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Climatic conditions and off-season crops in the municipality of Kozah 1 in northern Togo

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Abstract

Off-season farming activities in the urban commune of Kozah 1 depend on water availability and the varying effects of climatic conditions. The objective of this study is to analyze the climatic conditions under which off-season market gardening is carried out in the urban commune of Kozah 1 along the Kara River. Climatological data (temperature, precipitation, potential evapotranspiration, and relative humidity) collected from the Kara synoptic station over the period 1990–2024 were used to estimate available water resources. Similarly, socio-anthropological survey data collected from producers and direct field observations on market garden sites were used. The descriptive statistics method based on determining the SPI, hydroclimatic variation, climatic water balance and estimating the daily water requirements of market garden crops was applied. Results show that the evolution of climatic conditions, based on precipitation during the months of market gardening activities, reveals interannual rainfall variability characterized by a succession of weakly marked wet and dry years. The period from April to October accounts for 94.98% of annual rainfall, while the months from November to March known for off-season activities receive only about 5.01%. Meanwhile, maximum temperatures fluctuate between 29.4°C (May) and 36°C (January) and minimum temperatures vary from 19.1°C (July) to 23.3°C (December). Between November and June, relative humidity is low (38.94% to 65.32%), causing market garden beds to dry out and making plants vulnerable, resulting in wilting and leaf loss. This situation is exacerbated by insufficient irrigation due to lack of water in the Kara River bed and the drying up of surrounding natural water points. These findings were confirmed by 71% of respondents. Faced with this vulnerability, producers are developing adaptation options to limit the impacts.

Keywords: Climatic Conditions; Kozah 1 Commune; Market Gardening; Vulnerability; Climatic Water Balance

1. Introduction

Since the 1970s, changes in climatic parameters have been marked by rising temperatures and declining rainfall [1, 2]. Thus, agricultural production systems in developing countries, especially those in Sub-Saharan Africa due to their climate dependence [3, 4], are strongly influenced by the persistent changes in climatic conditions observed since the 1970s. In this context, there has been growing interest in studying climate and its instability [5]. The manifestations of this instability are marked primarily by reduced precipitation, shorter wet seasons, and recurring dry spells [6, 7]. This situation leads to the drying up of surface water points and many wells [8]. In this environment, water available for irrigating market garden beds decreases, resulting in crops' water needs not being met [9, 10]. This water deficit for crops is the greatest constraint, as it disrupts plant growth and reduces agricultural yields [11]. All these climatic constraints lead to socio-economic instability in most communities where economic activities, particularly agriculture, are highly climate-dependent [12].

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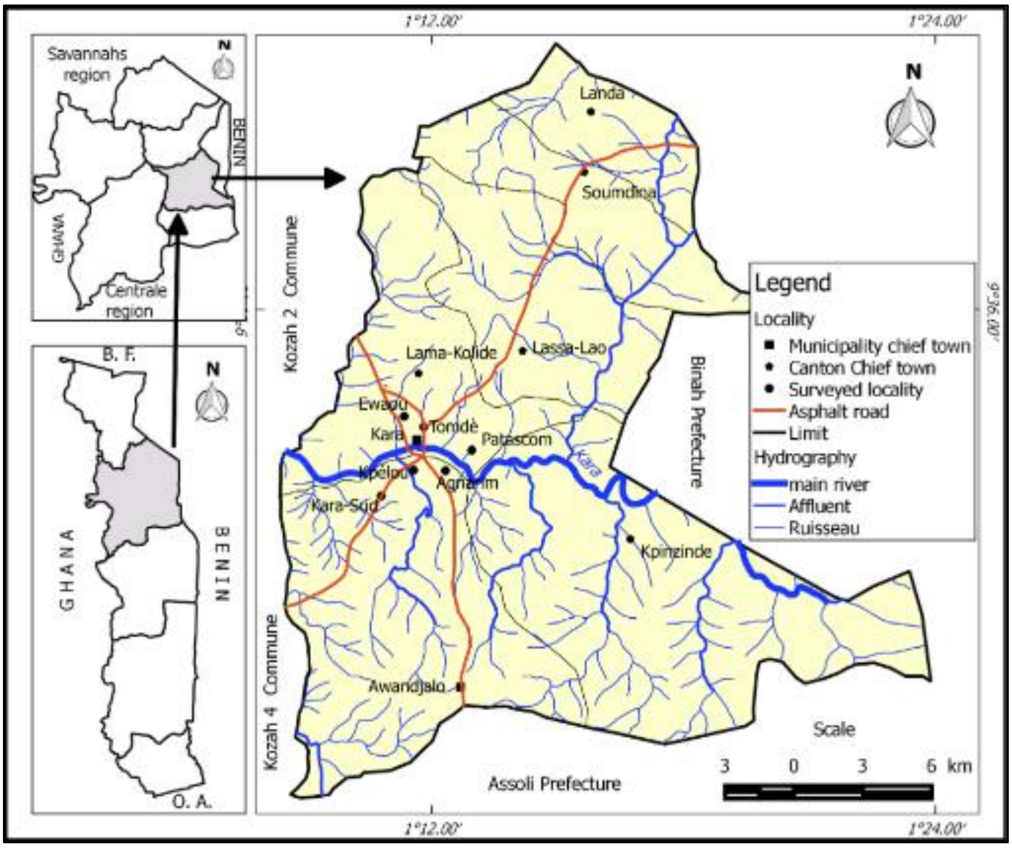
As in other West African countries, these climatic trends are similar in Togo [13, 14, 15], with considerable impacts on various farming systems. In this climatic context, yields of various agricultural productions in the Kara Region have declined, especially over recent decades [16]. These repercussions are evident in the Kara River valley through the vulnerability of off-season crops induced by water stress linked to changes in rainfall patterns with regular drying of the Kara River bed as well as temperature variations, increased evaporation and evapotranspiration and relative humidity. This agricultural activity during post-rainy periods, which provides a supplementary source of income to offset deficits in winter production, is declining. The objective of this study is to analyze the climatic conditions under which off-season crops are grown in the urban commune of Kozah 1, particularly along the Kara River.

