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Impacts of Climate Change on Water Stress 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

The increased pressures on water resources linked to climate and societal changes are recognized as global challenges. The objective of this study is to analyze the impacts of climate change on the water stress of populations in the N'zi (Bandama) watershed in Ivory Coast. The data used (flows,

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populations, etc.) cover the period 1991-2020. An approach based on the comparison of water resources (standard normalization index, linear regression method, frequency analysis, flow rate index, etc.) and demands through the water needs satisfaction rate index, was applied at interannual and monthly scales. This approach has made it possible to identify the major trends in water stress in Dimbokro populations. It appears that on an interannual scale, the N'zi watershed is in a situation of water stress. The seasonal scale analysis shows that the city of Dimbokro experiences six months (December to May) of water stress. In the future horizons, the water stress of the city of Dimbokro could intensify.

Keywords: Climate change; water needs satisfaction index; water stress; N'zi (Bandama); Côte d'Ivoire.

1. INTRODUCTION

Increased pressure on water resources due to climate and anthropogenic changes as well as competition between water uses are recognized as global issues [1]. However, the IPCC scenarios envisage a possible increase in water needs (evolution of agricultural, food and energy demand, urbanization, technological innovations in particular). The hydroclimatic events observed recently in Ivory Coast highlight an upsurge in extreme events in general and low water levels in particular, which calls into question the current management methods for rivers and, more broadly, for water resources. Indeed, several studies agree on an intensification of seasonal contrasts with more severe low-water periods, a significant and almost generalized decrease in water resources, and a modification of river regimes [2,3]. These potentially damaging impacts are transformations of the functioning of hydrosystems that could have repercussions on water management in the future. This is particularly the case when these impacts reduce the availability of water resources needed to meet water demands, which is the case for many regions of the world. From a demand perspective, population pressure, agricultural intensification, urbanization and industrialization are all seen as factors tending to worsen the situation. The trend is towards increasing pressure on water resources, both from the quantitative (increase in withdrawals) and qualitative (pollution) points of view, due to demographic growth, the expansion of irrigated areas and water pollution by domestic and industrial discharges. In addition, for certain sectors, there are the direct impacts of climate change. As a result, water security, i.e., the guarantee of access to sufficient water resources of good quality to meet all the needs of the various users without contravening ecological imperatives, is tending to deteriorate. In this context, the questions of future access to the resource and the adequacy between water resources and demands arise. In this context, it is clear and commonly accepted that climate change plays and will play a central role, both on the availability of resources and on water demand. However, the importance of socio-economic factors should not be overlooked.

Indeed, a water management system of any kind (a hydroelectric scheme, a drinking water distribution system, an irrigation network, etc.) is part of a specific and well-defined natural (hydrology, climate) and socio-economic context. To understand its functioning, it is necessary to understand it as a socio-hydrological system and to analyze the different hydrological, social and technical elements that make it up.

The aim of this study is to analyze the impacts of climate change on the water stress of the populations of the N'zi (Bandama) watershed in Ivory Coast in order to propose tools for evaluating strategies for adapting water management in a context of climate change, in line with socio-economic development and integrating interactions between uses and the various accessible resources. Indeed, the N'zi (Bandama) watershed is identified as a watershed vulnerable to "water crises" due to limited water resources, significant climate change and increasing anthropic pressures. The N'zi serves to supply the needs of the population in general and those of Dimbokro in particular from a reservoir dam considered as the water intake. Water resource management issues are becoming increasingly important in these regions, which are particularly vulnerable during low water periods.

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 km^2. Due to its elongated geographical configuration, the N'zi watershed is representative of the major climatic zones of Côte d'Ivoire [4]. 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 (Soudanais climate) is characterized by two seasons, a rainy season from April to October (7 months) and a dry season from November to March (5 months) 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 (Baouléen climate) is located in the center of the basin. There is a four-season climate regime: a long rainy season from March to June (4 months), a short dry season from July to August (2 months), a short rainy season starting in September and ending in October (2 months) and a long dry season from November to February (4 months). 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 (Attiéen climate) which is characterized by four (4) seasons; the main rainy season occurs between March and June followed by a break (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 [5].

2.2 Study Data

The monthly flow data were made available to us by the Directorate General of Human Hydraulic Infrastructures (DGIHH), Sub-Directorate of Hydrology and cover the period 1991-2020. The hydrometric station chosen for the study is that of N'zi in Dimbokro, which has the particularity of presenting no gaps in the series covering the period 1991-2020.

