [7,8]. Thus, we have the following distribution of climatic stations according to the climatic regimes:

- subtropical climate (Sudanese climate): Korhogo, Tafiré and Niakara;
- humid tropical climate (Baoulean climate): Bouaké, Tiébissou, M'bahiakro, Katiola and Dabakala;
- sub-equatorial climate (Attiean climate of the interior): Dimbokro, Bocanda, Bongouanou, Daoukro and Tiassalé.

2.3.1 Estimation of agro-climatic indicators

Climatic indicators used in agriculture, also called agroclimatic indicators, express the relationship between climatological variables (air temperature, rainfall, etc.) and agronomic concepts such as the phrenological stages of a crop. They are used in agriculture as decision criteria. Thus, in this study, three agroclimatic indicators (AHI) were used. These are the agroclimatic moisture indicator (water balance), the agroclimatic water stress index and the rate or index of satisfaction of agricultural water needs [1,9-15]. The potential evapotranspiration (PET) and the actual evapotranspiration AET were calculated at monthly time step using Thornthwaite's empirical formulae [16].

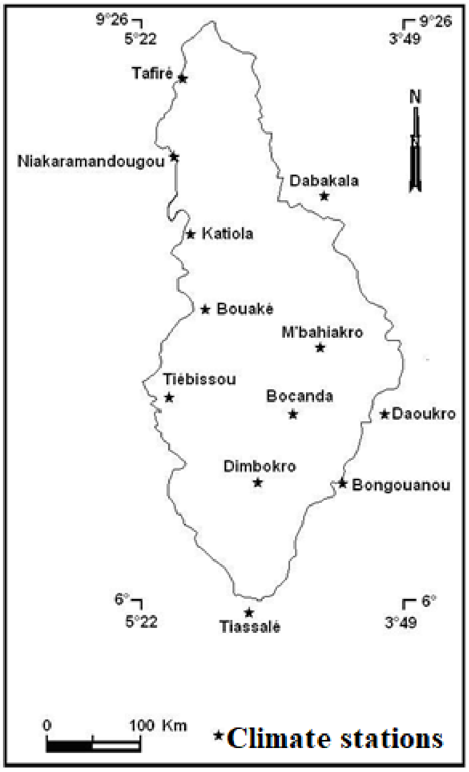

Fig. 2. Retained climate stations (N'zi watershed)

2.3.1.1 Agroclimatic moisture indicator

The agroclimatic moisture indicator (AHI) used in this study is the water balance [14-15]. It evaluates the efficiency of rainfall in relation to climatic demand and corresponds to a rough assessment of the agricultural water deficit. Thus, the mathematical equation of the agroclimatic moisture indicator used is defined by the following equation [12,14-15] (equation 1):

$$AHI = P - PET \tag{1}$$

With:

- P: monthly rainfall (mm) ;
- PET: monthly potential evapotranspiration (mm).

The lower the values of the agroclimatic humidity indicator, the drier periods and the less favorable the conditions for crops [12,14-15]. Thus, if the agroclimatic moisture indicator is positive, this is synonymous with a gain in moisture in the soil's useful reserve and a possible replenishment of water masses, i.e. water is available in sufficient quantity for the crop. If it is negative, a water deficit can be observed and it is very likely that the crop needs water. A strongly negative Agroclimatic Humidity Indicator that lasts can lead to a drying up of water bodies (limiting irrigation options) and of the useful soil reserve (water stress of the vegetation). Producers can thus correct deficits by providing water through irrigation.

2.3.1.2 Estimating the agroclimatic water stress index

In agriculture, water stress or agroclimatic stress is defined as a marked deficit in rainfall that significantly reduces agricultural production compared to the normal for a large area [16]. Indeed, water stress occurs when water demand exceeds the quantity available during a certain period or when its poor quality limits its use. Water stress is an important indicator as it provides information on the amount of water needed to irrigate crops. The agroclimatic water stress index (AWSI) is a very important parameter to take into account in agricultural risk management [11,13-14,17,18]. The AWSI is the ratio of evaporation deficit to potential evapotranspiration over a given period [1,9,11,14]. It is noted as follows (equation 2):

$$AWSI = 100 \times \frac{PET-AET}{PET} \tag{2}$$

In this case, the higher the value of the AWSI, the more unfavorable and therefore difficult the crops are. Thus, the Milano [19] classification was adopted as follows [20-21]:

- if AWSI< 10%, no agroclimatic water stress;
- if 10% < AWSI < 20%, low agroclimatic water stress;
- if 20% < AWSI < 40%, moderate agroclimatic water stress;
- if 40% < AWSI < 80%, high agroclimatic water stress;
- if AWSI > 80%, severe agroclimatic water stress (lack of water).