2. Data and Methods

2.1. Study Area

The study area, the commune of Kozah 1, is located precisely between 9°24′ and 9°40′ North latitude and between 1°08′ and 1°24′ East longitude. It is bordered to the north and east by the prefecture of Binah, to the west by the communes of Kozah 2 and Kozah 4, and to the south by the prefecture of Assoli (Fig. 1).



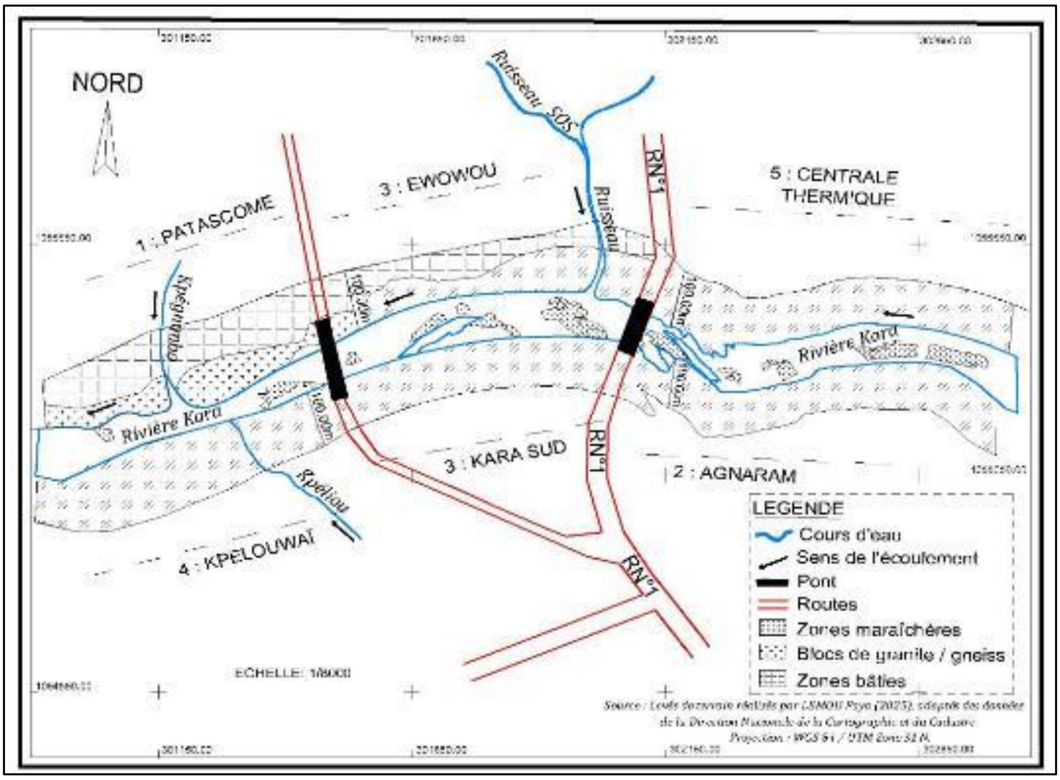
Source: Topographic maps of the Kara Regions

Figure 1 Location of the study area

The market gardening perimeter covered an area of 1.2 hectares according to estimates by [17]. However, due to its undeniable profitability, off-season market gardening now mobilizes an increasing number of young people and most agricultural stakeholders. Thus, given its importance especially monetary this geographic area today covers approximately 64 hectares 27 ares according to 100% of respondents. Climatically, the study area lies within the Sudano-Guinean tropical climate zone, marked by the alternation of a dry season and a wet season. However, due to the current disruption of the climate system, these seasons are consistently characterized by a shrinking of the rainy season, which, depending on the year, now extends over three or four months instead of the previous six. Under these conditions, agricultural stakeholders have opted to capitalize on the dry season by developing off-season market gardening, practiced mainly in the Kara valley (Figure 2).