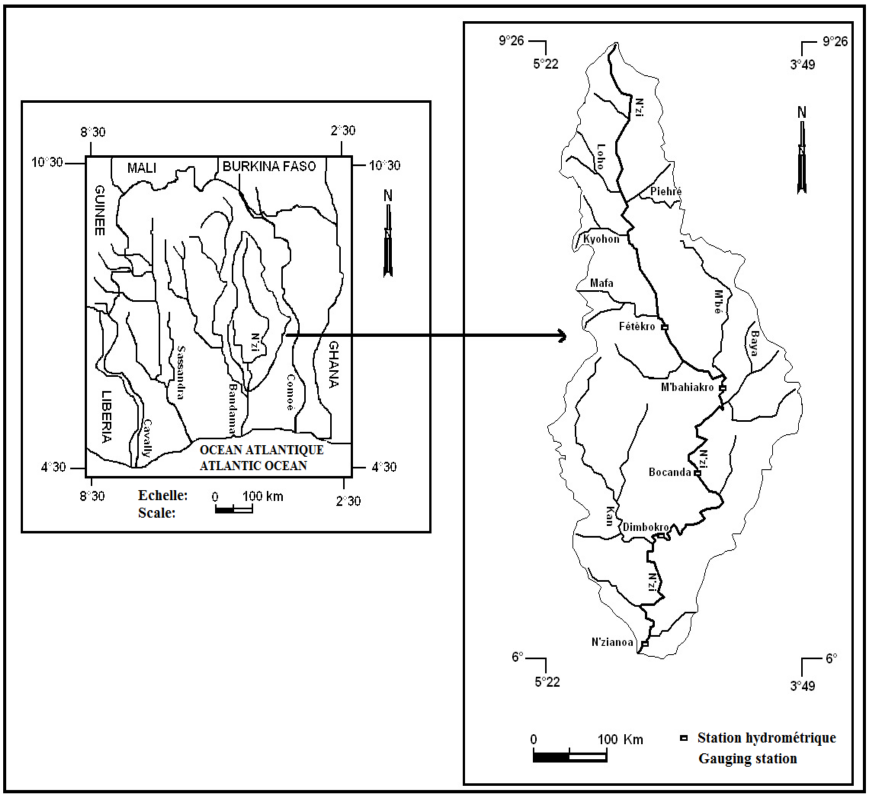

Fig. 1. Presentation of the N'zi (Bandama) watershed

2.3 Methods

2.3.1 Estimation of available water resources

The statistical characteristics (mean, variance, standard deviation, coefficient of asymmetry, coefficient of kurtosis, median and modal classes, etc.) of the average annual flow were determined. The evolution of annual mean flows was analyzed using the standard normalization index and the linear regression method [6-8]. The descriptive variable of the low water flow was extracted from the minimum value sampling method which consisted in selecting the minimum annual mean monthly flow (MAMF) for a given year.

The statistical characteristics of the MAMF (mean, variance, standard deviation, coefficient of asymmetry, median and modal classes, etc.) as well as the frequencies of the month of occurrence and distribution were analyzed. A definition of the hydrological regime of the watercourse was made from the comparison of the annual modulus with the average monthly flow. Indeed, the seasonal high water period defined as the period during which the average monthly flow of a river is higher than its modulus [9]. Thus, the months of low water are defined as the months in which the average flow is lower than the modulus.

2.3.2 Estimating water demand

Total water demand includes domestic, agricultural, industrial, social and environmental needs [10-12]. Domestic water demand accounts for 60-80% of the water demand for most small and medium-sized urban centers in sub-Saharan Africa [13]. Therefore, other needs outside of domestic needs can be estimated to be in the range of 20-40%. Domestic water demand has been defined as the volume of water supplied to the total population, businesses, social services and industries connected to the municipal network. This consumption varies according to several factors: standard of living, habits, availability of water, climate, price of water, etc. [14]. In the N'zi (Bandama) watershed, domestic demand predominates over other demands. In addition, the domestic sector is often defined as having priority over other users in terms of water supply.

The methods for estimating and modeling water demand are multiple, and vary according to the type of demand encountered. For domestic demand, several approaches exist. The simplest method, frequently used, for estimating annual or even seasonal domestic water demand, is based on knowledge of the population of an area, and the average unit consumption per capita [15]. For Benzannache [14], the following ratios can be assumed depending on the number of inhabitants in the locality:

- For a large city (more than 100,000 inhabitants): from 100 to 120 l/day/inhabitant;
- For a city with 20,000 to 100,000 inhabitants: 80 to 100 l/day/inhabitant;
- For a medium-sized city (5,000 to 20,000 inhabitants): 60 to 80 l/day/inhabitant;
- For a rural area (fewer than 5,000 inhabitants): 40 to 60 l/day/inhabitant;
- For standpipes: 20 to 40 l/day/inhabitant;
- For public services or social needs (mosques, churches, hospitals, administrative centers, markets, etc.): 13% of domestic needs are added to domestic consumption.

