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Original article

Observed climate trends, perceived impacts and community adaptation practices in Côte d'Ivoire

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ABSTRACT

Climate change is a serious threat to local communities in West Africa. This study evaluated climatic trends and the perceptions of farmers to climate change in central Côte d'Ivoire. We surveyed 259 households across three agro-ecological zones. The knowledge of farmers about climate change was compared to observed trends of various climatic parameters from meteorological records (1973-2016). Results from trend analysis and descriptive analysis showed that the minimum, maximum and mean temperatures and rainfall showed a significant upward trend in all ecoregions. The average temperature and amount of rainfall increased by 3.2% (0.89°C) and 166.58% (645.5 mm) respectively over the 44 years. Local farmers perceived an increasing trend in temperature (all respondents) and a decreasing trend in rainfall (91.51%). Most of the respondents identified deforestation (76.83%), natural climate variation (50.97%) and wildfires (31.27%) as the main causes of these climatic disturbances, which induced plant dieback (92.66%), poor crop growth (59.46%) and crop loss (20.46%). The impacts on people and their assets encompassed a decrease in household income (63.71%), demolition of roofs (44..4%) and walls (43.91%) of houses, the scarcity of water points (39.38%) and the emergence of new diseases (30.89%). These climatic disturbances resulted in specific endogenous on-farm and off-farm strategies to adapt to the impacts of observed changes on their livelihoods.

KEY WORDS: climate change, local perception, coping strategies, rural livelihoods, smallholder agriculture, N'Zi River Watershed

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1. Introduction

Climate change is the major and perhaps the most critical of all environmental challenges facing societies in the current century. The global average surface temperature increased by +1.09°C over the last century, with the hottest temperatures ever recorded in the last three decades (IPCC, 2022). Besides, the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) indicated that under a business as usual scenario, West African countries will experience a 1.7°C increase in temperature by 2050 with no significant increase in rainfall and a marked reduction in suitable cultivation area (IPCC, 2022; LÄDERACH ET AL., 2013).

Across tropical West Africa, climate change has already led to warmer temperatures, extended periods of drought, loss of soil fertility and shorter growing seasons (FAO ET AL., 2018). This threat has also undermined crop production with extreme climate events and amplified the occurrence of risky natural phenomena such as floods and wildfires (IPCC, 2022). Consequently, climate change, by compromising household food and income security, is expected to cause major economic losses and hunger for more than 70% of households (BUNN ET AL., 2019; FAO ET AL., 2018; LÄDERACH ET AL., 2013).

In Côte d'Ivoire, the increase in temperature and reduction in rainfall have had severe impacts on major cash crops such as cocoa, coffee, rubber, palm oil and cashews (FAO ET AL., 2018; LÄDERACH ET AL., 2013). These tree crops also face several challenges including soil erosion (KASSIN ET AL., 2012), land tenure insecurity (CHAUVEAU, 2000), weather variability and climate change (FAO ET AL., 2018; LÄDERACH ET AL., 2013). Tree crops mostly prosper in rainforests with fairly uniform temperatures, high humidity, abundant rain, nitrogen-rich soil, and protection from wind (WOOD & LASS, 2001). The economy of this country is largely dependent on these crops for export and local livelihoods, accounting for 21.2% of Gross Domestic Product and 47% of total exports (DSDI, 2016; FAO ET AL., 2018).

In recent decades, changes in climate and ecological conditions that have occurred at the national scale have led to low crop productivity and triggered massive deforestation. The forest cover has declined from about 7.9 million hectares in 1990 to 3.4 million hectares in 2015 (BNETD, 2016; FAO & SEP-REDD+, 2017). This deforestation affected rural people by exacerbating poverty and food insecurity (GERBER ET AL., 2014; KOUASSI ET AL., 2021a).

As smallholder farmers rely heavily on agricultural production, they are likely to suffer unstable income and food supplies due to increased input prices caused by the high demand and tensions on fossil fuel energy and phosphorus markets (BRUNELLE ET AL., 2015). Local communities have a lower capacity to adapt mainly because of economic reasons including the means of implementation and better scaling up of resources. Nevertheless, they try to respond to the changing climate via different indigenous coping and adaptation mechanisms (YÉO ET AL., 2016).

While several studies have been conducted on the impacts of climate change on the livelihood of smallholder farmers, they are generally based on the characterization of long-term trends in key climate indicators and their variability in relation to a reference period (BIGOT ET AL., 2005; KANOHIN ET AL., 2012; YÉO ET AL., 2016). Some scientists have disapproved of these climate observations often made by non-scientists (DE LONGUEVILLE ET AL., 2020). They argued that farmers' perceptions of climate regimes and variability can add valuable information to these conventional weather statistics (DE LONGUEVILLE ET AL., 2020).

With the climate projections showing continuous deterioration of the climate and regarding requirements of developing sustainable landscape management strategies, it is important to understand the perceptions of local people of the changes they have experienced in their environment coupled with historical meteorological comparisons, its effects on their livelihoods and strategies to be adopted.

This study aimed to analyze the understanding of farmers' perceptions of climate change and the strategies developed by local farmers to adapt to this threat in three ecoregions of Côte d'Ivoire. Especially, the study (i) assessed local farmers' perception towards variability in temperature and rainfall patterns from 1973-2016, (ii) verified the farmers' perceptions by analyzing 44-year-meteorological data, (iii) assessed the impacts of climate variability-induced shocks on farmers' livelihoods and the environment and (iv) identified ongoing adaptation strategies employed in response to the perceived variability in temperature and rainfall.

2. Materials and methods

2.1. Study area

The study was conducted in the N'Zi River Watershed (NRW) in central Côte d'Ivoire. This watershed is a tributary of the River Bandama and is located between 3°46′ W and 5°24′ W longitude and between 5°58′ N and 9°26′ N latitude. The altitude ranges between less than 100 meters above sea level (masl) in the south and more than 600 masl in the north (Fig. 1). The NRW covers an area of 35,309 km^2, nearly 11% of the national territory and straddles 80 subdistricts (KOUASSI ET AL., 2018). Mainly composed of rural communities (70.64%), the population of the NRW was estimated at 2.9 million inhabitants in 2014 with a population density of 81.2 inhabitants per km^2 (INS, 2014). The watershed spans the three major climatic regions of Côte d'Ivoire and is covered by forest ecosystems in the south, mosaic forest–savannah ecosystems so-called "V Baoulé" in the centre and savannah ecosystems in the north (GOULA ET AL., 2006; GUILLAUMET, 1971).