This geographic area is primarily dominated by the Kara River and three of its tributaries: Kpiyinbo, Welou, and Feyinbo. Unlike the meridional flow direction (north–south) of most rivers in Togo, this watercourse flows southeast to northwest and crosses the study area over approximately 1,500 meters.

The market gardening perimeters of the urban commune of Kozah 1 are mainly located along the banks of the Kara River. These include the sites in the Patascom, Ewowou, and Tomdè or centrale thermique neighborhoods on the right bank and those of Kpelouwaï, Kara Sud, and Agnaram developed along the left bank (Fig. 2).



Source: Fieldwork, 2025

Figure 2 Market gardening perimeter of the study area

Analysis of the survey results reveals an uneven distribution of market gardeners along the Kara River. The lowest rates of market gardeners are observed in Patascom: 5.4%, EWAOU: 6.7%, and the Centrale Thermique sector: 17.3%. In contrast, in Agnarim, Kara Sud, and Kpélou, the rates are higher at 40.7%, 16%, and 14%, respectively, due to relatively favorable conditions marked by the nature of the bedrock, which allows for greater or lesser retention of natural water points.

2.2. Data

The data used are climate series (temperature, precipitation, potential evapotranspiration (PET), and relative humidity) from the Kara synoptic station covering the period 1990–2024. This time series was selected to better assess recent climatic manifestations and their effects on off-season market gardening in the commune of Kazah 1. Indeed, the premature drying up of watercourses in the Kara region is becoming increasingly alarming, hence the interest of this research in identifying options to sustain market gardening activities, a true source of supplementary income for the populations of the study area. Socio-anthropological survey data collected from producers and direct observation data from market garden sites in the commune of Kozah 1 were also used. The information collected mainly concerns the physical characteristics of market garden sites, production systems, market garden products, yields, and water sources used for irrigating market garden crops.

2.3. Method

2.3.1. Analysis of climatic variation

Climatic variation was analyzed through the seasonal pattern of precipitation and temperatures. The values of the Standardized Precipitation Index (SPI) for these two climatic parameters were determined after calculating the means and standard deviation using the following formula:

$$Z = \frac{Xi - M}{S}$$

Where:

- Xi: rainfall for year i;
- M: mean interannual rainfall over the reference period;
- S: standard deviation of interannual rainfall.

In addition, the hydroclimatic variation rate (Txh, in %) was determined using the index.

$$Txh = 100 \times \frac{\text{M2} - \text{M1}}{\text{M1}}$$

Where:

M1 and M2 represent the respective means of two periods, one older and one more recent.

To analyze the pattern of rainwater and even surface water availability, the climatic water balance was calculated. It makes it possible to highlight the months or periods of the year when rainwater is available in surplus (P – PET > 0) or in deficit (P – PET < 0), and is calculated using the following formula:

Bc = P – PET

Where:

- Bc = climatic water balance (in mm),
- P = precipitation (mm), and
- PET = potential evapotranspiration.

2.3.2. Estimation of crop water requirements

The estimation of the daily water requirement (DWR, in L/day) of a market garden crop is based on the formula:

$$DWR = PET \times Kc \times Sc$$

Where:

- PET is the potential evapotranspiration (mm);
- Kc is the crop coefficient;
- Sc is the cultivated surface (m^2).

Table 1 shows the crop coefficient (Kc) of the main market garden crops in the commune of Kozah 1.

Table 1 Crop coefficient (Kc) of the main market garden crops in the study area

Market garden crop	Crop coefficient (Kc)
Cabbage	0.9
Carrot	0.9
Lettuce	0.8
Okra	0.8
Tomato	0.9
Green pepper	0.8
Ademe	0.8
Gboma	0.9

Source: FAO (1998) www.fao.org/3/x0490f/x0490f00.htm

The data in Table 1 indicate a crop coefficient (Kc) of 0.8 for vegetables such as lettuce, green pepper, and cucumber, while others namely cabbage, carrot, tomato, and onion have a Kc equal to 0.9.

Note: There is a discrepancy with Table 1 above. The table lists okra, ademe, and gboma at Kc = 0.8/0.9, but does not include cucumber or onion. You may want to check and harmonize the list of crops with the Kc values from FAO.

