Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

ISSN NO. 2320-5407

Article DOI:10.21474/IJAR01/21879
DOI URL: http://dx.doi.org/10.21474/IJAR01/21879

RESEARCH ARTICLE

APPLICATION OF SOIL MOISTURE DATA FOR THE EVALUATION OF CURRENT AGRICULTURAL DROUGHT IN THE DISTRICTDES MONTAGNES, WESTERN COTE D'IVOIRE

Coulibaly Lereyaha[1,] ,Ouedraogo Moussa[1], Ouattara Ismaïla[1], Yao Kouadio Assemien François[1], Haba Lamine, Dao Amidou[2], Soro Gneneyougo Emile[2] and Kamagate Bamory[2]

1. Department of Mines and Reservoirs, Training and Research Unit in Geological and Mining Sciences, University of Man, Man; Côte d'Ivoire.
2. Geosciences and Environment Laboratory, Training and Research Unit in Environmental Sciences and Management, Nangui Abrogoua University, Abidjan, Côte d'Ivoire.

Manuscript Info

Manuscript History
Received: 21 July 2025
Final Accepted: 24 August 2025
Published: September 2025

Key words:-
Agricultural drought, SSWI, soilmoisture, spatial and temporal variability, Côte d'Ivoire.

Abstract

This study analyzes the temporal and spatial variability of soil moisture to assess agricultural drought in the District des Montagnes, western Côte d'Ivoire, over the period 1981–2020. The Standardized Soil Moisture Index (SSWI) was applied at a six-month cumulative scale (SSWI-6). Trend (Sen's slope) and change-point (Pettitt test) analyses were conducted on the SSWI-6 series. Results revealed alternating dry and wet periods across the study area, with slightly negative trends indicating a gradual shift toward agricultural drought, particularly after 1992. The decade 1981–1990 was the wettest, while severe droughts emerged from 2000 and became widespread in the 2010s, except in the Taï zone. The most frequent drought duration exceeded five months, with prolonged events concentrated in Biankouma. Overall, the findings demonstrate that the district has been affected by agricultural drought, despite a slight recovery in soil moisture since 2011–2020.

Introduction:-

Over the past decades, several regions across the world have experienced a notable increase in the frequency, duration, and intensity of drought episodes, largely attributable to the effects of global climate change [1]. These trends are not merely theoretical: according to the Copernicus Global Drought Observatory, vast areas of Africa are currently exposed to persistent and severe droughts, driven by abnormally low rainfall and high temperatures.
In West Africa specifically, recent studies have revealed significant changes in climate patterns, including more irregular rainfall, increased variability, and rising temperatures.

Among them, [2] highlight the multi-scale variability of droughts in the region, with a growing occurrence of agricultural droughts. Furthermore, within Côte d'Ivoire, [3] identify a clear trend towards more frequent climatic extremes combining heat and precipitation deficits, which exacerbate drought periods. The consequences of these climatic transformations are already visible in Ivorian agriculture. Cocoa and coffee production-the backbone of the

Corresponding Author: Coulibaly Lereyaha
Address:-Department of Mines and Reservoirs, Training and Research Unit in Geological and Mining Sciences, University of Man, Man; Cote dIvoire.

economy in the western part of the country-are increasingly affected by water stress caused by unreliable rainfall and prolonged dry spells. For instance, a study conducted by the International Water Management Institute [4] demonstrates that droughts and rainfall extremes significantly reduce cocoa yields in Côte d'Ivoire and Ghana, with yield losses reaching up to 37% during very dry years. In addition, recent reports indicate that, due to extended dry periods before and during the mid-season, many cocoa farmers in western Côte d'Ivoire are facing delayed flowering and reduced pod formation, leading to an estimated 40% drop in mid-crop production in 2025 [5]. Similarly, in the coffee sector-though less documented-field observations report the abandonment of some plantations and a noticeable decline in production, resulting from unpredictable rainfall patterns, rising costs, and limited water resources [6].

Moreover, farming communities have reported the loss of cropping cycles, notably the disappearance of a second growing season in rainfed areas, as well as increased difficulties in planning sowing and harvesting periods. In this context, soil moisture emerges as a particularly relevant indicator for monitoring agricultural drought. It integrates both meteorological (rainfall, evapotranspiration) and pedological–vegetative dimensions, allowing a better estimation of the actual water availability for crops-something rainfall-based indices alone tend to underestimate. The District des Mountagnes, located in western Côte d'Ivoire, holds particular importance as a major cocoa- and coffee-growing region that depends heavily on rainfed agriculture. Any variation in soil moisture therefore has a direct impact on yields, livelihoods, and community resilience. It is within this context that the present study aims to analyse, using soil moisture data, the recent dynamics of agricultural drought in this region.

Materials and Methods:-

Study Area

The District des Mountagnes, located in the western part of Côte d'Ivoire, lies between latitudes 5°50′ and 8°00′ N and longitudes 7°00′ and 8°40′ W. It is characterized by a rugged relief, abundant rainfall, and intense agricultural activity. The district covers an area of approximately 31,000 km² and includes the regions of Tonkpi, Guemon, and Cavally. The city of Man serves as the administrative capital of the district.

The climate is of the montane type, with a rainy season extending from March to October and a dry season from November to February (Figure 1). The area is bordered by two major rivers: the Sassandra River to the east and the Cavally River to the west. These main rivers receive several tributaries, the most important being the Kouin and the N'zo (tributaries of the Sassandra River) and the Nuon (a tributary of the Cavally River).