Thus, the ratio of 50 l per day per inhabitant was retained for the estimation of domestic needs within the framework of this study based on the work of Zoungrana [13], Benzannache [14], ONEP [16]. Indeed, this ratio is applied for small and medium urban centers in sub-Saharan Africa such as Dimbokro [13,16]. Other needs outside domestic needs (agricultural, industrial, social and environmental needs) have been estimated at 15 l per day per capita. Thus, domestic water demand represents 77% against 23% for other water demands.

The geometric method was used to estimate the population at a given date by knowing the population at horizon 0 and relying on the natural growth rate and the number of years between horizon 0 and the given date (equation 1):

$$P_n = P_0(1+\alpha)^n \quad (1)$$

with:

- P_n: the population at horizon n;
- P_0: the population at horizon 0;
- α: the growth rate of the population;
- n: number of years between horizon 0 and horizon n.

The information relating to the populations (number of inhabitants, growth rate, etc.) was obtained from the technical reports of the National Institute of Statistics (INS) on the general population and housing censuses of 1988, 1998, 2014 and 2021.

2.3.3 Estimation of the water demand satisfaction rate

The analysis of water stress was based on the Water Allocation Index (WAI), which was developed to compare the estimate of available water resources with that of water demand. It determines the proportion of demand that could be met. It thus makes it possible to highlight the periods most vulnerable to a decrease in water resources [10]. The expression of the domestic water demand satisfaction indicator is presented as the ratio of available water resources (m^3) to water demand (m^3) [1,10,11] (equation 2):

$$\textbf{WAI} = \frac{Available\ water\ resources}{Water\ demand} \quad (2)$$

Several classes of domestic water demand satisfaction have been defined according to the values taken by the indicator [1,10-12]. The thresholds chosen to establish these different classes can, if necessary, be adapted to the criteria deemed significant by the basin managers. The classes for meeting domestic water demands are as follows [1,10-12]:

- if WAI < 50%, very low satisfaction of domestic water demands;
- if 50% < WAI < 85%, low satisfaction of domestic water demands;
- if 85% < WAI < 95%, moderate satisfaction of domestic water demands;
- if 95% < WAI < 97.5%, high satisfaction of domestic water demands;
- if 97.5% < WAI < 100%, very high satisfaction of domestic water demands.

The index of satisfaction of domestic water demands was calculated on the N'zi (Bandama) catchment area of Dimbokro outlets over the period 1991-2020 and at annual and monthly scales, to assess the current state of satisfaction of domestic water demands.

3. RESULTS

3.1 Evolution of Water Resources

The average annual flow varies between 10.09 and 61.72 m3/s with a means of 32.39 m3/s and a standard deviation of 13.15 m3/s (Table 1). The coefficient of skewness is positive and is 0.61, which leads to the conclusion that the bass flow data studied are spread to the right of the mean distribution. The kurtosis coefficient is -0.23, which reflects a platikurtic distribution peak. The coefficient of variation is well above 40.60%, which explains the high heterogeneity of the mean annual flow series.

The interannual evolution of average annual flows over the period 1991-2020 (Fig. 2) shows a predominance of deficit years, an extremely high interannual variability (R2=0.005) with a downward trend.

The hydrometric regime observed at the N'Zi station in Dimbokro is a simple regime with a minimum in February and a maximum in October (Fig. 3). The low water period extends from December to May with a mean flow of 6.14 m3/s and the high water period is from June to November with a mean flow of 58.64 m3/s.

The average quarterly flows are calculated over the four quarters of the year which are (Fig. 4):

- January-February-March (JFM): whose flow is 2 m3/s;
- April-May-June (AMJ): with a flow of 19 m3/s;
- July-August-September (JAS): with a flow of 54.26 m3/s;
- October-November-December (OND): with a flow of 54.16 m3/s.

This analysis, represented by Fig. 4, has enabled us to highlight the wettest quarter, which is JAS (July-August-September), and the driest quarter, which is JFM (January-February-March).

Table 1. Statistical characteristics of past mean annual flows (1991-2020)

Statistical characteristics	Values
Average	32,39
Standard deviation	13,15
Coefficient of variation (%)	40,60
Maximum	61,72
Minimum	10,39
Skewness coefficient	0,61
Kurtosis coefficient	-0,23

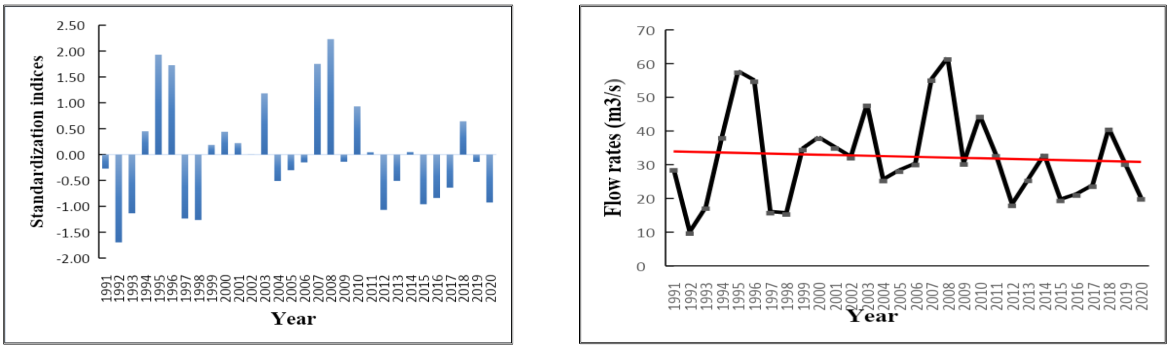

Fig. 2. Trends in mean annual flows (m3/s) of the N'zi (Bandama) at Dimbokro (1991-2020)