2.3.3. Field investigation method

Surveys were conducted among market gardeners in the commune of Kozah 1 to gather their knowledge of climatic conditions and off-season crops. A random sample of 80 market gardeners, men and women, from the commune of Kozah 1 was interviewed. This made it possible to analyze vulnerability indicators and adaptation strategies of market garden crops to climate variability in the commune of Kozah 1. SPSS software was used to process the questionnaire and interview forms.

3. Results

3.1. Main climatic determinants of off-season market gardening in the commune of Kozah 1

Several climatic factors condition the proper conduct of off-season activities in the commune of Kozah 1. Among these production factors for non-wet season crops are: monthly rainfall variations, fluctuations in the rainfall regime, the climatic water balance of the study area, as well as temperature and humidity conditions.

3.1.1. Rainfall variation and off-season market garden production

Monthly rainfall makes it possible to assess whether or not water is available for market gardeners to irrigate off-season crop beds. Table 2 summarizes the monthly rainfall statistics from the Kara synoptic station for 1990–2024.

Table 2 Statistics of monthly rainfall amounts from 1990–2024

Month	1	2	3	4	5	6	7	8	9	10	11	12
Max	34.9	63.7	160.3	146	347	358	351.3	421.3	405.9	240.3	59.1	49.3
Min	0	0	0	0.6	59.6	51.1	158	216	169	24.8	0	0
Std dev	8.22	14.96	29.13	35.17	54.33	73.64	56.16	83.61	68.82	55.68	17.85	8.80
CV (%)	306.71	175.41	100.91	46.14	43.49	40.29	27.41	32.47	27.31	42.67	130.04	423.65
Range	38.4	63.7	160	145.4	287.4	306.9	193.3	205.3	236.9	215.5	59.1	49.3

Source: Statistical processing of ANAMET data, 2025

Analysis of the data in Table 2 shows that the monthly total varies widely over the 1990–2024 period. Maximum rainfall is recorded in June, July, August, and September; August and September being the wettest months in Kara, with 421.3 mm and 405.9 mm of rainfall respectively. However, despite these accumulated rains, the early drying of the riverbed is becoming increasingly evident. This is explained by climate disruption marked by a clear warming of the atmosphere. This situation accelerates the drying of the Kara River bed as well as natural water points around the valley.

Similarly, the data in Table 2 show that monthly rainfall varies from year to year at the station. Standard deviations range from 55 to 80 mm in the heart of the rainy season (July, August, and September). Conversely, apart from March with a value of 100.91%, the coefficients of variation of monthly rainfall are very high, with values exceeding 130% during the dry season. The range values from November to February, which are the periods of intense market gardening activity, are between 55 and 63 mm. All of these conditions reflect the extreme scarcity or even absence of precipitation during these months of off-season vegetable production.

Overall, the monthly values reflect global changes in rainfall distribution, especially their decrease at the beginning and end of the rainy seasons. Added to these changes is the increasingly evident shortening of wet seasons, as well as the appearance of long dry spells of 7 to 10 days in the middle of the rainy season, depending on the year. All of this leads to poor groundwater recharge in the study area, particularly in the bed of the Kara River. In this climatic context, water availability for off-season activities becomes critical.

According to 80% of the producers surveyed, under these conditions, vegetables most vulnerable to water stress such as cabbage, lettuce, and gboma dry out. This leads some gardeners to abandon their market garden plots. The rainfall regime of the study area makes it possible to assess the calendar of market gardening activities over the period considered.