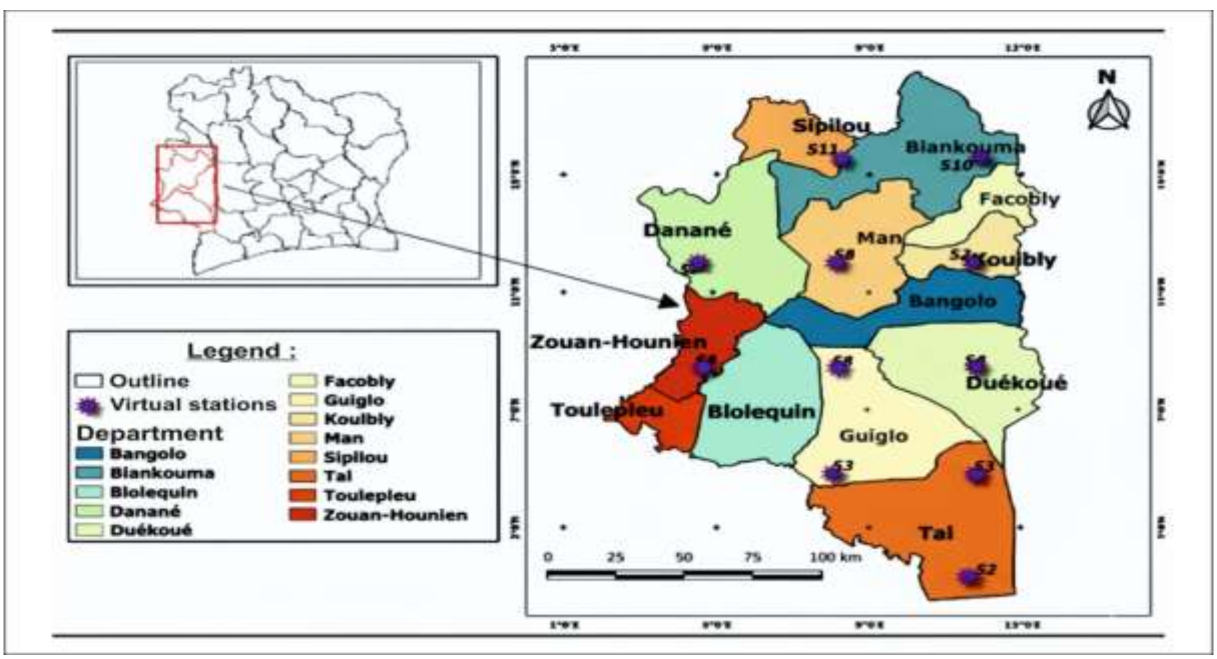


Figure 1 :Administrative Map of District des Montagnes

Data Used:
The data used in this study consist of climatic variables derived from satellite observations obtained from the NASA POWER Access Climate Data database. These data were collected from virtual stations distributed across the District des Montagnesover the period 1981–2020. The POWER dataset provides monthly climate and water balance information for all global land surfaces, and it constitutes an important source for hydrological and climatic studies at both regional and global scales. All data have a spatial resolution of 0.5° × 0.625° and are freely available from the NASA POWER Data Access Viewer (http://power.larc.nasa.gov/data-access-viewer/).

Data processing was performed using several specialized tools. The Standardized Soil Water Index (SSWI) was computed with the SPEI package (version 1.8.1) under RStudio, using different time steps covering the period 1981–2020. Trend and change-point analyses of the SSWI were conducted using the Trend package (version 1.1.5), also under RStudio, employing statistical tests such as Sen's slope and Pettitt's test. Finally, spatial analysis was carried out with QGIS 3.4.12, which was used to produce maps of the study area (administrative, geological, and hydrographic maps derived from a DEM) and to spatialize the drought index through Inverse Distance Weighting (IDW) interpolation.

Methods:-

Calculation and Interpretation of the Standardised Soil Water Index (SSWI)
The available soil moisture is averaged over a month to obtain the soil wetness for each department. The soil wetness data were used to derive the Standardized Soil Wetness Index (SSWI) to account for drought. This index requires, as a necessary parameter, soil moisture data recorded at various ground stations. The SSWI for a given location, and for the chosen period, is calculated from long-term soil moisture records. The Standardized Soil Wetness Index is statistically similar to the other more commonly used standardized precipitation indices. The index for a monthly period is defined as the difference between the monthly average and the standard deviation of the soil moisture, calculated on a monthly basis.

$$SSWI_t = \frac{SWvt - \overline{SWt}}{\sigma_t} \quad (1)$$

With $\overline{SWt} = \frac{1}{n}\sum_{v=1}^{n} F_{v,t}$ (2)

$$\sigma_t = \sqrt{\frac{1}{n-1}} \sum_{v=1}^{n} (SW_{V,t} - \overline{SWt} \quad (3)$$

Where denotes the interval within the year and denotes the year ; and are the mean and standard deviation for month, which ranges from 1 to 12 for the monthly calculations.Negative SSWI values can be used as threshold levels to classify the intensity of agricultural drought. Here, we employed the classification system suggested by [7] to classify the onset, intensity, and termination of agricultural activities (Table II). To this end, this system was used by [8] to monitor drought conditions and their uncertainty in Africa. It is also used worldwide in many different applications by other authors. In the classification system proposed by [7], a "moderate" drought episode begins when the SSWI (or SSMI) value is less than or equal to and ends when its value becomes positive.The Standardized Soil Wetness Index (SSWI) was chosen for the characterization of agricultural drought. The SSWI calculation procedure involves estimating soil moisture over different time scales and fitting it to a specified parameter distribution. For the present study, 6- and 9-month time steps were used.

Table 1. Drought classification by value according to [16].

Valeurs SSWI	Drought class
SSWI ≥ 2.0	Extremely wet
1.5 ≤ SSWI < 2.0	Very wet
1.0 ≤ SSWI < 1.5	Moderately wet
1.0 ≤ SSWI < 0	Slightly wet
-1.0 < SSWI ≤ 0	Slightly dry
-1.5 < SSWI ≤ -1.0	Moderately dry
-2.0 < SSWI ≤ -1.5	Severe drought

Methods for analyzing the temporal variability of the SSWI

The Pettitt and Sen tests were used to detect breakpoints (or change-points) and trends in the SSWI time series. The magnitude of the trend is estimated using the Sen's slope estimator (or Sen's method). Sen's slope provides a more robust estimate of the trend and calculates the slope as a change in the distribution's value over a given time interval. If a linear trend is present in the time series, the true slope can be estimated using a simple non-parametric test, known as the Sen's slope estimator. [9] developed a non-parametric procedure to estimate the trend slope from a sample of data pairs.