2.3.1.3 Estimation of the agricultural water needs index or rate

Among the best known agroclimatic indices is the agricultural water needs index or rate (AWAI) [1,3,9,14]. The agricultural water satisfaction index (AWAI) is defined as the ratio of AET to PET and its selection is consistent with the international bibliography on this subject [1,9,10-11,14]. The index AWAI is noted as follows (equation 3):

$$AWAI = 100 \times \frac{AET}{PET} \tag{3}$$

The lower the agricultural water needs satisfaction index (AWAI), the more unfavorable and therefore difficult the crops are [11]. Thus, several agricultural water requirement satisfaction classes based on the agroclimatic water requirement satisfaction or allocation index (AWAI) have been defined as follows [11,19-21]:

- if AWAI < 25%, very low satisfaction of agricultural water needs;
- if 25% < AWAI < 45%, low satisfaction of agricultural water needs;
- if 45% < AWAI < 55%, moderate satisfaction of agricultural water needs;
- if 55% < AWAI < 75%, high satisfaction of agricultural water needs;
- if AWAI > 75%, very high satisfaction of agricultural water needs.

2.3.2 Estimation of agro-climatic indicator parameters

2.3.2.1 Estimation of potential evapotranspiration (PET)

PTE was calculated on a monthly time step using the empirical formula of Thornthwaite [16]. Indeed, the Thornthwaite model gives an excellent approximation of the potential evapotranspiration (PET) since the air temperature is fairly representative of the net radiation. Regarding annual basis, Thornthwaite's method has comparable values to those calculated by Penman's method, which is considered the most realistic by several hydrologists [16]. The equations defining the Thornthwaite model are as follows (equations 4 to 7):

$$PET(mm) = 16\left(\frac{10t}{I}\right)^a F \tag{4}$$

$$I = \sum_{j=1}^{12} i \tag{5}$$

$$i_j = \left(\frac{t_j}{5}\right)^{1,514} \tag{6}$$

$$a = 0,49239 + 1,79.10^{-2} I - 7,71.10^{-5} I^2 + 6,75.10^{-7} I^3 \tag{7}$$

with:

- t: monthly average temperature in °C ;
- I: annual thermal index ;
- i: monthly thermal index ;
- F: correction coefficient, function of the latitude and the given month.

2.3.2.2 Estimation of actual evapotranspiration (AET)

AET can be calculated using several methods (Penman-Monteith, Turkish, Thornthwaite, etc.). Thus, the AET has been carried out using the empirical Thornthwaite formula.

This method is based on the notion of water reserve and more specifically of the useful reserve (UR). Indeed, the UR designates the water retained by the soil and exploitable by the plant. It is assumed that the soil is capable of storing a certain amount of water (RU) and this water can be taken up for evapotranspiration by plants. The amount of water stored in the reserve is between 0 (the reserve is empty) and 200 mm (the reserve is full). This quantity varies according to the soils and subsoil considered, with an average of 100 mm. It is admitted that the satisfaction of the PET has priority over the runoff, i.e., before there is any runoff, the evaporating capacity must be satisfied (PET=AET). Furthermore, the competition of the UR also has priority over the runoff.

A monthly balance is thus established from the rainfall (P) of the month, the PET and the (RU) according to the following rules (equations 8 and 9):

-if $P \geq PET$ then $AET = PET$; (8)

-if $P < PET$ then $AET = P + \Delta RU$. (9)

The UR is estimated from the last month when rainfall (P) is greater than or equal to potential evapotranspiration (PET). The model proposed by Thornthwaite for the evaluation of the UR is as follows (equation 10):

$$RU_t = RU_0 \times e^{-a\sum DP} \tag{10}$$

With:

- RUt: state of the reserves at time t ;
- RU0: useful soil reserve reached at the end of the wet season;

- DP (rainfall deficit = PET-P) ;
- a: constant depending on RU.

2.3.3 Variations in agroclimatic indicators

The agroclimatic indicators studied were analyzed on an interannual scale over different periods related to plant growth:

- the vegetative growth period was chosen from April to September (six months);
- the spring period from April to June
- the summer period from July to September.