According to the Köppen-Geiger climate classification, the climate of the study area is of Aw type (warm and humid). In the forest zone, an equatorial transition climate (Guinean climate) with an annual rainfall between 1300 mm and 2400 mm can be found (GOULA ET AL., 2006). In this area, the vegetation is a dense moist forest with some remaining forests on the tops of hills and in the classified forests (GUILLAUMET, 1971). In the pre-forest zone, there is an attenuated equatorial transition climate (Baoulean climate). The annual rainfall ranges between 1500 mm and 2200 mm. The vegetation is characterized by a Guinean

forest–savannah mosaic, with forest patches along the river (GOULA ET AL., 2006). These two ecoregions have two dry seasons and two rainy seasons. In the Sudanian zone, the climate is characterized by a dry tropical transition climate (Sudano-Guinean climate) with two seasons (GOULA ET AL., 2006). The landscape is mainly composed of grasslands and wooded grasslands. In this phytogeographical region, the herbaceous cover, ranging in height from 20 cm to 1.5 m, is composed of species of Panicum and Pennisetum, which are regularly affected by wildfires (GUILLAUMET, 1971; KOUASSI ET Al., 2022).

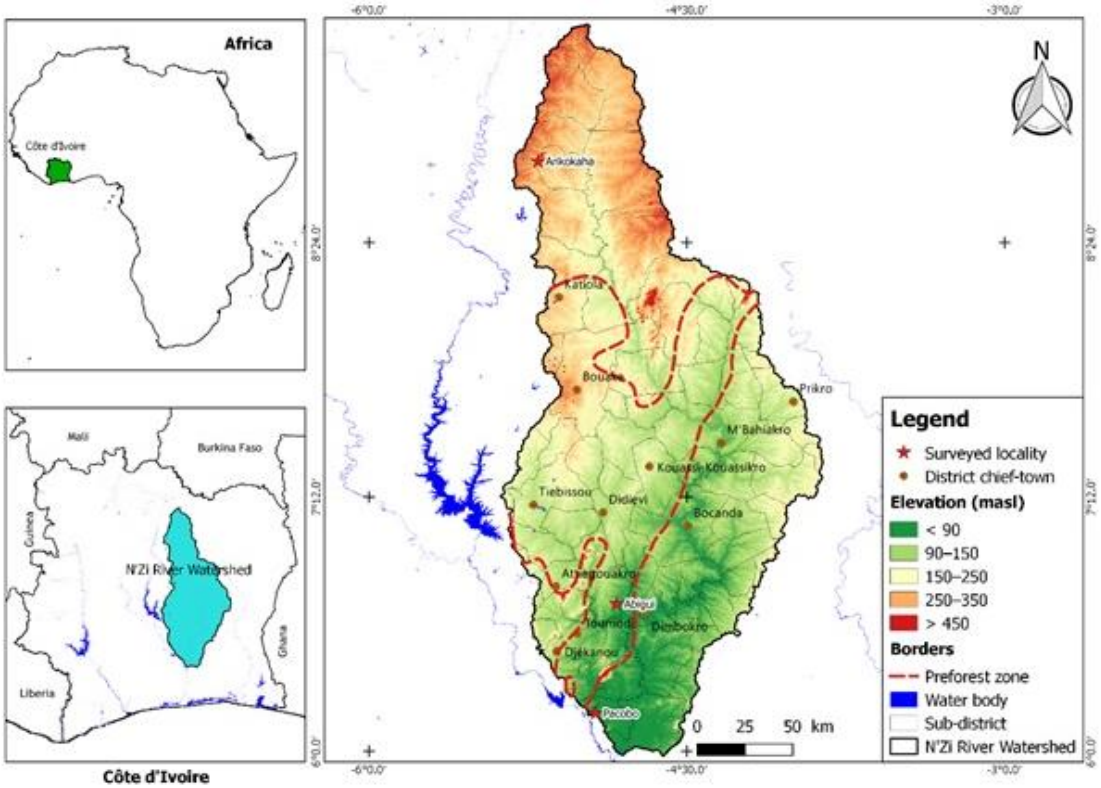


Fig. 1. Map of the N'Zi River Watershed

The region is drained by numerous permanent and highly eroded water streams and tributaries to the River N'Zi (PELTRE, 1977). The soils are moderately desaturated ferrallitic soils in the North and highly desaturated ferrallitic soils in the Centre and South (CPCS, 1967). However, hydromorphic soils can be found at the bottom of the slopes and in the lowlands and tropical ferruginous soils in savannah ecosystems. Agriculture dominates the economy of the watershed and employs two-thirds of the population (DSDI, 2016).

2.2. Data collection

2.2.1. Household survey

In this study, a stratified random sampling technique was used to select agricultural households. The stratification was made according to the phytogeographical location (ecoregion) and the administrative districts (sub-prefectures and localities). The stratification technique consisted of considering the three ecoregions (forest, pre-forest and Sudanian zones). For household data collection, the localities of Pacobo, Abigui and Arikokaha were purposively selected in the forest, pre-forest and Sudanian zones, respectively. In these three localities, about 790 households were identified (INS, 2014).

A total of 259 households were randomly selected and surveyed through the use of structured face-to-face interviews. This sample size was calculated using a simple random sample formula at the 95% confidence level with a ±5% margin of error (ROSS ET AL., 2002). Among the 259 surveyed farmers, 33.2% of them were in the forest zone, 32.82% in the pre-forest zone and 33.98% in the Sudanian zone.

Interviews were held with the heads of agricultural households in January 2017 and focused on climatic manifestations for the period 1973-2016 or since they were over 18 years. The questionnaire was designed after a review of the literature about farmers' perceptions of climate change and its impacts. The questionnaire included information on farmers' socio-economic profiles as well as their opinion of climate change manifestations. The questionnaire also provided insights on how climate change impacted crops, assets and livelihood

systems of farmers. Furthermore, the farmers were questioned about their perception of the causes of frequent climate change issues and their coping mechanisms for climate change manifestations and their adaptation measures. A pilot survey was conducted before the data collection to identify and revise unclear questions, ensure the suitability of the data collection tools and allow enumerators to familiarize themselves with the data collection process. Data were collected using the Open Data Kit (ODK) mobile data collection application (HARTUNG ET AL., 2010). The farmers' prior informed consent was obtained and the anonymity of the study was explained to the participants before they undertook the household survey.