3.1.2. Rainfall regime of the study area and off-season market garden production periods over 1990–2024

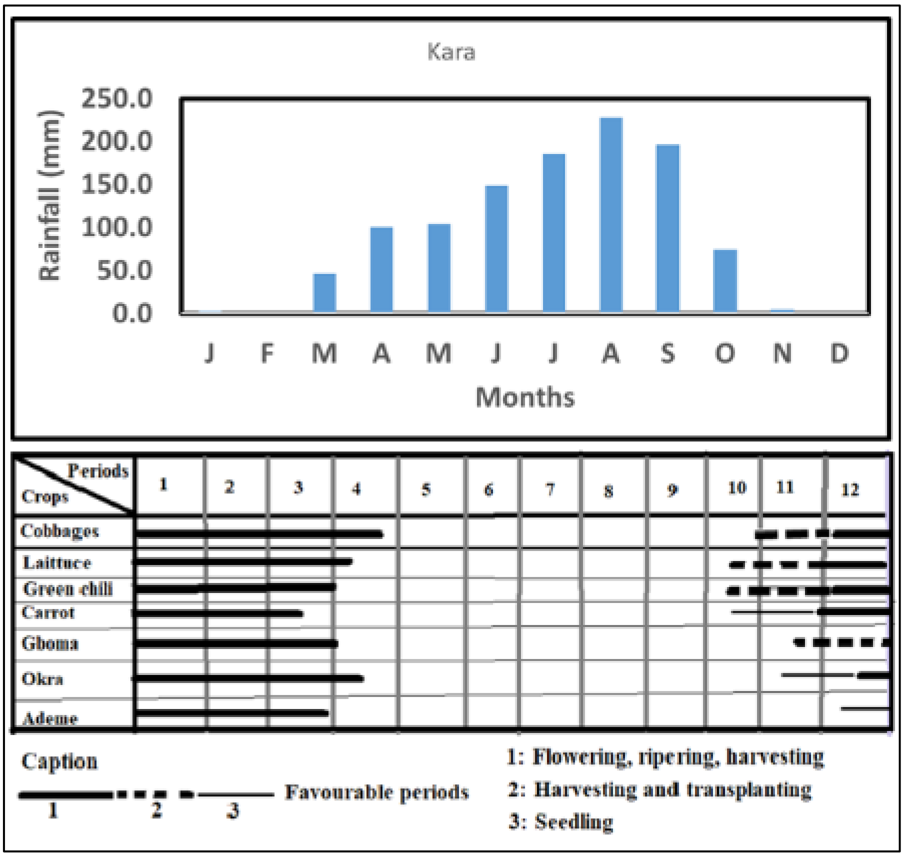


Figure 3 presents the monthly hydroclimatic regime from 1990 to 2024 for the Kara synoptic station and the calendar of off-season market gardening activities

Analysis of Figure 3 shows that off-season market gardening activities generally begin in the first ten days of November with the cleaning and preparation of market garden perimeters, followed by sowing and transplanting of the main vegetables such as cabbage (Brassica oleracea), lettuce (Lactuca sativa), green pepper, and carrot (Capsicum annuum or Capsicum frutescens). Gboma (Solanum) is sown and transplanted in December, and okra (Abelmoschus esculentus) is generally sown in the first and second five-day periods of December. For 98% of respondents, these periods are chosen based on climatic conditions favorable to the development of each vegetable. The good yield of these productions depends on water conditions namely, water availability and on their maintenance by market garden workers.

3.1.3. Climatic water balance and vulnerability of off-season market garden crops over the period 1990 to 2024

Water availability for off-season market gardening activities along the banks of the Kara River depends on rainfall inputs and losses due to actual evaporation.

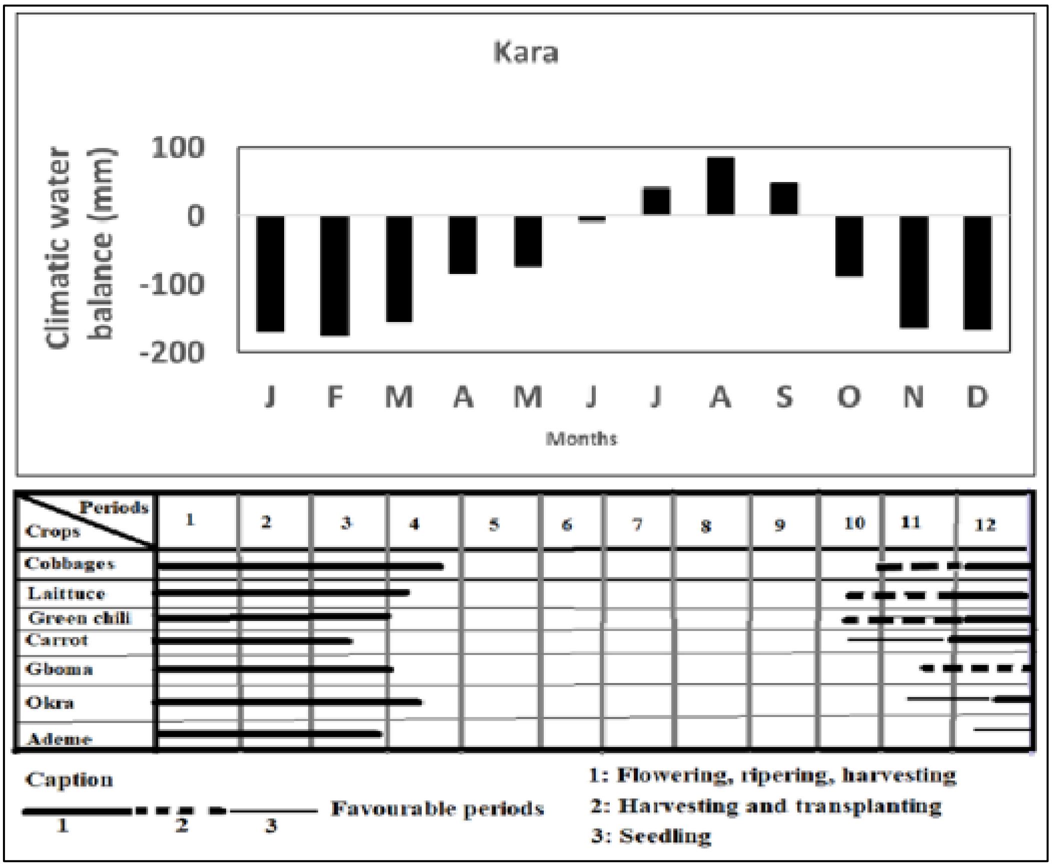
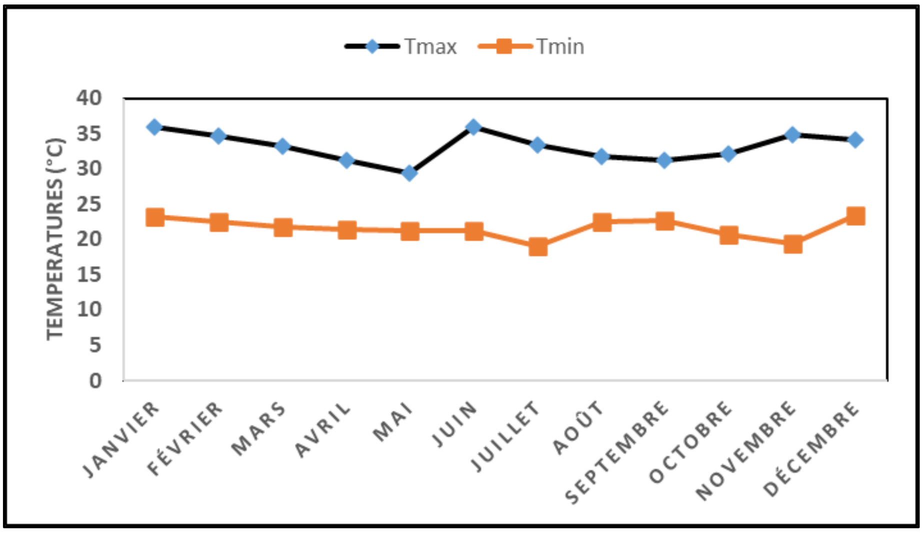