The analysis of the evolution of the agroclimatic parameters studied over the period 1991-2020 required the application of the linear regression method. This method aims to determine, by means of linear regression, the evolution of climatic parameters. The analysis of the evolution of temperatures makes it possible to determine, on the one hand, the influence of global warming on local warming and, on the other hand, the concordance between the temperature and precipitation trends [22]. It consists of a graphical representation of an affine-type regression line that presents the linear evolution of a climatic parameter (Y) as a function of time (X) and allows the temporal trend to be detected [23-24]. The equation of the trend line is in the following form (equation 11):

$$Y = aX + b \tag{11}$$

Where:

a is the directing coefficient and represents the slope, and b is a constant.

- If a > 0, there is an increase;
- If a < 0, there is a decrease

The quality of the regression model is indicated by the R2 coefficient. It represents the proportion of the measurement points that is explained by the linear regression. This value ranges from 0 (model explains nothing) to 1 (model is perfect and all points are on the regression line). Classes of the coefficient of determination to express the importance of interannual variability are defined as follows:

- $R^2<0.1$: extremely important;
- $0.1<R^2<0.2$: very important;
- $0.2<R^2<0.3$: important;
- $R^2>0.3$: average.

3. RESULTS AND DISCUSSION

3.1 Interannual Evolution of Evapotranspiration

The analysis of the evolution of potential evapotranspiration (PET) during the vegetative period (April to September), the spring period (April to June) and the summer period (July to September) over the reference period (1991-2020) shows an increase in PET whatever the observation period and the climatic zone (Fig. 3). However, in each climatic zone and during each growing season, the growth in PET is higher in the spring period than in the summer period. The growth observed is generally of average levels ($R^2>0.30$). However, it was very high ($0.10<R^2<0.20$) in the sub-equatorial climate. The humid tropical climate recorded a significant increase in PET ($0.20<R^2<0.30$) during the spring period. The increase in PET during the vegetative period is estimated at between 29 mm/decade (subtropical climate) and 56 mm/decade (humid tropical climate), with a value of 51 mm/decade in the subequatorial climate. For the spring period, the gradual trend in PET varies between 22 mm/decade (subtropical climate) and 33 mm/decade (humid tropical climate). For the summer period, the growth in PET fluctuates between 8 mm/decade (subtropical climate) and 23 mm/decade (humid tropical climate).

The evolution of cumulative seasonal actual evapotranspiration (AET) for the different climate zones studied shows that the linear adjustment trends observed between 1991 and 2020 show a significant upward trend during the summer period, but this increase is more marked in the sub-equatorial climate (50 mm/decade) than in the other climate zones, with respectively +24 mm per decade in the tropical climate and +4 mm in the subtropical climate (Fig. 4). Contrasting variations are observed in the spring and vegetative periods. During the spring period, there is an increase in AET in the humid tropical climate (+24 mm/decade) and a decrease in AET in the subtropical climate (-5 mm/decade) and the subequatorial climate (-18 mm/decade). The vegetative period is marked by an increase in AET in the humid tropical climate (+48 mm/decade) and in the subequatorial climate (+31 mm/decade) and a decrease in AET in the subtropical climate (-1 mm/decade).