$$T_i = \frac{X_j - X_k}{j - k}, \qquad \mathrm{i} = 1,2,3, \ldots \mathrm{N} (4)$$

where X_j and X_k represent the data values at time steps "j" and "k" respectively, with "j" being greater than "k". The median of these "N" Ti values is called the Sen's slope estimator and is calculated using the following formulas:
Where X_j and X_k represent the data values at times " and ", respectively, with " greater than ". The median of these values, , is called the Sen's slope estimator and is calculated using the following formulas:
where $X_j$and X_k represent the data values at time steps "j" and "k" respectively, with "j" being greater than "k". The median of these "N" Ti values is called the Sen's slope estimator and is calculated using the following formulas:

If N is even:

$$\beta = \frac{1}{2}\left(\frac{T_N}{2} + \frac{T_{N+2}}{2}\right) \qquad (5)$$

If N is odd:

$$\beta = \left(\frac{T_{N+1}}{2}\right) \qquad (6)$$

The Pettitt test is used to determine the existence of a single breakpoint (or change-point) in a data series (Pettitt, 1979). A series (X_1, X_2, …,X_N, …,Xn) exhibits a breakpoint at rank N if the variables Xt at times t=1,2,…,N share a common distribution function F1(x) , while the variables Xt for t =N+1,…,n follow a different distribution function $F_1(x)$, with $F_1(x) \neq F_2(x)$.

Table 2: Tests selected for the study

Test	**Break detection**	**Trend detection**
Non-parametric	Pettitt.test	Sen slope

Method of Analysis of the Spatial Variability of the SSWI

The Inverse Distance Weighting (IDW) method is an interpolation technique used for estimation based on the distances between the point whose value is to be estimated and the neighbouring points for which measurements are already available. IDW interpolation explicitly implements the assumption that things closer to one another are more alike than those that are farther apart.To predict a value for an unmeasured location, IDW uses the measured values surrounding the prediction location. The measured values closest to the prediction location will have more influence on the predicted value than those that are farther away. Thus, the IDW function assumes that each measured point has a local influence that diminishes with distance.

The IDW function should be used when the point set is dense enough to capture the extent of the local surface variation required for the analysis. The IDW function determines cell values using a set of sample points combined with linear weighting. It assigns greater weight to points nearer to the prediction location than to those farther away, hence the name Inverse Distance Weighting.The average of the measurements from the surrounding observation points (virtual stations, in our case) is calculated, with a greater weight given to the nearest points. The predicted value for a point in space is:

$$Z=\left[\sum_{i=1}^{N} \frac{Zi}{d_i^k}\right] / \left[\sum_{i=1}^{N} \frac{1}{d_i^k}\right] \qquad (7)$$

With,
Z = the estimated variable;

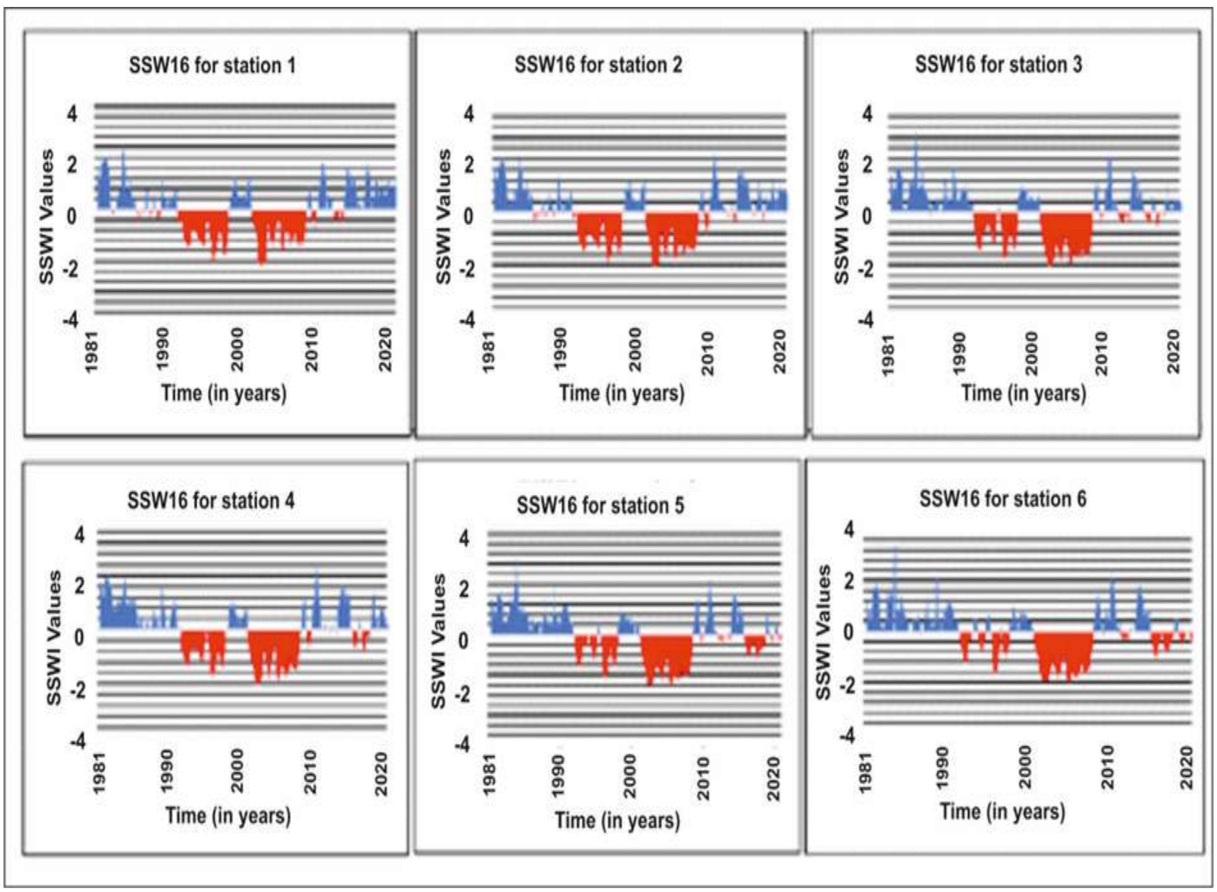
Z_i= the observed value at the measurement points i;
d = the distance between the prediction point and the observation point i;
N= represents the number of stations used in the interpolation process;
k = the power to which the distance is raised.
In most cases, k = 2. However, it may be relevant to use other values of k depending on the time step under consideration. For rainfall in particular, the optimal value of k for annual totals appears to be less than 1.5.