2.2.2. Climate data

In order to assess the impact of climate change on agriculture and local assets, the 44-year daily climate data (precipitation, temperature, wind speed and relative humidity) ranging from 1973–2016 from all the five meteorological stations within the study area were obtained from the online NOAA National Climatic Data Center (NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION, 2017). Data were then pooled and mean values computed to evaluate long-term trends in climatic variables. In addition to meteorological variables, the Standardized Precipitation Index (SPI) was used to quantify the precipitation deficit, the intensity, duration and frequency of drought episodes in the different ecoregions of the study area. The negative (positive) values of the SPI indicate drought (wet) conditions. SPI values less than –0.99, comprised between –1.99 and –1.50, and less than –2 show moderate, severe and extreme droughts, respectively (SEILER ET AL., 2002). The rainfall and temperature anomalies were computed by differencing observed rainfall and temperature to their average over the baseline period (1980–1990).

2.3. Data analysis

In this study, both descriptive statistics and Mann-Kendall trend analysis were applied for the data analysis. The non-parametric Mann–Kendall test was used to identify the trend for essential climate variables (temperature, rainfall, wind speed, etc.) between 1973 and 2016 (KENDALL, 1970; MANN, 1945). The Sen's slope estimator was applied to estimate the magnitude of the trend (SEN, 1968). An upward trend is indicated by a positive Z value, while a downward trend is shown by a negative Z value. The trend analysis was computed using the package trend (POHLERT, 2015) of R statistical software (R CORE TEAM, 2019).

For household data, basic descriptive statistics, such as mean, frequency and percentage were used to provide insights into farmers' perception of climate change. The significance of differences between the perceptions of climate pattern changes, causes, impacts and coping strategies against climate change was assessed using the Kruskal-Wallis test for quantitative variables, differentiated with Bonferroni adjustment used as a post hoc test and Pearson chi-squared test for qualitative variables at a 95% confidence interval.

These analyses were carried out using the package questionr (BARNIER ET AL., 2017), and stats of the R statistical software (R CORE TEAM, 2019).

3. Results

3.1. Recorded climate trends

The results of the Mann-Kendall test applied to the essential climatic variables for the period 1973-2016 are presented in Table 1. The Mann-Kendall test showed a significant increasing trend at the 5% level (test Z> 0) within the minimum (MIN), maximum (MAX) and mean (TM) temperatures in all the ecoregions, except for the minimum and maximum temperatures of the forest and Sudanian zones. For rainfall, the results showed a significant upward trend in all the ecoregions of the NRW. The relative humidity (RH) showed a significant decreasing trend in the forest and Sudanian zones while a non-significant uptrend was detected in the pre-forest zone. Across the NRW, the relative humidity exhibited a significant uptrend. The average wind speed (WDSP) and maximum wind speed (MXSPD) showed a significant increasing trend in all ecoregions, except the forest zone which showed a statistically insignificant uptrend. The reference evapotranspiration (ETo) showed a significant upward trend over the NRW except for the Sudanian zone, which presented non-significant values at the 5% level. The Sen's slope suggested that the rainfall, reference evapo-transpiration and relative humidity increased at an annual rate of 5.68%, 5.28% and 0.43%, respectively in the whole NRW. The maximum, minimum and average temperature increased respectively at a rate of about 5.75%, 2.06% and 3.29% over the 44 years. Conversely, the wind speed decreased by 0.02% over the study period. Annually, the maximum, minimum, and average temperatures increased at rates of roughly 0.41%, 0.14%, and 0.28% per year, respectively, while wind speed dropped at a rate of 0.02% per year.

Table 1. Trends in climate series in the different ecoregions of the N'Zi River Watershed

Climate variables	Ecoregions						N'Zi River Watershed	
	Forest zone		Pre-forest zone		Sudanian zone			
	Sen's slope	Test Z	Sen's slope	Test Z	Sen's slope	Test Z	Sen's slope	Test Z
PRCP	8.40×10^{-2}	5.129***	4.22×10^{-2}	3.931***	0	2.475*	5.68×10^{-2}	4.289***
MAX	4.36×10^{-3}	7.631***	3.85×10^{-3}	6.353***	0	0.943ns	4.14×10^{-3}	6.778***
MIN	8.11×10^{-4}	3.417***	3.89×10^{-4}	1.088ns	5.49×10^{-4}	4.283***	1.39×10^{-3}	4.499***
TM	2.56×10^{-3}	7.115***	2.26×10^{-3}	5.738***	1.86×10^{-4}	3.185**	2.80×10^{-3}	7.095***
RH	-6.69×10^{-3}	−4.55***	1.23×10^{-3}	0.728ns	0	−2.43*	4.32×10^{-3}	2.112*
ETo	8.35×10^{-2}	8.092***	5.45×10^{-2}	4.921***	0	0.96ns	5.28×10^{-2}	5.647***
WDSP	5.51×10^{-5}	1.172ns	9.74×10^{-4}	14.9***	1.12×10^{-4}	4.607***	-1.98×10^{-4}	−2.33*
MXSPD	0	−0.34ns	3.34×10^{-3}	17.14***	9.32×10^{-5}	4.171***	2.64×10^{-5}	0.14ns

ns: not significant; * p <0.05; ** p <0.01; *** p <0.001; PRCP: Precipitation; MAX: Maximum temperature; MIN: Minimum temperature; TM: Average temperature; RH: Average relative humidity; ETo: Potential evapotranspiration; WDSP: Average wind speed; MXSPD: Maximum wind speed

The number of rainy days in the dataset showed an increase in all the ecoregions, with a rate of roughly 121.26% at the NRW level (Fig. 2). On average, the analysis of daily rainfall highlighted 69, 47 and 34 rainy days in the forest, pre-forest and Sudanian zones, respectively. The temperature and rainfall anomalies significantly increased by +0.36 °C and +5.2 mm from 1973 to 2016 (Fig. 3).

Overall, based on the SPI values, the study area experienced two dry periods (1973-1976 and 1992-2008) and two wet periods (1977-1991 and 2009-2016) (Fig. 4). In the NRW, moderate drought was experienced in 1973, 2000 and 2001, severe drought in 1976, and extreme drought in 1975 and 1999. The magnitude of the extreme drought of 1975 and 1999 was almost similar in all the ecoregions. Spatially, drought was mostly observed in the forest and preforest zones. The average drought conditions based on the SPI showed that the forest zone (β_r = 0.04, R = 0.48, p < 0.05), pre-forest zone (β_r = 0.03, R = 0.38, p = 0.01) and the whole NRW (β_r= 0.03, R = 0.40, p < 0.05) were significantly trending upwards, while the Sudanian zone showed a non-significant upward trend.