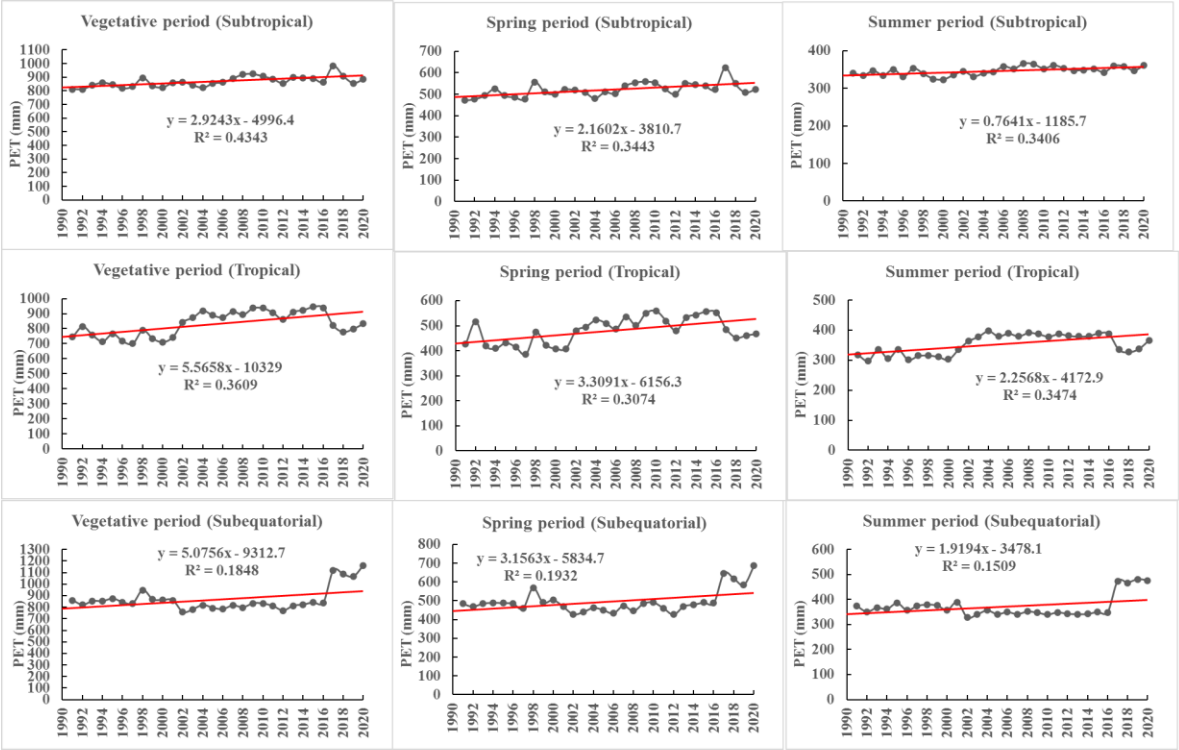

Fig. 3. Evolution of potential evapotranspiration (PET) over the period 1991-2020

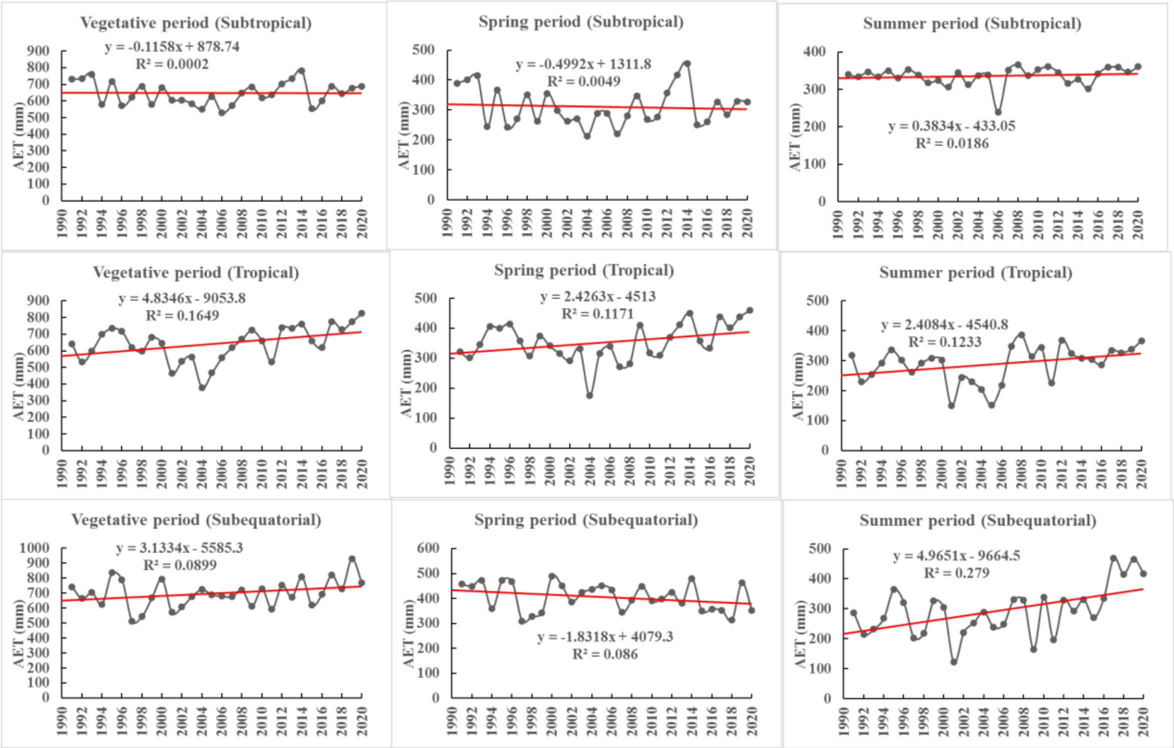

Fig. 4. Evolution of real evapotranspiration (AET) over the period 1991-2020

The strong increase in AET during the summer combined with a small or even a decrease in AET during the spring reflects the general increase in AET during the vegetative period in the subtropical and subequatorial climate regimes. The humid tropical zone is characterized by a combined increase in AET during the spring and summer periods.