Results:-

Temporal Variability of the Standardised Soil Wetness Index (SSWI)

Time series analysis of the soil moisture data between 1981 and 2020 reveals significant changes in water availability for crops in the Districtdes Montagnes. Over this 40-year period, a general trend of gradual decrease in soil moisture is observed, along with increasingly pronounced drought periods.The years 1983, 1992, 2008, and 2016 stand out due to particularly severe water deficits. These episodes are associated with significant drops in precipitation recorded by local meteorological stations. Beginning in the 2000s, the periods of water deficit became more frequent and longer, indicating a progressive intensification of the drought phenomenon.

The interannual variations highlight alternations of dry and wet periods, with a more pronounced drought tendency observed after 1992. Figure 2 illustrates this trend by showing the annual evolution of soil moisture. Marked fluctuations are evident, with drought peaks corresponding to the years cited previously. The steady decline in moisture levels over the last two decades suggests a growing imbalance between rainfall input and the soil's water requirements.



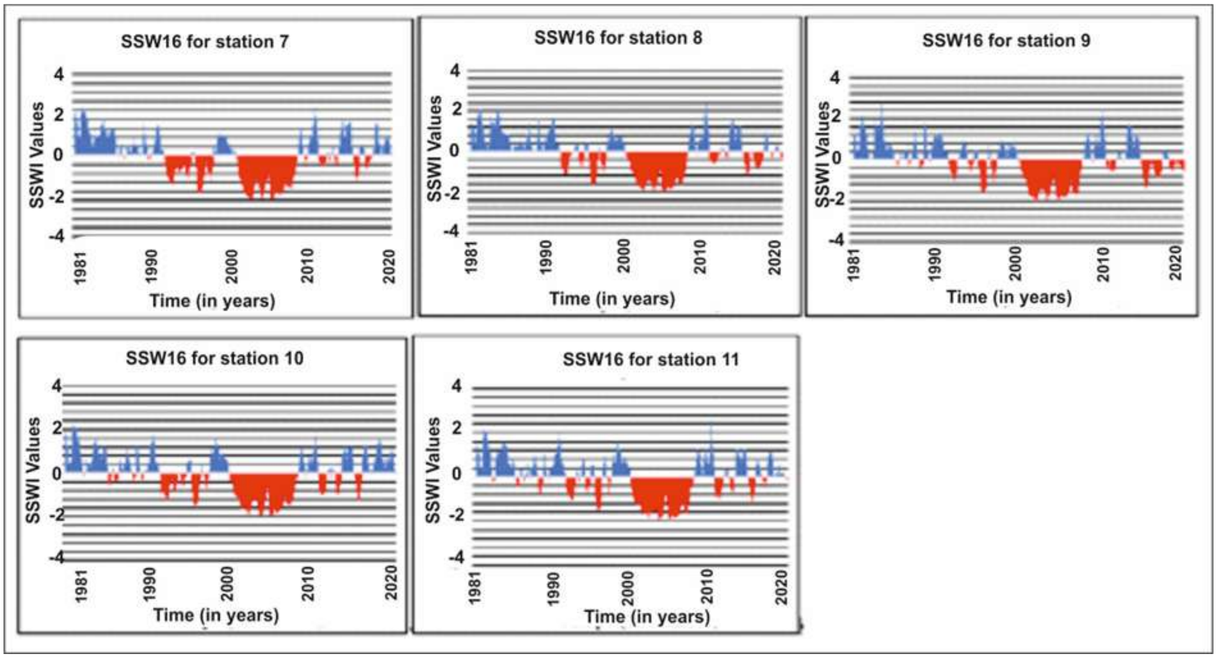


Figure 2 :Interannual variability of SSWI-6 indices recorded from stations 1 through station 11

Stationarity breaks and trend analysis in SSWI series

Table 3 presents the results of the statistical tests for breakpoints (Pettitt test) and trends (Sen's slope) applied to the Standardized Soil Wetness Index (SSWI) at different stations within the Districtdes Montagnes.The analysis highlights significant breakpoints that occurred primarily between the 1990s and 2000s, indicating a structural change in the regional hydrological regime. Specifically, the year 1992 emerges as a critical date, common to several stations (3, 4, 5, 6, 7, 8, and 10), which points to a regional-scale hydrological shift. Two other notable breakpoint periods were observed in 2000 (Stations 9 and 11) and 2010 (Station 1), suggesting a recurrence of climatic disturbances over recent decades.

Regarding trends, the results indicate a preponderance of negative slopes (ranging -13.06 to -25.27 $\times 10^{-4}$), signifying a significant decrease in soil moisture over time across the majority of stations. Only Station 1 exhibits a positive slope (+3.59 $\times 10^{-4}$), suggesting a locally favourable trend. Stations 5, 6, 8, and 9 recorded the most marked declines, confirming an intensification of agricultural drought episodes in these areas.Overall, these results reveal a generalized drying trend across the District des Montagnessoils, with breakpoints concentrated in the early 1990s and around the turn of the millennium (2000s).

Table 3 :Break and trend tests of the SSWI-6 indices for stations in the District des Montagnes

Station	Break test	Trend test
	Pettit.test	Sen slope(.10-4)
Station 1	Fev. 2010	3.59
Station 2	Sep. 2008	-3.60
Station 3	Fev. 1992	-16.8
Station 4	Jan. 1992	-15.91
Station 5	Mar. 1992	-25.27
Station 6	May 1992	-23.70
Station 7	Jan. 1992	-17.14
Station 8	Mar. 1992	-24.49
Station 9	Aug. 2000	-24.08
Station 10	Mar. 1992	-13.06
Station 11	Jul. 2000	-17.10

Characterization of Drought Duration and Intensity
Frequency of Drought Intensities

Figure 3 illustrates the frequency and intensity of droughts across the 11 studied stations in the Districtdes Montagnes. The results show that drought is a recurrent phenomenon across all stations, with an overall frequency oscillating between 43% and 48%. This high recurrence confirms the vulnerability of the study area to climatic hazards. The distribution by intensity reveals a dominance of mild droughts, accounting for between 21% and 30% depending on the station. Moderate and severe droughts, although less frequent, remain significant : they vary from 7% to 15% and 8% to 13%, respectively. Extreme episodes, conversely, are rare, not exceeding 2% and only appearing at a few stations (S1, S2, and S9).A degree of homogeneity is noted among the stations, with total frequencies close to 45%. However, certain stations, such as S1 (48%) and S9–S10 (47%), record slightly higher rates, indicating increased exposure to dry episodes. Stations S3 and S4 exhibit the lowest frequencies (43–44%), but with non-negligible moderate and severe droughts.