Figure 4 The state of the climatic water balance in the study area.

The evolution of the climatic water balance illustrated in Figure 4 reveals two scenarios. Indeed, the annual climatic water balance of the study area is in deficit (-81.05%) but in surplus (18.95%) during the period from July to September, where it varies from +40 mm to +84.5 mm. Market gardening activities remain virtually non-existent due to excess water. Furthermore, the climatic water balance is in deficit from October to June, with a variation from -6.8 mm to -173.2 mm. This deficit situation, which lasts for more than eight months, increases the vulnerability of off-season crops and compromises market garden production.

3.1.4. Temperature conditions and off-season market garden crops

Figure 5 presents the evolution of monthly mean temperatures (maximum and minimum) in Kara from 1990–2024.



Source: Processing of ANAMET data, 2025

Figure 5 Mean temperature regime of Kara from 1990–2024

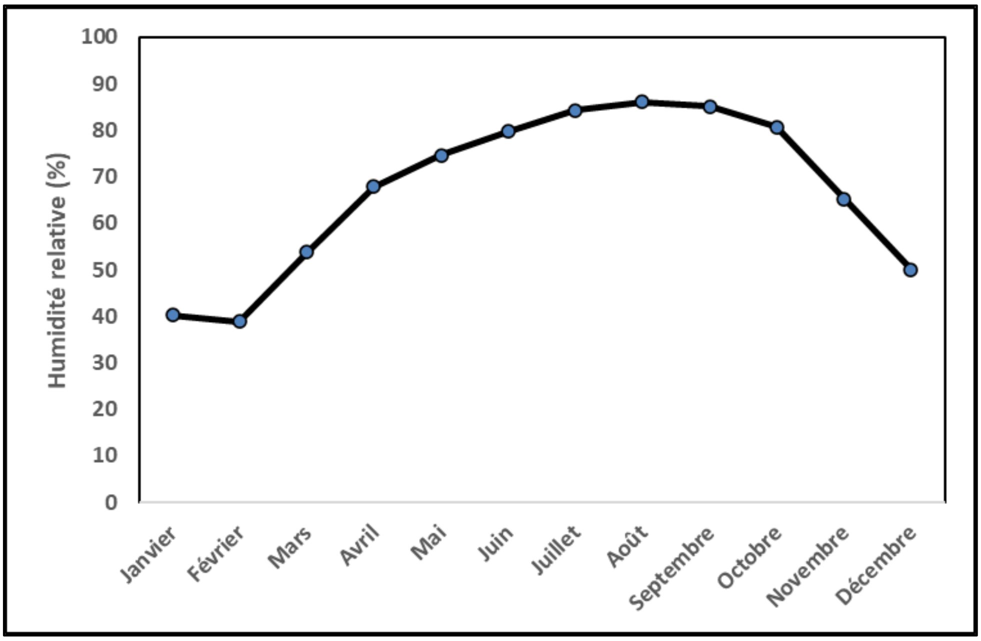
The growth temperature for vegetables produced in the study area ranges between 16 °C minimum temperature and 24 °C maximum temperature. At the same time, the evolution of temperatures over the 1990–2024 period shows that the average ambient temperature during off-season vegetable production periods ranges from 19.4 °C to 36 °C.