3.2 Inter-annual Evolution of Agro-climatic Indicators

The agroclimatic humidity indicator (AHI) calculated over the vegetative period (April to September) from 1991 to 2020 shows a water surplus from 1991 to 2000 and from 2017 to 2020 and a water deficit over the period 2001-2016 for the northern (subtropical climate) and central (humid tropical climate) climate zones (Fig. 5). However, a deterioration in the water deficit during the vegetative period was observed in the sub-equatorial climate over the entire period, apart from a few years (1995, 1996, 210, 2012 and 2014). The trend is regressive with rates of -92 mm/decade in the subtropical climate and -4 mm/decade in the humid tropical climate, and even almost zero in the subequatorial climate (1 mm/decade).

Generally speaking, the water balance during the vegetative period is predominantly negative and has evolved towards increasingly negative values over the 30 years of observation. During the spring, a total rainfall deficit was observed over the entire observation period in the subtropical climate, with a downward trend towards greater amplitudes (-35 mm/decade). The humid tropical climate is marked by a predominance of water surpluses with a downward trend (-22 mm/decade). The sub-equatorial climate is marked by alternating water surpluses and deficits with a downward trend reflected in a rate of -56 mm/decade. The agroclimatic humidity indicator (AHI) during the summer period is on the rise (+1 mm/decade), almost surplus in the subtropical climate and almost deficit in the subequatorial climate. This period is characterized by alternating water surpluses (at the beginning and end of the reference period) and water deficits in 2011 and 2016. The evolution of the agroclimatic humidity indicator (AHI) shows a relative surplus period in the 1990s, followed by a phase of significant summer water deficits during the decade of 2000 and again an increase in the water surplus during the last decade of 2010. This evolution of the agroclimatic humidity indicator (AHI) shows that the linear adjustment trends observed over the reference period 1991-2020 are -57 mm per decade in the subtropical, +18 mm per decade in the humid tropical and +57 mm per decade in the subequatorial climate.

During the vegetative period, an increase in agroclimatic moisture stress (AWSI) was observed, from low to moderate in the subtropical climate and from no moisture stress at times to moderate to high moisture stress in the subequatorial climate (Fig. 6). However, in the humid tropical climate, there is a slight decrease in water stress while fluctuating between no water stress and high water stress. A general increase in agro-climatic water stress (AWSI) was observed during the spring period. Water stress increased from low to high levels in the subtropical climate over the observation period. In the humid tropical climate, there was a shift from a lack of water stress to low water stress at the beginning and end of the study period (1991-2020), while the intermediate period is characterized by moderate to high water stress. Water stress has increased from low to high levels in the subtropical climate over the observation period. In the sub-equatorial climate, an absence of agroclimatic water stress (AWSI) is observed at the beginning (1991-1993), which leads to a significant agroclimatic water stress (AWSI) through low to moderate phases.

During the summer period, there is an absence of agricultural water stress in the northern part of the basin (subtropical climate) except in 2006 and 2015 when a high and moderate degree of stress is observed respectively. However, the general trend of water stress is increasing. In the humid tropical and sub-equatorial climate, there is a strong downward trend in agricultural water stress, which varies from zero to high, with a predominance of years progressing from low to high. In general, agricultural water stress is more marked during the spring period than during the summer period. A strong opposite behavior of agricultural water stress was found when moving from spring to summer in the sub-equatorial and humid tropical climates.