Overall, these findings indicate that drought in the District des Montagnesis primarily of low intensity, but its high recurrence (nearly one year out of two) has significant consequences for rainfed agriculture and food security. Furthermore, the non-negligible occurrence of moderate to severe droughts suggests a growing threat to the sustainability of local agricultural production systems.

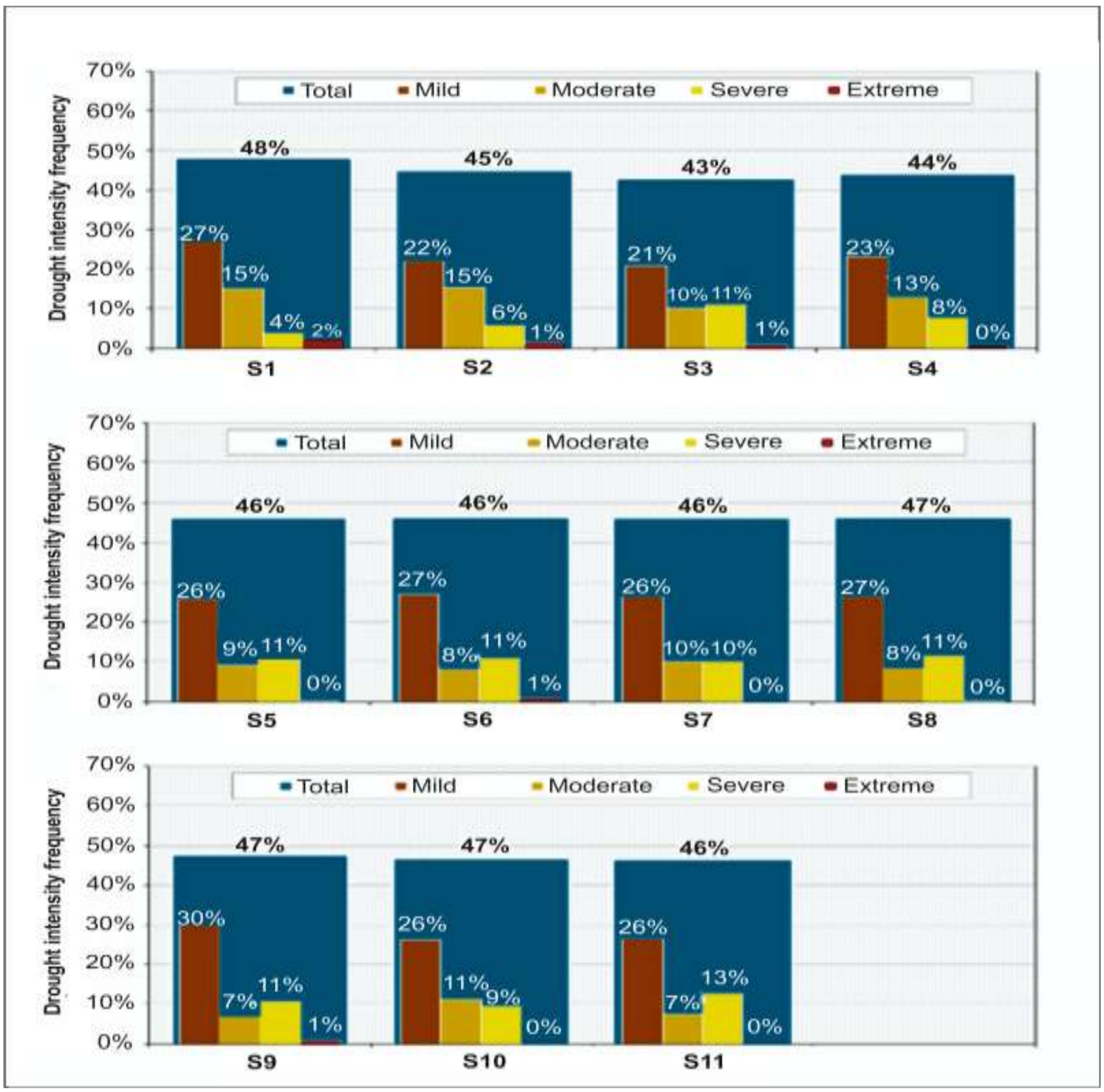


Figure 3: Frequency of Observed Drought Intensities in the Districtdes Montagnes

Frequency of Drought Durations

The duration of drought episodes shows high variability across the Districtdes Montagnes. In the majority of stations, the duration generally ranges from 1 to 5 months, but certain areas record much longer periods, occasionally reaching 86 months and even an extreme case of 99 months at the Biankouma station (S10).Long-duration droughts (exceeding 5 months) are largely dominant, accounting for nearly 80% of the cases observed across all stations. Conversely, 3-month droughts appear to be the least frequent, with an average occurrence of about 4%. Figure 4 highlights this distribution, underlining the prevalence of long episodes in certain localities, such as Biankouma, while also demonstrating a diversity of frequencies and intensities among the stations.