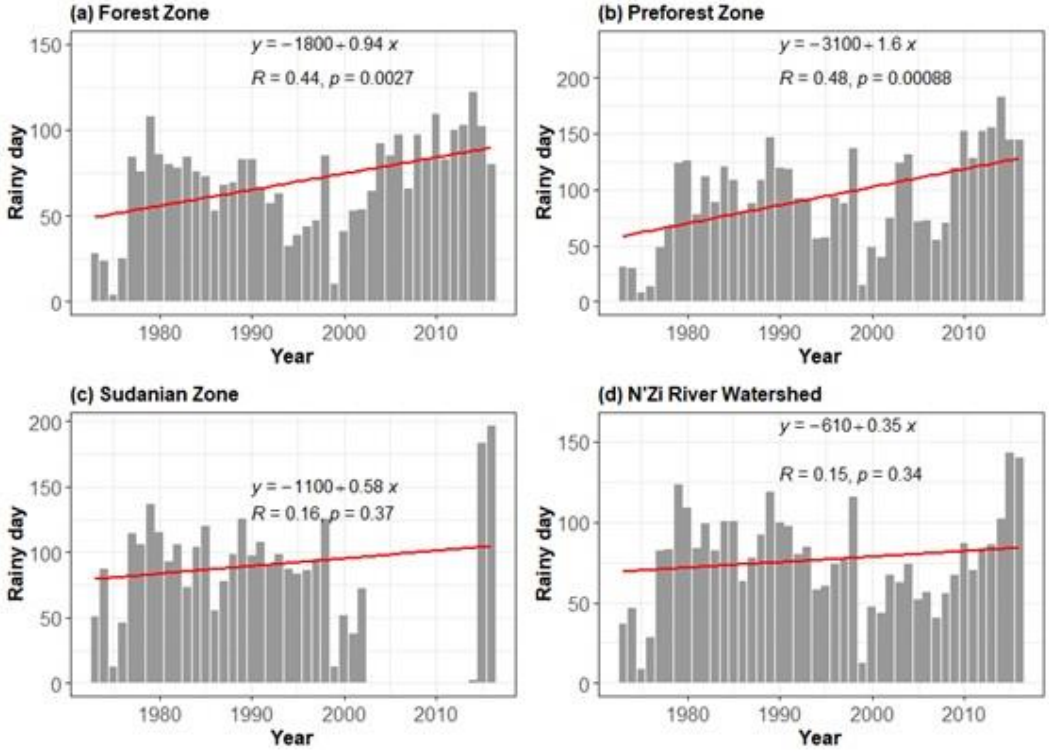


Fig. 2. Number of rainy days over the three ecoregions of the N'Zi River Watershed

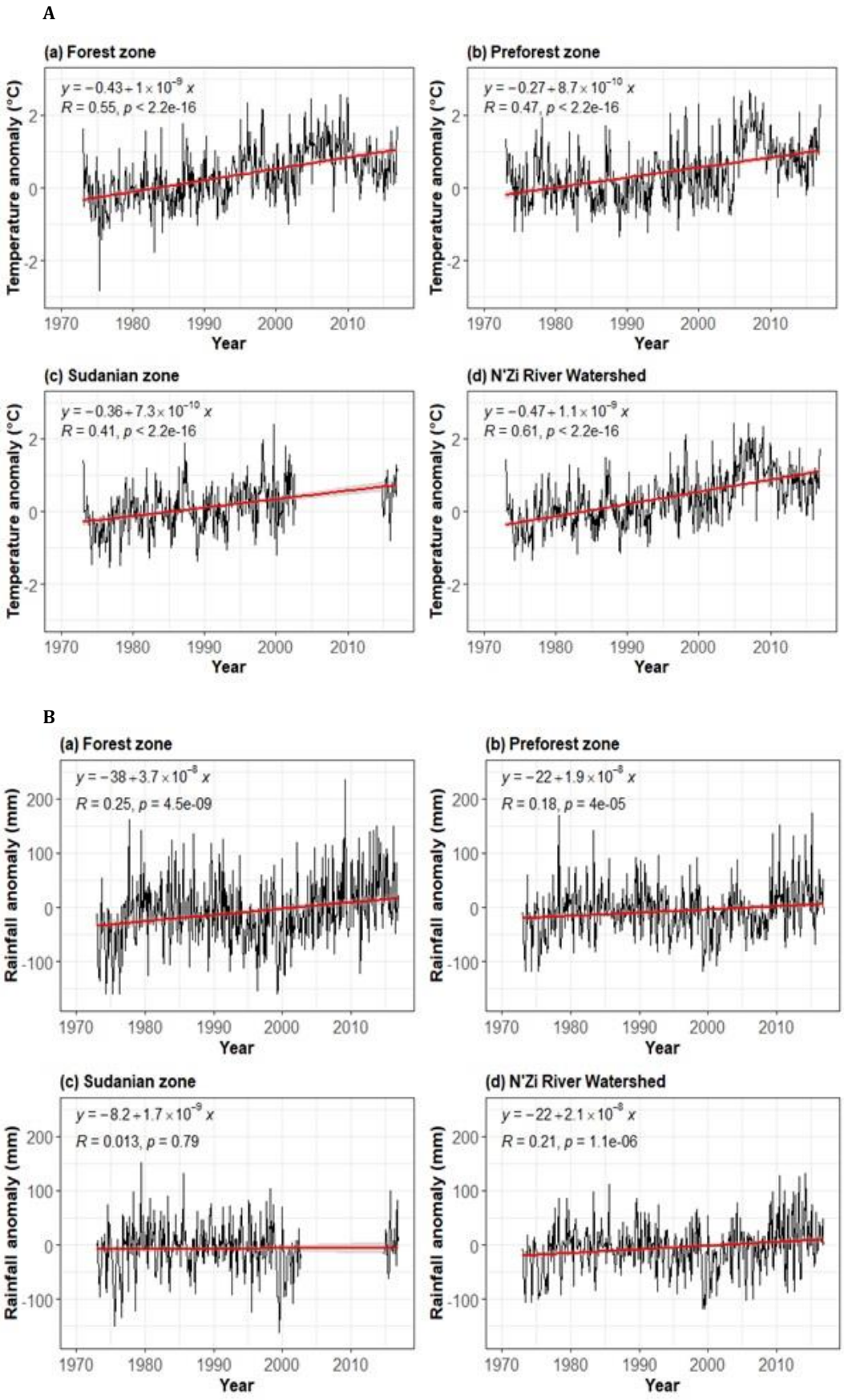


Fig. 3. Monthly temperature (A) and rainfall (B) anomalies over the three ecoregions of the N'Zi River Watershed. Anomalies are the departures from the 1980–1990 standard averaging period.