It is shown that the satisfaction of agricultural water needs (AWAI) is high or very high throughout the N'zi catchment area during the 1991-2020 growing season (vegetative period), with a downward trend in the rate of satisfaction of agricultural water needs in the subtropical and subequatorial climates and an upward trend in the humid tropical climate (Fig. 7). During the spring period, the rate of water demand satisfaction deteriorates over the entire

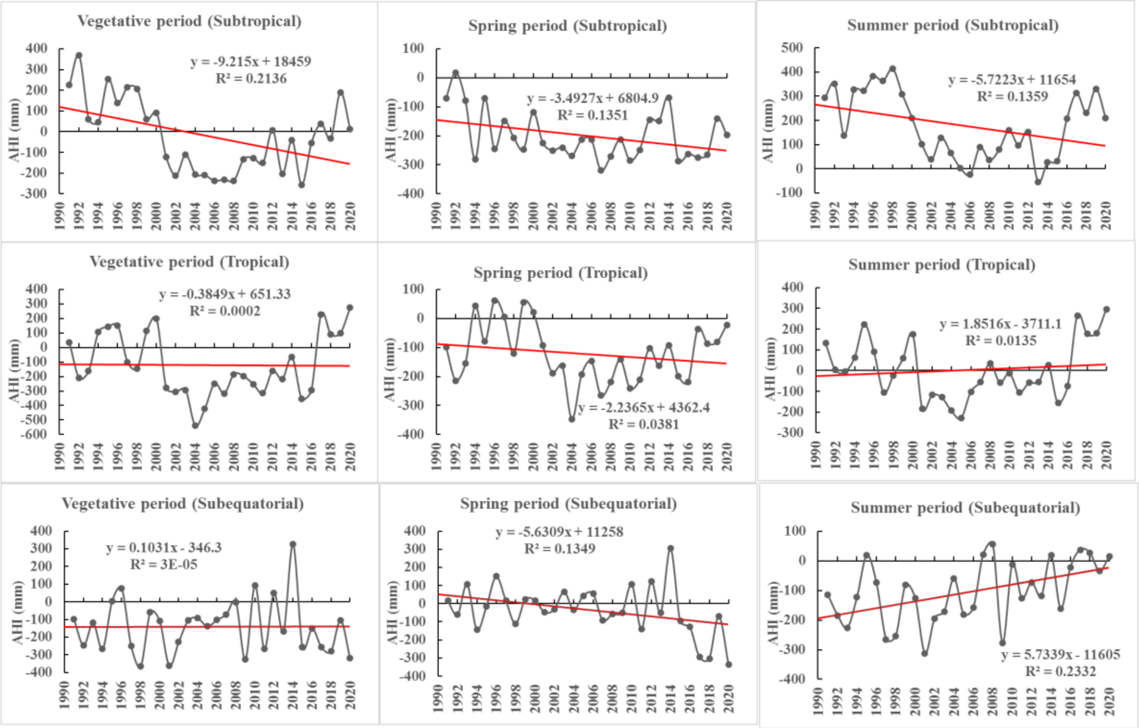

Fig. 5. Evolution of the agroclimatic moisture indicator (AHI) over the period 1991-2020