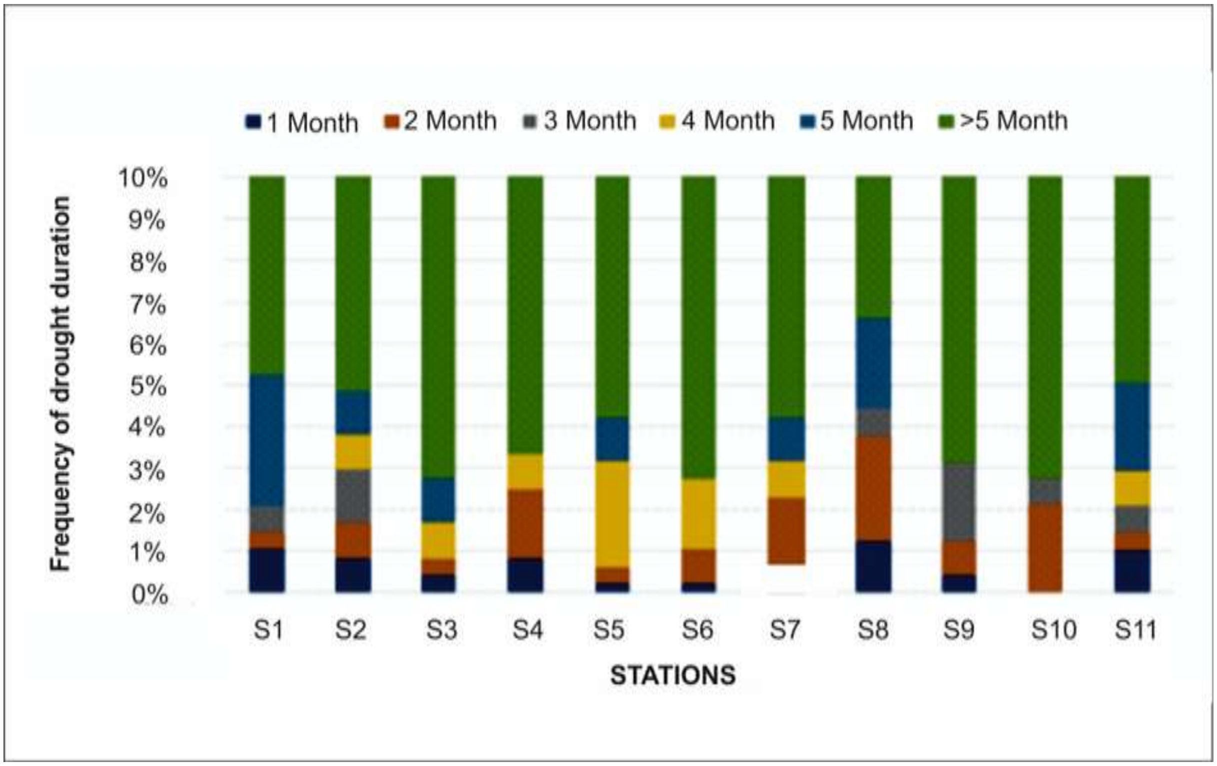


Figure 4: Distribution of Drought Durations in the Districtdes Montagnes

Spatial Variation of the Standardized Soil Wetness Index (SSWI)

Decadal Variability of the SSWI

The decadal analysis of the SSWI over the 1981–2020 period highlights significant changes in the spatial distribution of soil moisture. The results show a general trend of decreasing wetness, accompanied by increasing spatial disparities over the decades. From 1981 to 1990, SSWI values were generally high, indicating good water availability in the majority of the study areas. Drought episodes were rare and mainly localized in the northern part of the district, where indices occasionally reached values close to 0.4. The central and southern areas exhibited SSWI values between 0.5 and 0.7, suggesting favourable hydrological conditions.

Subsequently, from 1991 to 2000, a slight decline in wetness indices was observed, with the drought-affected areas extending towards the centre of the district. SSWI values fluctuated between 0.3 and 0.5, reflecting a more erratic water availability. This period marks the beginning of a perceptible climate change, with increasingly irregular precipitation. From 2001 to 2010, the decrease in soil moisture intensified. The northern and central regions became particularly vulnerable, with SSWI values often below 0.3. Droughts were not only more frequent but also longer, impacting agricultural production and water resource availability.Finally, the last decade, 2011 to 2020, was marked by a partial recovery of soil moisture. However, SSWI indices showed values below 0.3 in the central-western part of the district, reflecting light to extreme drought conditions. This situation is particularly concerning for agricultural activities in the central-western sector.

Figure 5 illustrates these decadal trends, highlighting the progressive degradation of water availability across the entire DistrictdesMontagnes.