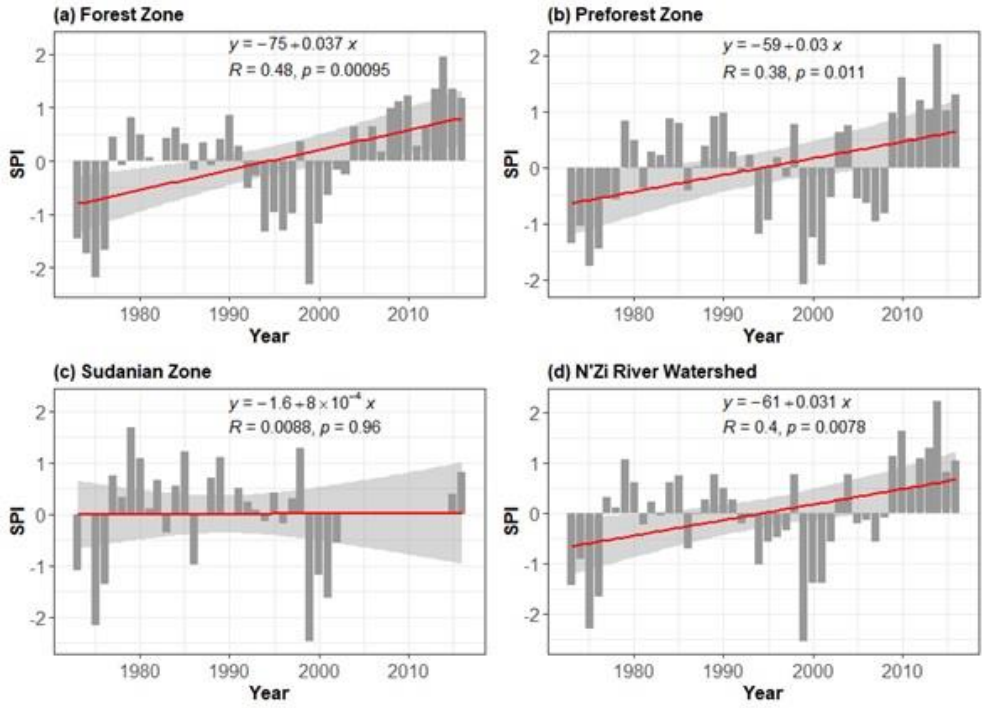


Fig. 4. Annual variation of the Standardized Precipitation Index (SPI) in the three different ecoregions of the NRW in central Côte d'Ivoire

3.2. Perceived climate change

3.2.1. Sociodemographic and socioeconomic characteristics of households

Most respondents (81.85%) were men of about 48 years old (Table 2). As a result, the surveyed farmers were mostly adults (71.88%) and married (82.63%). These farmers were mainly natives (88.8%), literate (56.37%) and Christian (52.9%) growing mostly cash and food crops for economical purposes and their household subsistence, respectively. The mean farm size was 6.22 hectares with about 4.25 hectares for cash crops and 1.96 hectares for food crops.

Table 2. Socio-demographic characteristics of the sampled household in the N'Zi River Watershed (n = 259)

Household attributes	Ecoregions			N'Zi River Watershed	p-value
	Forest zone	Pre-forest zone	Sudanian zone		
Household proportion (%)	33.2	32.82	33.98	100	–
Mean respondent age (years old)	44.73b	52.14a	46.94b	47.89	p < 0.05
Gender (male, %)	91.86	68.24	85.23	81.85	p < 0.05
Marital status (married, %)	82.56	97.65	68.18	82.63	p < 0.05
Education status (literate, %)	40	56.83	72.09	56.37	p < 0.05
Religion (Christians, %)	70.93	28.24	59.09	52.9	p < 0.05
Migration status (migrant, %)	27.91	3.53	2.27	11.20	p < 0.05
Duration of residence (years)	24.15b	39.27a	35.06a	32.72	p < 0.05
Occupation (farmer, %)	100	100	100	100	–
Mean household size (no.)	4.91b	7.29a	5.64b	5.94	p < 0.05
Cultivated crops (no.)	2.41c	3.55a	2.99b	2.98	p < 0.05
Farm size (hectares)	4.07c	7.52a	7.06b	6.22	p < 0.05

Means within a column with the same letter are not significantly different from each other at the 5% level

3.2.2. Perception of climate change

The perception of farmers of the evolution of climate patterns in the study area over the last four decades is presented in Table 3. Most farmers (98.07%) perceived that the start of the rainy season in these ecoregions was very late. Besides, more than 98% of the farmers argued that the duration of the rainy season is reduced compared to previous years and the number of rainy days had decreased. In addition, 99.61% of the respondents highlighted that the early start of the dry season reduced the duration of the rainy season. With a longer duration of the dry season (98.84% of responses), most of the respondents were unanimous on the increase in the intensity of pockets of heat and drought. Most of the farmers (91.51%) experienced a decrease in the amount of rainfall in the landscape.

The Chi-squared test showed a significant difference between ecoregions and farmers' perception of the start and duration of the rainy season and the change in the amount of rainfall. The perceptions of the causes of climate change are presented in Table 4. The farmers stated that the main causes of climate change observed in past decades were excessive deforestation (76.83%), natural variations in climate (50.93%) and wildfires (31.27%). Only 11.3% of farmers attributed the causes of climate deterioration to non-compliance with local norms and beliefs. In addition, about 10% of farmers indicated that the observed climate change was a divine will.

Table 3. Perceptions of farmers on changes in climate patterns

Perceptions attributes		Proportion (%)				Chi-squared test
		Forest zone	Pre-forest zone	Sudanian zone	N'Zi River Watershed+	
Beginning of the rainy season	Early	5.81	0	0	1.93	$p < 0.05$
	Late	94.19	100	100	98.07	
Duration of the rainy season	Shorter	96.51	100	100	98.84	$p < 0.05$
	Longer	3.49	0	0	1.16	
Number of rainy days	Increase	1.16	0	0	0.39	$p > 0.05$
	Decrease	98.84	100	96.59	98.46	
	No change	0	0	2.27	0.77	
	Do not know	0	0	1.14	0.39	
Rainfall amount	Increase	3.49	0	0	1.16	$p < 0.05$
	Decrease	96.51	98.82	79.55	91.51	
	No change	0	1.18	13.64	5.02	
	Do not know	0	0	6.82	2.32	
Start of the dry season	Early	100	98.82	100	99.61	$p > 0.05$
	Late	0	1.18	0	0.39	
Duration of the dry season	Shorter	1.16	1.18	0	0.77	$p > 0.05$
	Longer	98.84	98.82	100	99.23	
Heat intensity (temperature)	Increase	100	100	100	100	$p > 0.05$
	Decrease	0	0	0	0	
Existence of drought period	Increase	97.67	100	100	99.23	$p > 0.05$
	Decrease	2.33	0	0	0.77	
Flooding during the rainy season	Increase	1.16	0	0	0.39	$p < 0.05$
	Decrease	95.35	2.35	2.27	33.2	
	No change	2.33	64.71	18.18	28.19	
	Do not know	1.16	32.94	79.55	38.22	