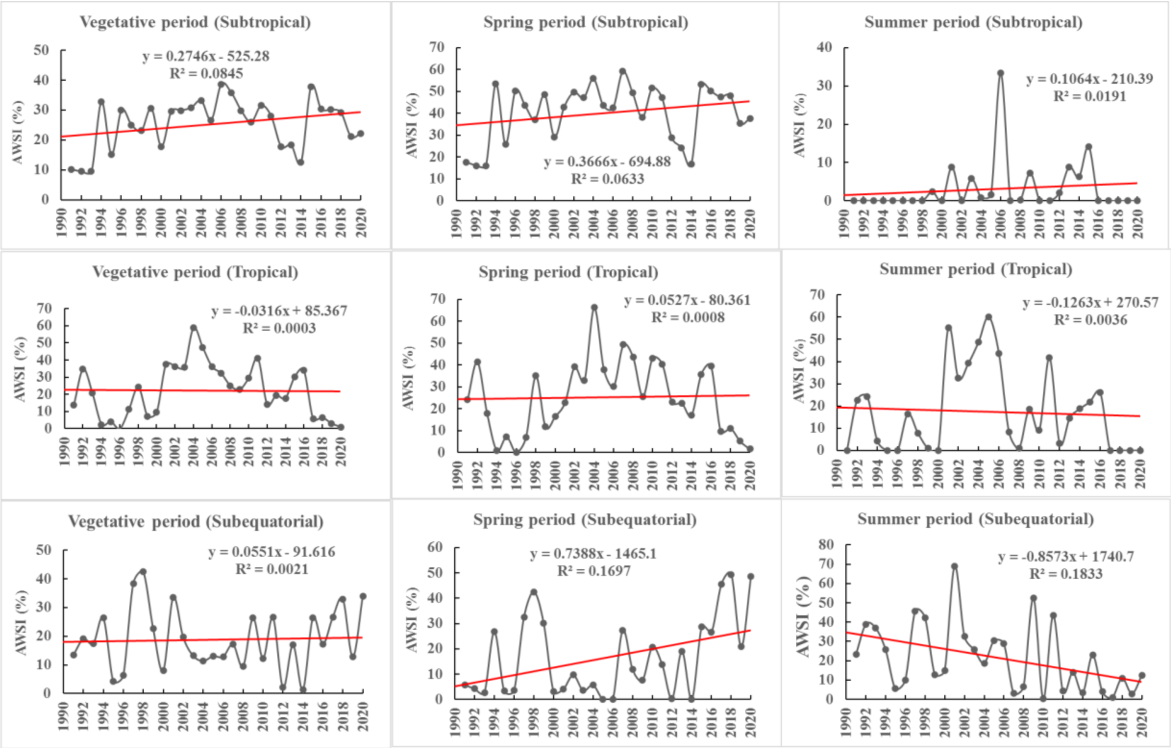

Fig. 6. Evolution of the agro-climatic water stress index (AWSI) over the period 1991-2020

observation period. Thus, agricultural water needs are strongly or even very strongly met in the sub-equatorial climate, although there is a downward trend in the satisfaction rate.

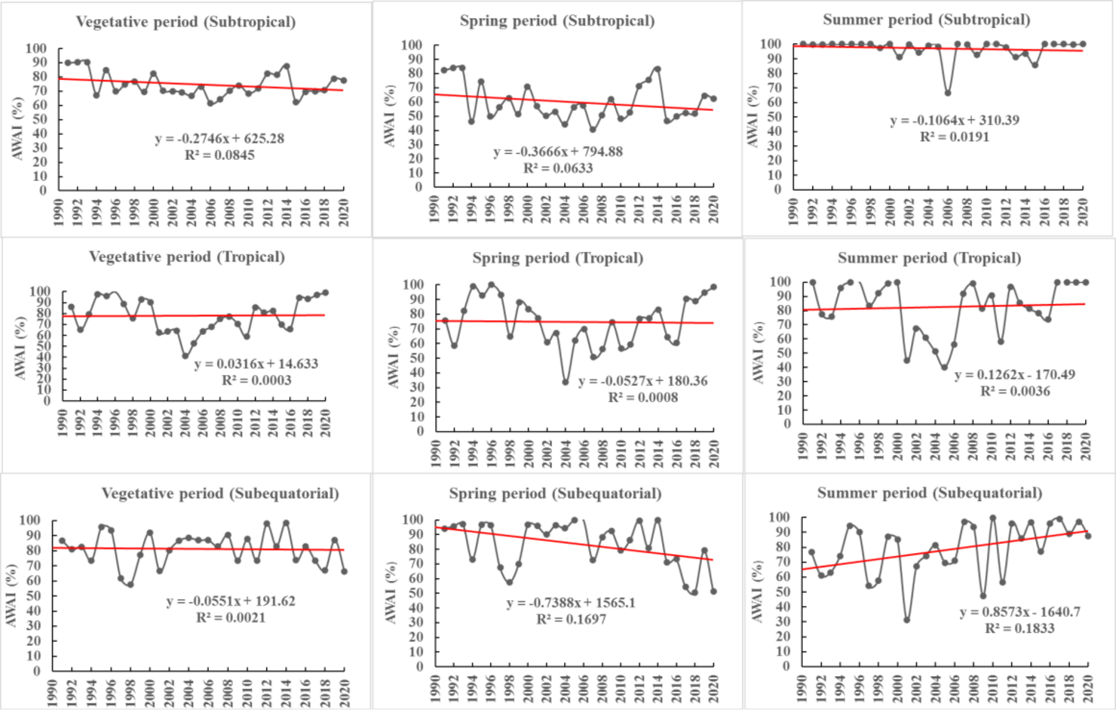

Fig. 7. Evolution of the agricultural water demand index (AWAI) over the period 1991-2020

In the humid tropical climate, water needs range from moderate to very high satisfaction, with strong and very strong satisfaction dominating. The subtropical climate is characterized by a three-tiered progression from moderate to very high satisfaction with a predominance of moderate and high. There is an increasing gradient in the satisfaction rate of agricultural water needs from north to south. During the summer, agricultural water requirements are moderate to very strongly satisfied in the southern and central part of the basin with an increasing trend and very strongly satisfied in the northern part of the basin with a decreasing trend. There is an increasing gradient in the satisfaction rate of agricultural water needs from the South to the North. There is a contrasting gradient in the rate of satisfaction of agricultural water needs between the spring and summer periods.