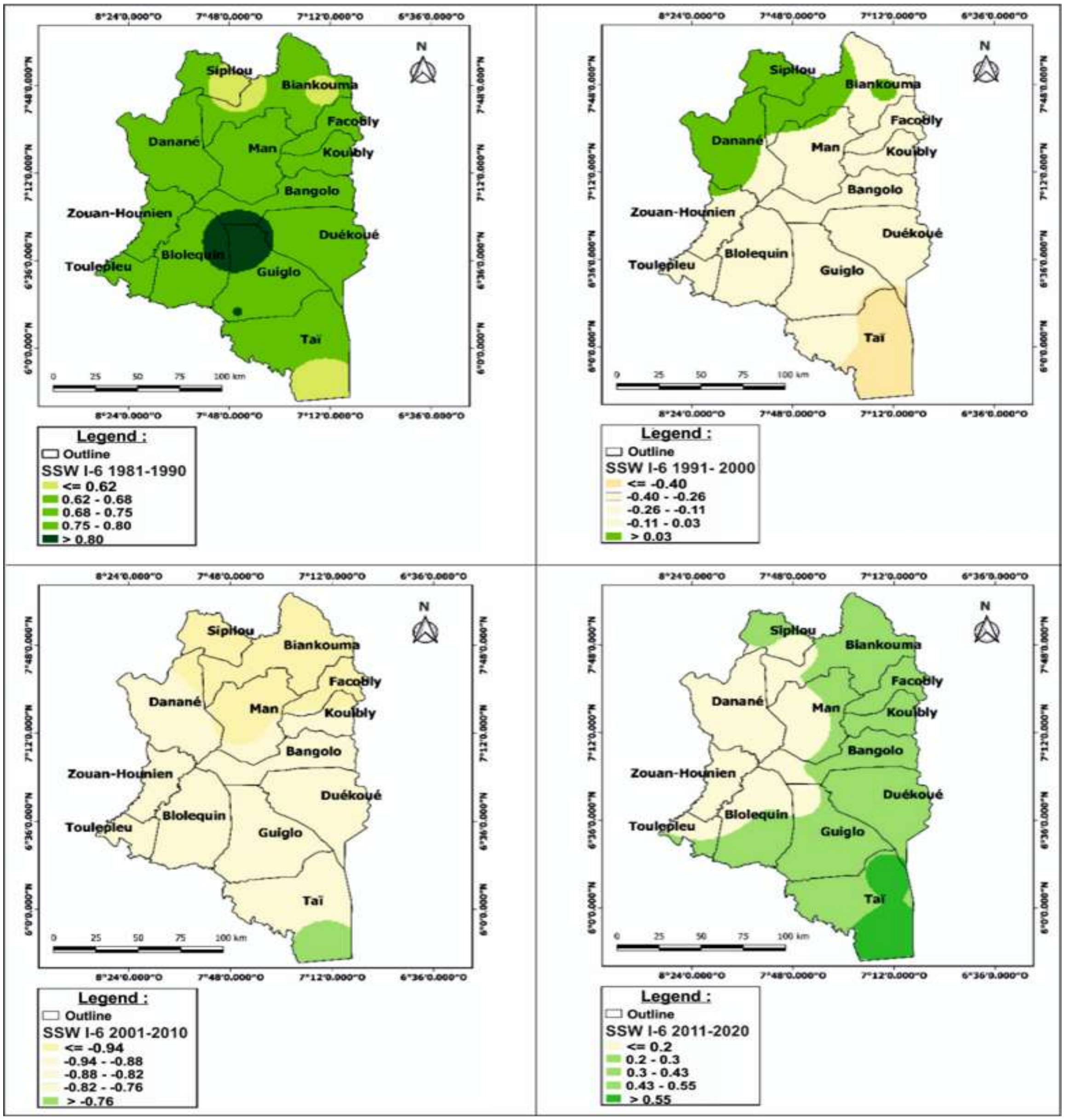


Figure 5: Map of the Decadal Variation of the SSWI-6 Indices in the Districtdes Montagnes

Specialization of SSWI-6 Slopes Before and After Breakpoint

The spatial analysis of the SSWI-6 index trends (Figure 6) reveals a high temporal and regional variability in soil wetness across the District des Montagnesbetween 1981 and 2020. Before the breakpoint (Figure 6b), the majority of localities, particularly those in the central and northern areas such as Man, Biankouma, Facobly, Kouibly, Danane, and Sipilou, exhibited significant negative slopes ($\leq -18.07 \times 10^{-4}$). This indicates a persistent water deficit. In contrast, only a few marginal areas like Taï showed a slight positive trend, suggesting better resilience.After the breakpoint (Figure 6a), the trend reversed with a significant improvement in soil wetness: most sub-prefectures, especially Guiglo, Taï, Duekoue, Bangolo, and Kouibly, displayed high positive slopes ($> 31.96 \times 10^{-4}$, event $> 54.14 \times 10^{-4}$ inTaï). This testifies to a clear increase in wetness, while Danane and Sipilou maintained weaker or stable trends.

These results suggest that the district experienced a phase of soil moisture degradation before 2000, linked to the recurrent droughts of the 1980s–1990s, followed by a gradual return to wetter conditions after 2000. This is consistent with rainfall recovery reported by several recent climatic studies in West Africa.

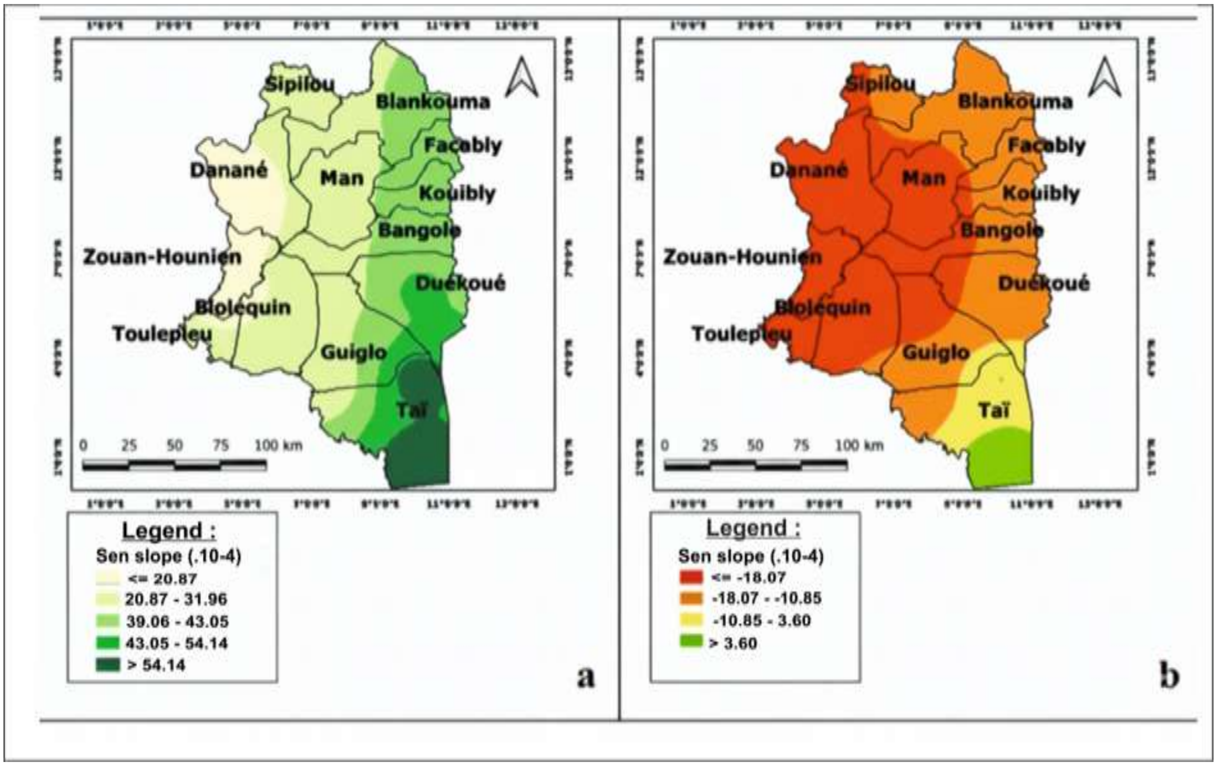


Figure 6: Spatial Distribution of SSWI-6 Index Trends Before (b) and After (a) the Breakpoint (1981–2020)