Table 4. Perceptions of farmers about the causes of climate change in the study area

Perceived causes	Proportion (%)			
	Forest zone	Pre-forest zone	Sudanian zone	N'Zi River Watershed+
Abusive deforestation	74.42	92.94	63.64	76.83
Natural variations in climate	17.44	98.82	37.5	50.97
Wildfires	43.02	34.12	17.05	31.27
Non-compliance with social standards	32.56	0	1.14	11.2
God's will	27.91	0	2.27	10.04
Increase in cultivated areas	12.79	7.06	3.41	7.72
Non-respect of divinities	6.98	0	2.27	3.09
Transhumance	0	0	9.09	3.09
Do not know	1.16	0	15.91	5.79

+ represents the overall statistics of the three ecoregions of the watershed

3.2.3. Perceived impacts of climate change

The perceived impacts of climate change on crops are presented in Table 5. The results showed that the main impacts of climate change on crops were plant dieback (92.66%), poor crop growth (59.46%), harvest losses (20.46%), the death of some crop plants (13.13%), the scorching of crops (10.81%), and non-maturation of crops (10.04%). These observations negatively affected crop yields and food security.

The perceived impacts of climate change on humans and human settlements are shown in Table 6. The analysis of these results showed that the major perceived impacts of climate change on people and human settlements were mainly a decrease in household income (63.71%), the removal of house roofs (47.1%), the scarcity of water supply points (39.38%), the appearance of new diseases (30.89%), the remoteness of water supply sources (25.1%), poor water quality (22.01%) and the resurgence of certain diseases (16.22%). However, a small number of respondents (3.09%) noted an increase in household income.

Table 5. Perceived impacts of climate change on crops

Perceived impacts	Proportion (%)			
	Forest zone	Pre-forest zone	Sudanian zone	N'Zi River Watershed+
Plants dieback	88.37	95.29	94.32	92.66
Poor crop growth	52.33	89.41	37.5	59.46
Harvest losses	55.81	2.35	3.41	20.46
Death of crop plants	33.72	3.53	2.27	13.13
Scorching of crops	32.56	0	0	10.81
Immaturation of fruits and crops	9.3	8.24	12.5	10.04
Rotting of ears and fruits	10.47	0	1.14	3.86
Loss / dessication of seedlings and crops	9.3	1.18	0	3.47
Disruption of the agricultural calendar	9.3	1.18	0	3.47
Poor quality of harvested products	3.49	1.18	3.41	2.7
Breakage / destruction of stems and leaves	4.65	0	0	1.54
Attack by insects (caterpillars, termites, etc.)	4.65	0	0	1.54
Appearance of certain diseases	2.33	0	1.14	1.16
Lodging of crops	1.16	0	0	0.39
Storage losses	1.16	0	0	0.39

+ represents the overall statistics of the three ecoregions of the watershed

Table 6. Perceived impacts of climate change on people and their settlements

Perceived impacts on human	Proportion (%)			
	Forest zone	Pre-forest zone	Sudanian zone	N'Zi River Watershed
Decrease in household income	98.84	94.12	0	63.71
Removal of house roofs	95.35	21.18	25	47.1
Scarcity of water points	67.44	1.18	48.86	39.38
Emergence of new diseases	4.65	32.94	54.55	30.89
Remoteness of water supply sources	60.47	2.35	12.5	25.1
Poor water quality	59.3	0	6.82	22.01
Resurgence of certain diseases	26.74	14.12	7.95	16.22
Do not know	1.16	1.18	7.95	3.47
Increase in household income	0	2.35	6.82	3.09
Demolishing the walls of houses	5.81	1.18	1.14	2.7

3.2.4. Adaptation strategies

In a changing climate, farmers adopted adaptation strategies based on the perceived climate impacts on crops (Table 7). The adaptation strategies adopted to cope with the death of young plants included the resumption of sowing and planting of crops (96.94%), the uprooting of impacted plants (6.56%) and crop diversification (4.25%). Indeed, by growing several plant species on the same farm (diversification), some crops could benefit others by providing various services (shade, fertilization, pest control, etc.). Also, this practice minimized the risk of a bad harvest, a situation that could be disastrous in the case of monocropping.

The surveyed farmers who observed scorching of crops, such as cereals (rice, corn, etc.) and vegetables (tomatoes, etc.), testified that they did nothing to respond to these negative impacts (90.7% in the forest zone, 95.3% in the pre-forest zone and 88.6% in the Sudanian zone). On the other hand, they stated that they used phytosanitary products (57.9%) or confided in God (42.5%) to help them fight against crop loss.

Besides, poor crop growth inevitably led to the resumption of sowing, or planting, according to 48.65% of the interviewees. For the non-maturity of crops, 44% of the respondents indicated that they were not taking any action. Others, on the other hand, harvested very early at the start of the crop ripening process (19.7%) or they practice crop diversification and association (19.3%).

Among the respondents who noted the rotting of ears and fruits, 56.8% (including 52.3% in the forest zone, 52.9% in the pre-forest zone and 64.8% in the Sudanian zone) stated that they did not take any action. To fight against losses recorded during the storage of agricultural products, the majority of the respondents (64.9%) claimed modifying their conservation practices by using granaries, racks, etc. or taking no action in coping with this constraint (32.8%).

In the NRW, local communities developed strategies to adapt to the effects of climate change on them and their habitat (Table 8). The respondents reinforced the construction materials and the supports of their buildings to fight against the strong winds and the torrential rains that caused the removal of their house roofs (44.4%) and the demolition of the walls of their houses (43.91%). Moreover, 24.77% of the farmers created drains to prevent the demolition of their walls or damage to their house foundations. More than 19% of respondents claimed to go to the hospital regularly or to use traditional medicine to cope with the onset and recurrence of diseases (typhoid fever, malaria, diarrhoea, etc.). Against water scarcity, the respondents in the Sudanian zone claimed to collect water early in the morning at the pump or backwater (23.9%) or to collect water elsewhere by motorbike or bicycle in containers (19.3%). In addition, a small share of the respondents (8.1%) stated that they built water retention facilities. Also, farmers admitted to not taking any action about the decrease in household income (27.03%) and poor water quality (30.79%) observed in the study area.