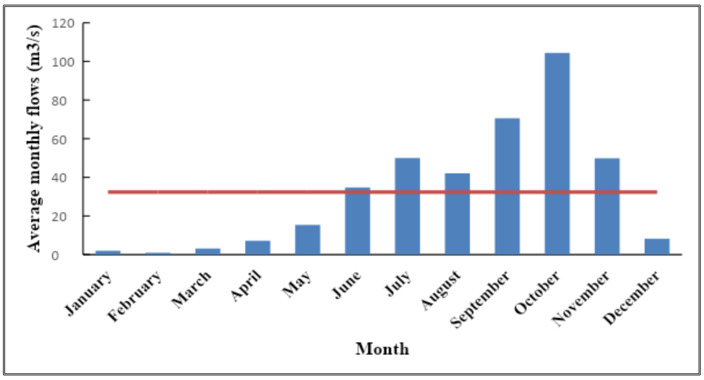

Fig. 3. Analysis of the hydrological regime of the N'zi (Bandama) at Dimbokro (1991-2020)

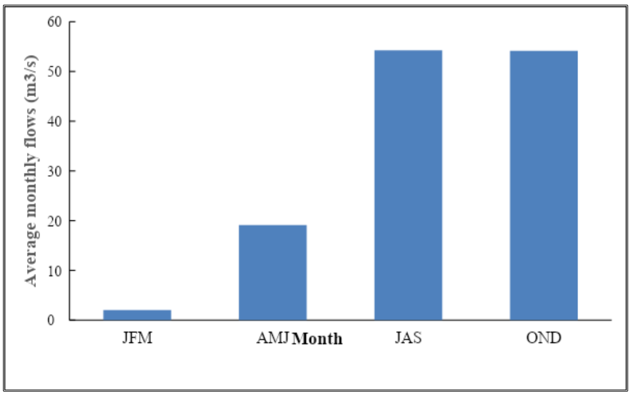

Fig. 4. Quarterly mean flows of the N'zi (Bandama) at Dimbokro (1991-2020)

The minimum annual mean monthly flows (MAMF) evaluated over the period 1991-2020 varies between 0.02 and 0.97 m^3/s with a means of 0.31 m^3/s and a standard deviation of 0.28 m^3/s (Table 2). The skewness coefficient is positive and is 0.85, which leads to the conclusion that the studied bass flow data are spread to the right of the mean of the distributions. The kurtosis coefficient is negative and has a value of -0.25; this translates into a less platikurtic distribution of the MAMF. The coefficient of variation of a value of 90.79% is largely higher than 25%, which explains a great heterogeneity of the series of MAMF.

The MAMF occur mainly in February (13%) and March (18%) (Fig. 5). They occur less frequently in May, August (2%) and April (3%). The lowest water levels are therefore observed in January, February and March.

The most frequent values of MAMF are in the interval [0-0.25 m^3/s] with a frequency of 53% (Fig. 6). The modal class and the median class of the MAMF are merged into the class [0-0.25 m3 /s].

3.2 Evolution of the Rate of Satisfaction of Water Needs

The rate of satisfaction of the water needs of the population of Dimbokro during the period 1991-2020 varies between 16.16% (1992) and 128.56% (2008) with an average of 65.23% and a standard deviation of 27.93% (Fig. 7). Thus, the rates (in terms of years of satisfaction of water needs) were respectively 3.3% of very low satisfaction of water needs, 23.3% of low satisfaction of needs, 13.3% of moderate satisfaction of water resources, 26.7% of high satisfaction of water needs and 33.3% of very high satisfaction of water needs. These results show that the water needs of the population of Dimbokro were well met during the period 1991-2020. Overall, there is a general decline in the rate of satisfaction of the population's water needs. A deeper analysis shows that there is a significant increase ($0.20<R^2=0.22<0.30$) of 25.1% per decade in the rate of satisfaction of the population's water needs from the decade 1991-2000 to the decade 2001-2010. However, from the decade 2001-2010 to the decade 2011-2020, a significant decrease ($0.20<R^2=0.24<0.30$) in the rate of satisfaction of water needs estimated at -21.3% per decade was highlighted.