3.3 Discussion

The observed PET over the whole of the current normal reference period 1991-2020 has increased overall in all climatic zones and during the different cropping seasons for rainfed crops with a preeminence of the spring period over the summer period. The trend of increasing PET is explained by the rise in temperature [25]. This increase in potential evapotranspiration during the different growth periods reflects a hardening of the water conditions for the plants. Indeed, Gnangouin et al. [25] found a modest increase in precipitation and a strong increase in temperature over the same period (1991-2020) within the same climatic zones studied. The increase in PET increases with increasing temperature. The increase in PET reflects an increasing need for water by plants and explains a trend towards a decrease in effective rainfall. This is because transpiration is the driving force behind water transport in plants. If the evapotranspiration of the plant is higher than the water resource at the root level, then the plant is short of water. With regard to AET, an increase is generally observed within the different climatic zones but with sometimes decreasing trends during the different cropping seasons (spring and summer), thus a divergent behavior with regard to PET.

During the current normal reference period (1991-2020), a heterogeneous variation of agroclimatic indicators (agroclimatic moisture index, agricultural water stress index and water demand satisfaction rate) of rainfed crops during the whole vegetative period was observed throughout the N'zi watershed with its three climatic zones. Indeed, a general degradation of agricultural humidity, an aggravation of agricultural water stress and a degradation of the rate of satisfaction of agricultural water demands were highlighted. However, the evolution of agroclimatic indicators differs according to climatic zones and cropping seasons (spring and summer). According to the work of Rusagara [3] carried out in Burkina Faso, the spatial evolution of the values of the water demand satisfaction index of the cereals studied (millet, sorghum, maize) highlights an extreme vulnerability to water stress in the northern part (the Sahel) than in the southern part (the Subsahel) whatever the crop. Indeed, the values of the water requirement index for crops were generally below 50% in the Sahel. This reflects a complete crop failure. As one moves towards the south of the Burkinabe Sahel, these conditions improve from poor (50 to 59%) to average (80 to 94%). In the sub-Sahelian zone, the rate of satisfaction of agricultural water needs remains better than in the Sahelian zone (95 to 99% or even 100%). This observed water trend could be explained by low rainfall, which accentuates water deficits in the Sahel more than in the Sub-Sahara [2,26]. The results obtained in this study confirm the trends of the results obtained by Rusagara [3]. Indeed, the behavior of water stress is consistent with the rainfall gradient of the studied regions. Insufficient water requirements led to complete crop failure in some areas except sorghum during the mid-season phase [3,27]. Radhouane et al. [28] confirm that sorghum is more resilient to water stress compared to millet and maize because it has physiological mechanisms to recover vegetative growth after water stress. But among these two crops, maize is more vulnerable to water stress than millet [3-4,29].

4. CONCLUSION

The aim of this study was to analyze the impacts of climate change on agroclimatic indicators (agricultural moisture index, agricultural water stress index and agricultural water requirement index) within the main Ivorian climatic regimes across the N'zi (Bandama) watershed. The inter-annual analysis showed that the observed PET over the entire current normal reference period 1991-2020 during the vegetative period as well as during the spring and summer periods, increased overall climatic zones with a preeminence of the spring period over the summer period. However, the AET, although characterized by a general upward trend whatever the climatic zone, sometimes shows divergent trends to the PET. The interannual evolution of the water balance expressed by the water moisture index during the different cropping periods shows a predominance of deficit years. The N'zi watershed was marked by water stress varying between low and high levels during the 1991-2020 period. It has also been shown that the rate of satisfaction of agricultural water needs has deteriorated from a very satisfactory level to a low level. However, the evolution of the agroclimatic indicators differs according to the climatic zones and the cropping seasons (cropping season, spring and summer). The results obtained constitute a series of important indicators for the economic development of an agricultural country such as Côte d'Ivoire. The study of the evolution of these indicators on a seasonal scale would constitute a metric for analysis in the short (2030 horizon), medium (2050 horizon) and long term (2100 horizon) and would provide information on risks and/or opportunities for the development of certain crops (cereals, etc.).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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