Table 7. Adaptation strategies developed against perceived climate change impacts on crops

Perceived impacts	Adopted strategies	Proportion (%)			
		Forest zone	Pre-forest zone	Sudanian zone	N'Zi River Watershed+
Death of young plants	Resume sowing and planting	97.67	97.65	95.45	96.94
	Dig up dead plants	18.6	1.18	0	6.56
	Practice crop diversification and association	0	7.06	5.68	4.25
Poor crop growth	Resume sowing and planting	6.98	91.76	47.73	48.65
	No action	75.58	0	14.77	30.12
	Practice crop association and agroforestry	0	9.41	26.14	11.97
	Apply chemical fertilizer	15.12	0	3.41	6.18
Harvest losses	Use phytosanitary products	84.88	63.53	26.14	57.92
	Surrender to God through prayers	0	52.94	73.86	42.47
	No action	89.53	14.12	20.45	41.31
Scorching of crops	No action	90.7	95.29	88.64	91.51
Non-maturation of crops	No action	94.19	5.88	31.82	44.02
	Harvest as soon as ripening begins	3.49	56.47	0	19.69
	Practice crop diversification and association	0	17.65	39.77	19.31
Storage loss	Change conservation practices for agricultural products	5.81	98.82	89.77	64.86
	No action	94.19	0	4.55	32.82
Rotting of ears and fruits	No action	52.33	52.94	64.77	56.76
	Harvest impacted ears and fruits	27.91	4.71	11.36	14.67
	Destroy diseased crops	0	21.18	12.5	11.2

+ represents the overall statistics of the three ecoregions of the watershed

Table 8. Adaptation strategies developed against the perceived impacts of climate change on humans and their habitat

Perceived impacts	Adopted strategies	Proportion (%)			
		Forest zone	Pre-forest zone	Sudanian zone	N'Zi River Watershed+
Removal of house roofs	Reinforce construction materials and building supports	98.84	16.47	18.18	44.4
Demolishing house walls	Reinforce construction materials and building supports	90.31	19.63	21.8	43.91
	Make drains	45.63	12.37	16.32	24.77
Emergence of new diseases	Getting to the hospital	0	22.35	19.32	13.9
	Cure oneself using traditional medicine	0	11.76	7.95	6.56
Resurgence of certain diseases	Getting to the hospital	23.12	29.21	15.69	22.67
	Cure oneself using traditional medicine	12.47	13.68	9.32	11.82
Scarcity and distance from water points	Fetch water elsewhere using containers by motorbike or bicycle	0	0	19.32	6.56
	Collect water early in the morning at the pump or backwater	0	0	23.86	8.11
	Build water retention facilities	0	0	2.27	0.77
Decrease in income	No action	0	52.94	28.41	27.03
	Other	1.16	15.29	7.95	8.11
Poor water quality	No action	16.42	56.3	19.67	30.79

3.3. Comparison between perceived and recorded changes

Our results showed a strong agreement between NRW farmers' perceptions of changes in temperature and recorded trends in the average temperature gathered from meteorological data during the period 1973-2016 (Table 9). Also, farmers' perceptions about drought spell trends in the landscape matched with the drought index trends from climate observations. Conversely, inconsistencies were noted between the perceptions of respondents about the rainfall change and calculated rainfall trends in all the ecoregions. The same inconsistencies were observed with the number of rainy days.

Table 9. Comparison between recorded and perceived change in climate variables in the N'Zi River Watershed from 1973–2016

Climate variables	Comparison	Proportion (%)				Chi-squared test
		Forest zone	Pre-forest zone	Sudanian zone	N'Zi River Watershed+	
Rainfall amount	Good fit	3.49	0	0	1.16	$p < 0.05$
	Bad fit	96.51	100	100	98.84	
Number of rainy days	Good fit	1.16	0	0	0.39	$p > 0.05$
	Bad fit	98.84	100	100	99.61	
Temperature	Good fit	100	100	100	100	$p > 0.05$
	Bad fit	0	0	0	0	
Drought spells	Good fit	97.67	100	100	99.23	$p > 0.05$
	Bad fit	2.33	0	0	0.77	

+ represents the overall statistics of the three ecoregions of the watershed

4. Discussion

The findings of this research revealed that the study area was subjected to climate variability during the period between 1973 and 2016. However, the intensity of the variation was not uniform over the whole area of the NRW given the influence of local climates (equatorial climate in the South, subtropical climate in the North and an equatorial transition climate in the centre of the NRW).

Temperatures significantly increased during the study period. Across the NRW, average temperatures increased by around 3.29% (0.89°C) over the period 1990-2016. This increase could be explained by the global changes underway since the end of the 19th century (IPCC, 2022). The results of the identified average temperature trends remained lower than those observed throughout Côte d'Ivoire by YAO ET AL. (2012) who noted an increase of 1.6°C in the average temperature at the national level over the period 1961-2010 (i.e. 0.03°C per year). However, this increasing temperature value of 0.89°C (i.e. 0.02°C per year) is consistent with the average increase of 1.09°C over the period 1900-2021 (i.e. 0.01°C per year) observed at the global level (IPCC, 2022) or of 0.18°C per decade over the period 1979-2010 (i.e. 0.02°C per year) recorded at the West African level (COLLINS, 2011). These temperature increases are particularly accentuated during years known as the El Niño years such as 1973, 1983, 1998 and 2016, globally recognized as the strongest (NULL, 2018; SARACHIK & CANE, 2010). These temperature increases negatively impact agriculture and lead to the occurrence of environmental disasters such as wildfires (KOUASSI ET AL., 2018; 2022).

The relative humidity increased in the forest zone, Sudanian zone and the whole NRW, but it decreased in the pre-forest zone. These results could be explained by the increase in rainfall patterns identified in these ecoregions. YAO ET AL. (2012) noted an increase in relative humidity from 1960 to 2010 in the forest and Sudanian zones and a decrease in relative humidity in the pre-forest zone. KOUASSI ET AL. (2010) showed a steady decline in the relative humidity since 1973 at the NRW level.

Regarding rainfall, the results of this study showed an increasing trend in the forest and Sudanian zones and the whole NRW. Similar results were found in West Africa in recent studies (NICHOLSON ET AL., 2018a; 2018b). However, several studies about rainfall in Côte d'Ivoire and the NRW revealed a negative trend at the beginning of the 21st century (ASSEMIAN ET AL., 2013; GOULA ET AL., 2006, 2012). Occurring at a fine scale, rainfall variations in any location at a given time can be

determined by the climate features, biophysical conditions of the location as well as by the type and the number of rain gauges used for data collection, explaining differences between the findings of this study and past studies.