The analysis of the seasonal evolution of the rate of satisfaction of water needs highlights during the decade 1991-2000 a very low satisfaction of water needs during the period from December to May with the peak recorded during the months of February and March (Fig. 8). A high satisfaction of water needs is observed during the months of June and August. Finally, a very high satisfaction of water needs is observed during the months of July, September, October and November. For the decade 2001-2010, two main levels of water demand satisfaction are observed. The first is a period of very low water demand satisfaction covering the months of December to May (6 months). The second phase is characterized by a very high level of satisfaction of water needs from June to November (6 months). A relatively higher water demand satisfaction rate is observed for all months than in the 1991-2000 decade. The decade 2011-2020 is distinguished by the observation of several levels of satisfaction of water needs. Thus, there is a period of very low water demand satisfaction (December-March), a period of low water demand satisfaction (April), a period of moderate water demand satisfaction (May and November), a period of high water demand satisfaction (June and August) and a period of very high water demand satisfaction (July, September and October). Water demand satisfaction rates remain higher in low water periods and relatively lower than other decades in high water periods during the decade 2011-2020. The entire period shows a period of very low water demand satisfaction during the months of December to April (5 months), a month of low water demand satisfaction (May), a month of high water demand satisfaction (June) and a long period of high water demand satisfaction from July to November (5 months). The water demand satisfaction rates of the 1991-2000 and 2001-2010 decades are lower than the average water demand satisfaction rates over the whole period (1991-2020) in low water seasons, while the rates of the 2011-2020 decade are higher than the average rate during the same seasons. On the other hand, the rates of water demand satisfaction for the decades 1991-2000 and 2001-2010 are generally higher than the average rates for the entire period (1991-2020) in the high water season.

Table 2. Statistical characteristics of past MAMF (1991-2020)

Statistical characteristics	Values
Average	0,31
Standard deviation	0,28
Coefficient of variation (%)	90,79
Maximum	0,97
Minimum	0,02
Skewness coefficient	0,85
Kurtosis coefficient	-0,25

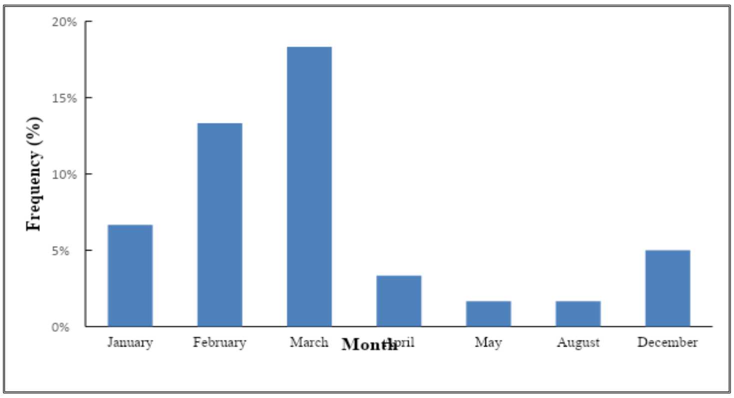

Fig. 5. Monthly frequency of occurrence of the MAMF of the N'zi (Bandama) at Dimbokro (1991-2020)

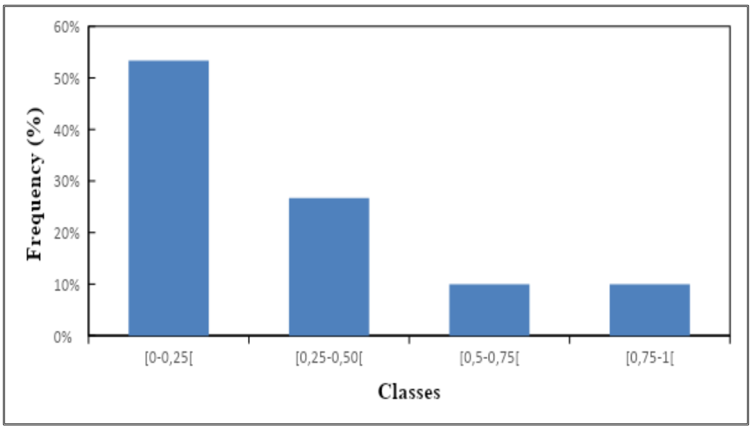

Fig. 6. Histogram of MAMF frequencies of the N'zi (Bandama) at Dimbokro (1991-2020)