In November, the minimum temperature is 19.4 °C and the maximum temperature is 34.9 °C. In December, the minimum temperature is 19.4 °C, while the maximum value is 34.4 °C. January records 23.3 °C and 36 °C as the average minimum and maximum temperatures, respectively. For February and March, their minima are rarely below 21 °C, while their maxima are 34.7 °C and 33.2 °C, respectively.

While the minimum ambient temperature poses no problem for these different crops, the rise in ambient temperature beyond the optimal growth temperature for certain vegetables such as cabbage (22 °C), carrot (26 °C), and lettuce (22 °C), as well as tomato (30 °C), leads to a reduction in the quality of their yields. These high thermal conditions rapidly deplete soil water reserves, overheat the soil, raise the level of PET, and tend to burn the crops. Under these conditions, vegetables look wilted.

3.1.5. Relative humidity indicator and climatic conditions for off-season vegetable production

The relative humidity of Kara follows a unimodal regime (Figure 6) that practically matches that of precipitation, with a peak in August.



Source: Processing of ANAMET data, 2025

Figure 6 Mean relative humidity regime 1990–2024 in Kara

Analysis of Figure 6 shows that maximum relative humidity is very high during the rainy season, with a peak in August and September (86.16%). The lowest values are recorded between December, January, and February (38.94% to 50.10%). From November to June, relative humidity is low, ranging from 38.94% to 65.32%. This low humidity causes market garden crops to dry out and lose leaves due to insufficient irrigation or lack of water, as confirmed by producers.

The hygrometric deficit of the air intensifies evaporation during the dry season, which reduces water resources for market garden crops. This is due to the rise in temperature from October to June, which lowers the degree of air moisture saturation. In short, the amount of precipitation in the commune of Kozah 1 varies over time and during the vegetative cycle of market garden species.

3.2. Manifestation of climatic constraints on off-season market garden production in the commune of Kozah 1

Climatic events condition the conduct of off-season market gardening activities in the commune of Kozah 1. The main water sources critical for off-season market gardening in the Kara River valley are primarily the bed of the Kara River and its tributaries. However, starting in December, these water sources begin to dry up, making market gardening activities difficult. Between January and March, a deficit period in the climatic water balance, water availability becomes critical, according to 76% of the market gardeners surveyed.

During this period, constraints from extreme water deficits intensify. Market gardeners then struggle to carry out the number of irrigations needed to meet crop water requirements. These conditions cause crops to wilt, slow plant growth, disrupt the development cycle and, consequently, reduce expected production. For 67% of market gardeners, the length of the off-season activity period in the study area depends on the recharge of the water table by rains from the wet season. But the increasingly evident reduction in the number of effective rainy days or months, which has dropped from an average of 6 to 4, does not favor water availability in the bed of the Kara River for off-season market garden production (Figure 7).

Photo credit: LEMOU, February 2024

Figure 7 Pond (1a) and water trapped between rock outcrops (1b) in the bed of the Kara River during the dry season

The early low flow of the Kara River bed is partly linked to the poor occupation of its banks for off-season vegetable production activities. Indeed, in an effort to maximize their income, market gardeners extend their gardens all the way to the riverbed. This situation causes it to be trampled and silted up, resulting in a reduction of the watercourse's bed width photo (1a) illustrates this type of practice. With the bed becoming increasingly narrow, its water retention capacity for market garden production remains limited. The scarce quantities of water retained evaporate, leaving only a few water points trapped between rock outcrops (Photo 2).

For 93% of respondents, lettuce, tomato, ademe, and cucumber (Figure 7) are crops more vulnerable to these water deficit constraints. For these respondents, only green pepper, onion, and tomato resist these water constraints to some extent.

Faced with these crop losses linked to water deficits, producers develop adaptation options to mitigate, as best they can, the difficulties encountered. They drill individual or collective wells for their water needs. This technique is the most widely used (75% of respondents) but remains limited by the low water retention of the soils in the market garden perimeter.

Overall, market gardeners in the Patascom sector where the nature of the bedrock favors relatively prolonged water retention in the riverbed up to the fifth five-day period of March depending on the year- opt to reduce the number of market garden beds. Under these conditions, several crop plots are abandoned due to their drying out caused by insufficient irrigation water (Figure 8).