The year 1998 has been identified as the hottest year in the NRW over the period 1973-2016. Earlier observations showed that 1998 was the hottest year of the 20th century and with the highest ENSO resulting in an increase in average air temperature from 0.5°C to 1°C during the dry season of 1997-1998 in Africa (LEAN & RIND, 2009; LU, 2005). The extreme weather conditions could be a major factor in the occurrence of increasingly frequent bushfires nationwide.

The analysis of climate records showed that the NRW experienced erratic climatic conditions observed in recent decades, in particular the increase in temperature and the occurrence of significant droughts. Local perceptions of climate variability and change appear to corroborate meteorological observations and scientific literature in the study area.

The local farmers perceived climate change manifestations including the increase in temperature, the decrease in rainfall and the number of rainy days, the late start of the rainy season, etc., that occurred in their landscape. The main causes of these climatic events were mainly deforestation, logging, bush or natural fires. These observations are consistent with the analysis of climatic variables and confirm several studies that have been carried out on climate change and deforestation at the national (e.g. KOUASSI ET AL., 2021a; 2022; YAO ET AL., 2005) and regional (e.g. CODJOE ET AL., 2013; YAMBA ET AL., 2019) levels. However, perceptions of rainfall patterns seemed to contradict the rainfall data and vary depending on the ecoregion. This inconsistency could be due to a great variability marked by "false starts of rainy seasons", the decrease in the number of rainy days and the recurrence of extreme rains (TA ET AL., 2016). These climatic events cause a change in the growing season and are harmful to sowing and plant growth. Moreover, this contradiction could provide more localized contexts of climate variability, insufficiently captured by the meteorological data used (BOMUHANGI ET AL., 2016). Perceptions of changes in the amount of rainfall do not match those of the populations of the surrounding surveyed localities (DOUMBIA & DEPIEU, 2013; YÉO ET AL., 2016). DE LONGUEVILLE ET AL. (2020) showed that other personal and environmental factors are important for determining climate change perceptions. Also, farmers consider rainfall as a process rather than as a quantity as they perceive a drier-than-normal rainy season as a season that would be shorter than usual rather than one that generated less rainfall (RONCOLI, 2006). Several authors demonstrated that farmers do not perceive climate trends in meteorological records although the climate affects agricultural activities (DE LONGUEVILLE ET AL., 2020; KOSMOWSKI ET AL., 2016). According to FOGUESATTO ET AL. (2020), perceptions of changing climate – regardless of their accuracy – are focused on the expected change in farmers' well-being and mental shortcuts experienced regarding the occurrence of events.

The perceived impacts of climate change on crops were multiple, including the death of young plants, poor crop growth, non-maturation of crops, death of standing crops, etc. These perceived impacts of climate change associated with environmental degradation led farmers to practice crop diversification (YÉO ET AL., 2016) and adopt new major climate-resilient crops such as cashew in the savannah regions (KOFFI & OURA, 2019; RUF ET AL., 2019). In the forest zone, banana-cocoa association and intercropping are used as a climate-smart practice (FAO ET AL., 2018). Also, agroforestry practices led to achieving mitigation and adaptation to climate change (KOUASSI ET AL., 2021b; MBOW ET AL., 2014) and enhanced yield (KOKO ET AL., 2013). Furthermore, they led to a lower income at the household level, the removal of house roofs and the upsurge of diseases such as malaria, dengue, tropical fever, etc. As a result, crop destruction which led to low yields, food shortage and communities' incomes declining, increased the cost of food and exacerbated food insecurity (YÉO ET AL., 2016). These results are consistent with the conclusions of several studies conducted in West Africa (e.g. BOISSIÈRE ET AL., 2013; MERTZ ET AL., 2011). Other authors have highlighted the recurrence of infectious (cholera) and vector-borne diseases (malaria, dengue, yellow fever, Burili ulcer, etc.) due to rising temperatures associated with heavy rainfall (CHRETIEN ET AL., 2015; MOORE ET AL., 2017; OMS ET AL., 2004).

Local communities employ various adaptation measures to respond to climate change. The main adaptation strategies adopted by the local communities included resuming sowing and replanting seedlings and plants. Also, they used crop diversification which has the advantage of compensating for the poor harvest of one crop with the harvest of another crop and reducing climate risks to household incomes (BUNN ET AL., 2019). Many crops are mixed and the common association for cash crops included cocoa-plantain, cocoa-cashew and cocoa-cashew-teak associations while food crop associations are composed of yams,

peanuts, taros, tomatoes, peppers and eggplants (YÉO ET AL., 2016).

Also, they apply chemical fertilizers such as NPK, KCl, etc. to increase the production of their farms. Several studies in the region showed the importance of fertilizers in enhancing yield (KOKO ET AL., 2011; SNOECK ET AL., 2012) and reducing the impact of diseases such as Cocoa Swollen Shoot Virus – CSSV (KOUADIO ET AL., 2017).

These strategies are consistent with current on-the-ground activities aimed at climate change adaptation, agricultural productivity, and hunger and poverty alleviation, such as the "Cutting-out and Replant" (CONSEIL CAFÉ-CACAO, 2017) and "Quantity, Quality and Growth" (CONSEIL CAFÉ-CACAO, 2014) programs, which attempt to rejuvenate degraded cocoa orchards by increasing soil health, combating CSSV disease, and planting improved seedlings and cocoa companion trees.

5. Conclusions

The current study assessed climate change manifestations, perceptions and coping strategies in the NRW. Our results outlined the precarious conditions of smallholder farmers in the NRW, their high exposure to climate risks and the urgent need to mitigate their current and future vulnerability to these risks. According to surveyed households, the rainfall pattern has become increasingly irregular, with shorter and lower amounts of rainfall, while the temperature of the growing season has increased. All of these changes, according to the sampled households, have serious implications for their farming operations and livelihoods. Temperature data from meteorological records verified these household views and perceptions of temperature trends, although there are some differences between the perceptions and scientific measurements of rainfall patterns. There are clear signs that climate change will have a significant impact on the livelihoods of smallholder households in the NRW. As a result, policymakers in this landscape should vigorously explore climate-smart agriculture and livelihood diversification options, including non-farm income sources. Policymakers must develop more precise and targeted climate adaptation policies in order to lessen the vulnerabilities of smallholder households, whose livelihoods rely heavily on rain-fed agriculture, to current and future climatic hazards.

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