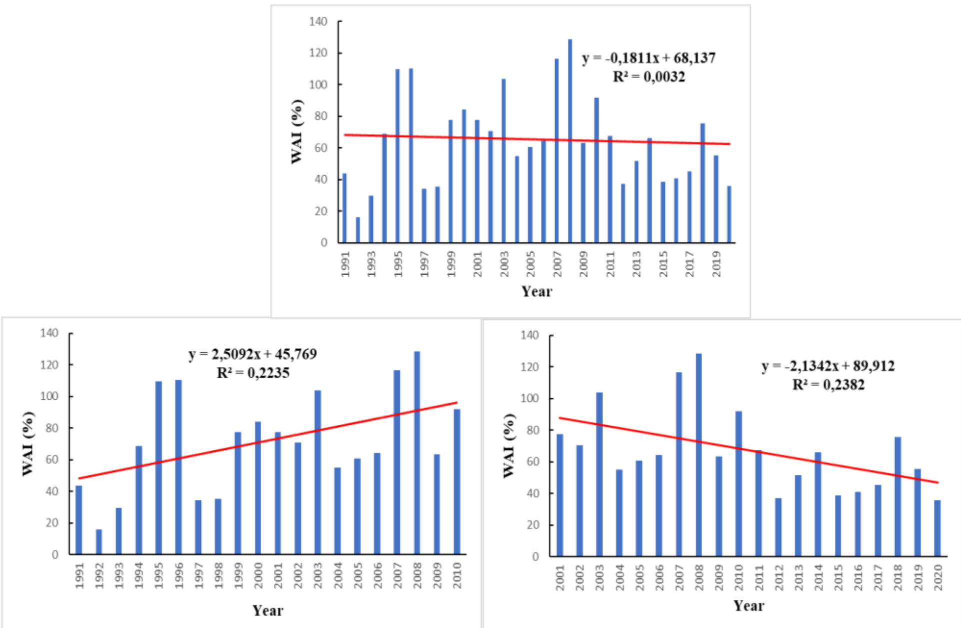

Fig. 7. Interannual water satisfaction rate (%) for the town of Dimbokro (1991-2020)

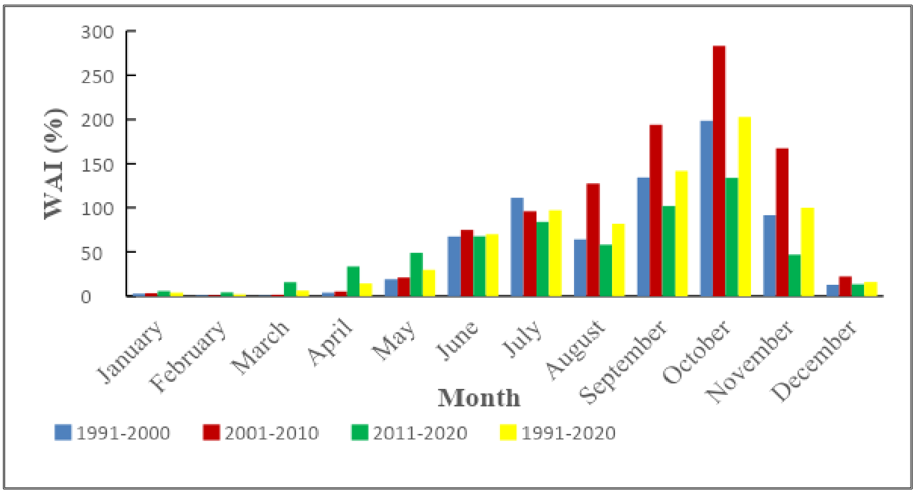

Fig. 8. Monthly water satisfaction rate (%) for the town of Dimbokro (1991-2020)

4. DISCUSSION

The mean annual flows of the N'zi at Dimbokro over the period 1991-2020 fluctuate between 10.09 and 61.72 m^3/s with an average of 32.39 m^3/s. An analysis of the inter-annual variation of these flows revealed a downward trend in these flows. This watercourse has a simple (unimodal) two-season regime with annual minimum monthly mean flows that vary between 0.02 and 0.97 m^3/s with an average of 0.31 m^3/s. The modal class and the median class of the MAMF are merged into the class [0-0.25 m^3 /s]. These MAMF occur mainly in February (13%) and March (18%).

We therefore have 26.67% of years of very low or even low satisfaction of the water needs of the populations against 73.33% of years of moderate to very high satisfaction of the water needs of the populations. These results show that the N'zi watershed is in a situation of water stress over the period 1991-2020, which translates into a high demand for water and a limited water resource. Indeed, the impacts of climate change on available water resources and water demand have affected the ability to meet water demand and impacted water stress in the town of Dimbokro. The decrease in available water resources and the increase in water consumption could explain this water stress.