Figure 8 Mixed vegetable gardens (Ademe, green pepper, and eggplant) 2a; (cabbage and Gboma) 2b, dried out due to water deficit

Photos 2a and 2b show vegetable gardens that have dried out and are almost abandoned due to the scarcity of irrigation water. Young plants of ademe, cabbage, and Gboma planted in soils that are mainly sandy-clay need a reasonable amount of water from December to mid-February to ensure their development. But due to this lack of water, these plants wilt and dry out under the effect of intense heat. As a result, yields decline, leading to increased economic hardship for market gardeners.

According to the respondents, reducing the size of market garden plots which could drop from 0.5 ha to 0.25 ha or even 0.15 ha per market gardener is an option that not only allows rational use of available water but, more importantly, enables market garden workers to maintain a minimum level of activity to ensure their survival.

4. Discussion

Water is a crucial element for agriculture, whether rainfed or irrigated, especially during the dry season when its availability is more limited. In Togo, current climate changes strongly impact available water resources, which directly affects crops. Crops need water to develop, and the availability of this resource depends closely on the local climatic context.

The results of this study show that out of an average annual rainfall of 1089 mm, the precipitation depth in the study area is estimated at 5.01% for the November to March period (dry season). This corroborates the research findings of [18] in Benin, which predict a decrease in rainfall from March to May on a seasonal scale, synonymous with an extension of the dry season. The same observations were made by [2] in West Africa.

Similarly, this study showed that inter-seasonal differences in the climatic water balance express enormous water losses during the dry season that are not compensated for during the rainy season. This is similar to the results of [2, 19]. This phenomenon is justified by the effect of rising temperatures, and consequently the strengthening of the evaporative power of the air in the study area.

The climate in the Sudanian zone shifts from sub-humid climatic conditions in October to hyper-arid conditions from December to March, which is consistent with the findings of [2]. This temporal sequence is marked in the commune of Kozah 1 by water scarcity and increased water requirements for market garden crops. Climate change will certainly exacerbate imbalances between water availability and demand. This aligns with the research results of [20]. This situation makes the development of irrigation systems mandatory.

The maximum values constitute the favorable hygrometric condition for most market garden crops. This had already been noted in the research of [21, 5]. Thus, the increase in evaporation rate reduces the moisture level of the soil and water resources available for the growth of off-season market garden crops, and water needs depend on the region's climate and the cultivated plant. This corroborates the findings of [22].

The conclusions of this study highlighted the vulnerability of local market garden crops to climatic conditions, particularly during the dry season. This observation is consistent with the work of [23, 24]. The consequences are manifested notably by root rot, especially for shallow-rooted crops. To overcome these difficulties, market gardeners have adopted various strategies, including hoeing, which is essential because water rises by capillarity in compacted soils and then evaporates into the atmosphere. These results are in line with the studies of [2].

The study also revealed that the degree of vulnerability is directly linked to each category of market gardeners' ability to mobilize the necessary resources to improve their access to production inputs. This finding is consistent with the research of [25].

5. Conclusion

Analysis of the evolution of climatic conditions, based on precipitation, temperatures, potential evapotranspiration (PET), and relative humidity, reveals an uneven distribution of rainfall. The period from April to October accounts for 94.98% of annual rainfall, while the months from November to March receive only about 5.01%.

At the same time, maximum temperatures fluctuate between 29.4 °C (May) and 36 °C (January), and minimum temperatures vary from 19.1 °C (July) to 23.3 °C (December). Between November and June, relative humidity is low (38.94% to 65.32%), leading to the drying out of market garden crops and leaf loss. This situation is exacerbated by insufficient irrigation or lack of water in the Kara River and surrounding water points, which are highly sensitive to climate variability.

Consequently, from the second ten-day period of October to the third ten-day period of February, or even the second ten-day period of March, market garden crops in the commune of Kozah 1 suffer from water deficits. These cause crops to wilt, disrupt their development cycle, cause marginal burns, and bursting when rains return. Conversely, the second agricultural season (from the first ten-day period of May to the third of July) is marked by crop destruction and rot due to excessive rains in June and July.

Faced with these water management challenges, market gardeners are developing strategies for rational management of available water resources and harvests, particularly during the rainy season. However, these current approaches to coping with water scarcity and access need to be strengthened to ensure sustainable management of water resources.

Thus, it is desirable for the municipal authorities of Kozah 1 to develop a proactive sectoral policy in response to climate change. This policy must holistically integrate the market gardening sector and its actors to ensure the sustainability of the industry. The present study, by providing a clear view of the influence of climatic parameters on market garden crops in the commune of Kozah 1, serves as a tool to aid in the planning and management of this sector in a context of climate variability and high population vulnerability.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflicts of interest.

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