According to the work of Kouassi et al. [2] carried out on the Bandama over the period 1961-2015, the various hydrological parameters (flow rates, infiltration) analyzed vary over the years and describe a regressive trend marked by a very significant break in 1980-1981. The hydrological deficits evaluated fluctuate between 15% (infiltration potential) and nearly 60% (flow rate). An analysis of the flows of the Marahoué (Bandama) at annual time steps (modules) over the period 1961-2017 revealed a decline in flows [3]. Kouassi et al. [17] defined the months of low water (low water period) as the months when the flow frequencies are lower than or equal to the frequency flow 0.2, and identified the months of January, February and March as the low water period in the N'zi watershed. There is therefore a concordance of results despite the choice of different low-water variables. The MAMF studied by Kouassi et al. [18] at the level of the N'zo (Sassandra) at Kahin, show that the quarter where low water flows frequently appears is the period from January to March with respective frequencies of 45.16% (February), 16.13% (January) and 13% (March). At this level, the modal and median classes of the MAMF are merged ([0-4 [m3/s]). The driest hydrological quarter is synchronous on the different rivers with a concordance of the modal and median classes. According to the work of Gnangouin et al. [19] on the N'zi catchment area during the period 1991-2020, climatic variability is manifested by a regressive dynamic of annual rainfall and a regular progressive evolution of the mean annual temperature.

As for the study of seasonal climatic regimes, it showed that the driest quarter in the N'zi basin across the three climatic regimes from North to South (Sudanese climate, tropical climate, sub-equatorial climate), is the January-February-March quarter. These results thus highlight an interannual and seasonal variation in hydrological conditions, which are the response to the climatic variations experienced by the different basins.

Water resource satisfaction difficulties hidden in interannual studies can thus be revealed at finer time scales such as monthly. The town of Dimbokro experiences six months (December to May) of very low to low levels of satisfaction of the population's water needs, against six months (June to November) of high to very high satisfaction of the population's water needs. The critical period is the quarter from January to March, corresponding to the quarter with the highest frequency rates of minimum annual average flows over the period 1991-2020 (6 to 18%). The period from December to May corresponds to the low water season at the level of the N'zi at Dimbokro. These results demonstrate a severe level of water stress for the population of Dimbokro over half the year (December to May). This period is characterized by high water demand and low available water resources. The water resource is therefore unable to meet the population's demand for water. The demand for water for human activities exceeds the available resource from June to November, which corresponds to the high water season. This period is therefore characterized by low or no water stress for the populations of Dimbokro, and therefore a situation of water comfort. The estimation of the rate of satisfaction of water needs on a monthly basis has made it possible to better understand the inter-annual and seasonal dynamics of the water resource and demand. The study recently carried out by Milano et al. [11] showed, by comparing the availability of water resources with water demand in the medium term exclusively in the Mediterranean basin, a region identified as one of the most vulnerable to global changes that the Maghreb countries as well as South-East Spain and the Ebro basin are currently in a situation of water stress. Indeed, the whole Mediterranean basin could then experience a situation of water stress, corresponding to 34 million inhabitants living under high water stress conditions and 202 million under severe water stress [20]. According to the work of Milano [10], over the period 1971-1990, 44 basins out of 73 studied are under water scarcity or severe water stress. In other words, 65 million inhabitants are in a situation of severe water stress (60% < WSI < 80%) and 47 million suffer from water shortage (WSI > 80%). The work of Collet [12] showed that the catchment areas of Northern Italy and Spain and those of Eastern Greece, show a moderate water stress index over the period 1971-1990. However, the French and Balkan watersheds do not appear to be under stress over the observed period. In the short (2030) and medium term (horizon 2050), these trends could intensify. Thus, the different climatic variations have influenced the available water resources and hence the evolution of water stress in the N'zi watershed (Bandama).

5. CONCLUSION

The objective of this study is to analyze the impacts of climate change on the water stress of the populations of the N'zi (Bandama) watershed in Ivory Coast. The analysis of water resources over the period 1991-2020 revealed average annual flows varying between 10.09 and 61.72 m3/s with an average of 32.39 m3/s. A downward trend in average annual flows was observed. The hydrometric regime observed at the N'Zi station in Dimbokro is a unimodal regime with two seasons. The minimum annual mean monthly flows (MAFM) evaluated over the period 1991-2020 varies between 0.02 and 0.97 m3/s with an average of 0.31 m3/s. Most of the MAMF occur in February (13%) and March (18%). The modal and median classes of the MAMF are merged into the class [0-0.25 m3 /s]. The results of the analysis of the rate of satisfaction of water needs on an interannual scale over the period 1991-2020 showed that the N'zi basin is under water stress. Seasonal analysis shows that the town of Dimbokro experiences six months (December to May) of water stress. In the future, water stress in the town of Dimbokro could intensify.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Milano M, Ruelland D, Dezetter A. Anticipation of water stress in the Mediterranean: a decision support tool for

better water resources management. Blue Plan Notes. 2013a;26:4.
2. Kouassi AM, Assoko AVS, Djé KB, Kouakou KE, Kouamé KF, Biemi J. Analysis of the persistence of drought in West Africa: Characterization of the recent climate variability in Ivory Coast. Environmental and Water Sciences, Public Heath & Territorial Intelligence. 2017;1(2): 47-59.
3. Kouassi AM, Assoko AVS, Kouakou KE. Hydrological characterization of the Marahoué watershed (Bandama, Ivory Coast). International Journal of Innovation and Applied Studies. 2021;34 (1): 91-101. Available:http://www.ijias.issr-journals.org
4. Koudou A, Brou E, Niamke K, Adjiri A, Sombo P, Niangoran KC. Productivity analysis and pollution vulnerability estimation for the optimization of boreholes implementation in the hard rock aquifers of N'zi watershed (Ivory Coast). Bulletin de l'Institut Scientifique, Rabat, Section Sciences de la Terre. 2016;n°38:149-164.
5. Kouassi AM, Kouamé KF, Goula BTA, Lasm T, Paturel JE, Biémi J. Influence of climate variability and on the rainfall-runoff relationship from a global rainfall-flow relationship based on a global modeling of the N'zi (Bandama) watershed in Ivory Coast. Ivorian Journal of Science and Technology. 2008;11:207-219.
6. Fayé C, Sow AA, N'Dong JB. Study of rainfall and hydrological droughts in tropical Africa: characterization and mapping of drought by indices in the upper Senegal River basin. Physio-Geo. 2015; 9: 17-35.
7. Kouao JM. Climatic variations and drought prediction by multiple linear regression of normalized precipitation indices: the case of Côte d'Ivoire (West Africa). Doctoral thesis from the Institut National Polytechnique Félix Houphouët-Boigny, Yamoussoukro, Côte d'Ivoire. 2022;215.
8. Gnangouin YJA, Kouassi AM, Diarrassouba D. Climatic prospective analysis in a context of climate change: Case of the N'zi watershed (Bandama, Ivory Coast). International Journal of Water and Environmental Sciences and Technology. 2022a;4:1-15.
9. Bard A, Renard B, Lang M. Trends observed on the hydrological regimes of the Alpine arc. La Houille Blanche, International Water Review. 2012;1:38-43.
10. Milano M. Global changes in the Mediterranean: Impacts on water stress and capacity to meet water demands. Thesis to obtain the degree of doctor of the University of Montpellier II /Discipline: Continental Waters & Societies Doctoral School: Integrated Systems in Biology, Agronomy, Geosciences, Hydro sciences, Environment (SIBAGHE). 2012;258.
11. Milano M, Ruelland D, Fernandez S. Current state of Mediterranean water resources and future trends under climatic and anthropogenic changes. Hydrological Sciences Journal. 2013b;58(3) : 1-21.
12. Collet L. Capacity to meet water demand under climatic and anthropogenic constraints in a Mediterranean basin. Thesis prepared within the doctoral school Systèmes Intégrés en Biologie, Agronomie, Géosciences, Hydro sciences, Environnement (SIBAGHE) and the research unit Hydro Sciences Montpellier Spécialité: Eaux Continentales & Sociétés the University of Montpellier II. Collège Doctoral de Languedoc-Roussillon. 2013;270.
13. Zoungrana D. Drinking water supply course (AEP). International Institute of Water and Environmental Engineering (2iE). Fascicule de Cours. 2003;136.
14. Benzannache N. Course of drinking water supply of licence in hydraulics. Université 8 Mai 1945 de Guelma Faculté des Sciences et de la Technologie Département de Génie Civil & Hydraulique. Algeria. 2021;68.
15. McFarlane D, Stone R, Martens S, Thomas J, Silberstein R, Ali R, Hodgson G. Climate change impacts on water yields and demands in southwestern Australia. J. Hydrol. 2012;475:488-498.
16. Office National de l'Eau Potable (ONEP). Guide de conception et de dimensionnement des ouvrages en hydraulique humaine. Service Planification et Etudes, Technical report. 2015;22.
17. Kouassi AM, Koffi YB, Nassa RAK, Kouamé KF, BIEMI J. Seasonal prediction of low water flows within West African river basins: the case of the N'zi-Bandama watershed (Ivory Coast). Rev. Ivoir. Sci. Technol. 2018;32: 153-171.
18. Kouassi AM, Gnangouin AYJ, Kouame KA, Yao CA, N'Guessan NE. Prospective analysis of low water flows in a context of climate change in West Africa:

Case of the N'zo watershed (Sassandra, West of Ivory Coast). Journal of new sciences, Agriculture and Biotechnology. 2022;88 (4):1-19.

19. Gnangouin YJA, Kouassi AM, Diarrassouba D, Kouao JM. Climate prospective analysis in a context of climate change: Case of the N'zi watershed (Bandama, Ivory Coast). Journal of new sciences, Agriculture and Biotechnology. 2022b;88(4):1-22.
20. Milano M, Ruelland D, Dezetter A. Assessing the capacity of water resources to meet current and future water demands over the Ebro catchment (Spain). In: Considering hydrological changein reservoir planning and management. IAHS Publ. 2013c;362: 199-206.

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