Discussion:-

The time series of the SSWI-6 index values show that the most severe droughts in the District des Montagnesoccurred mainly during the periods 1992–1998 and 2001–2008, characterized by dry conditions across the entire territory and intensities ranging from mild to severe. These episodes appear to be correlated with large-scale climatic events, notably El Niño episodes, which are frequently associated with rainfall deficits in West Africa [10]. More specifically, in their study on meteorological droughts in North and West Africa (1981–2019), these authors show that precipitation anomalies during El Niño years produce marked negative slopes in many sub-regions, supporting the results observed here. A recent study by [11] highlights that the 1970–1980 and 1980–1990 decades were strongly affected by prolonged droughts, with a partial return to wetter conditions after the 2000s in certain coastal areas, which aligns with the soil moisture recovery we observe after 2008.

The trend and breakpoint tests applied to the SSWI-6 index proved well-suited for detecting significant changes between 1981 and 2020 in all localities of the district. They confirm not only the reality of the initial moisture decline but also an inversion or attenuation of this trend in the last decades, which is consistent with observations on the variability of the SPEI and SPI indices in recent work conducted in West Africa.Regarding the possible causes of the negative trends observed before the breakpoint, several factors converge : decreasing precipitation, as shown by [12] for Côte d'Ivoire ; increasing temperatures and, consequently, potential evapotranspiration ; and the effects of global and regional climatic oscillations (El Niño, PDO, NAO) that modulate interannual rainfall. These elements are confirmed by recent studies that underline droughts in Sub-Saharan Africa are intensifying in frequency and severity, and that the combined effects of rainfall deficit and rising temperature worsen soil water stress.

The temporal breakpoint around 1992–2000 aligns with the results of local and regional climatic studies, particularly [13] in Côte d'Ivoire, which observe an overall drop in precipitation between 1940 and 2010, but particularly marked in the 1980s–1990s. This breakpoint interval is also noticeable in other work using the SPI or SPEI across West

Africa. The convergence of these results strengthens the robustness of the trends identified in the Districtdes Montagnes.

The recovery of soil wetness after 2008 can be explained not only by a rainfall recovery but also by more favourable rainfall variability in certain years, and possibly by changes in land use or agricultural practices that favour better water retention. Recent studies show that even if the overall trend remains uncertain, there are signs of a decrease in the frequency of extreme droughts in certain regions, although seasonal droughts remain significant threats [14].
The detailed characterization of drought via the 6-month SSWI-6 allows for distinguishing not only the intensity but also the duration, which is crucial for assessing agricultural impacts. The six-month timescale is considered relevant by the World Meteorological Organization for agricultural drought because it effectively captures seasonal accumulations or deficits and delays in soil recharge. This relevance is also observed in other contexts: [15] in Côte d'Ivoire, as well as in studies in Latin America or Asia, show that indices at medium or long temporal scales (3–12 months) are more stable and better correlated with actual impacts on vegetation.

Finally, the spatial variability of the SSWI-6 index shows that, unlike the periods before the breakpoint, the driest decades (1991–2000 and 2001–2010) affected a very high proportion of the territory (80–95% of the localities). This indicates a drought that was not only more intense but also more geographically extended. This suggests the existence of a heterogeneous territorial vulnerability, with some areas being more severely affected and others showing better resilience or recovery capacity. These results align with the observations made by [13] on deferred vulnerability depending on the regions in Africa.

Conclusion:-

The analysis of the temporal evolution and spatial variability of the Standardized Soil Wetness Index (SSWI-6) has highlighted strong hydroclimatic variability in the District des Montagnesduring the 1981–2020 period.The results show that the region has been affected by several drought episodes, the most marked of which occurred between 1992–1998 and 2001–2008. The generally negative trends observed in the time series confirm a general propensity for the onset of dry conditions, particularly accentuated in the localities of Guiglo, Zouan-Hounien, Man, and Danane, where the regression slopes reached absolute values greater than 24×10^{-4}. The stations of Duekoue, Kouibly, Biankouma, and Sipilou also show an intensification of drought, while Taï remains relatively more resilient, with a very low slope (3.60×10^{-4}).

The characterization in terms of intensity and duration confirms that mild droughts are the most frequent, with increased intensity during the 1991–2000 and 2001–2010 decades. The applied statistical tests allowed for the identification of a significant breakpoint in 1992, marking a major climatic transition. Before this date, the dominant trend was towards wetness, whereas after the breakpoint, the entire district experienced an increased propensity for drought. The spatial distribution corroborates these results, highlighting an extension of dry conditions over nearly 80% to 95% of the localities during the most critical decades.These findings confirm the vulnerability of the District des Montagnesto agricultural droughts and underline the need for local adaptation strategies based on sustainable water resource management and resilient agricultural planning. They are part of the broader climatic dynamic observed in West Africa, characterized by a persistent rainfall decline since the 1970s followed by a relative return to wetter conditions during the 2000s.

References:-

[1] Huang, J., Yu, H., Guo, X., Niu, Y., & Wang, Y. (2017). The global drought events in the 21st century : Characteristics, impacts and futures projections. International Journal of Climatology, 37(S1), 129–141. https://doi.org/10.1002/joc.5021
[2] Kouakou, K. E., Moussa, H., Kouassi, A. M., Goula, B. T. A., & Savane, I. (2017). Redefinition of homogeneous climatic zones in Côte d’Ivoire in a context of climate change. International Journal of Scientific & Engineering Research, 8(11), 453–462.
[3] Akobe, Y. A., Yao, A. K., Kouadio, K. A., &Dongo, K. K. (2024). Projected changes in extreme climate events and water availability in Côte d’Ivoire. Atmosphere, 16(1), 3. https://doi.org/10.3390/atmos16010003
[4] International Water Management Institute (IWMI). (2023). Implications of changes in water stress and precipitation extremes for cocoa production in Côte d’Ivoire and Ghana. CGIAR. https://www.cgiar.org/research/publication/implications-of-changes-in-water-stress-and-precipitation-extremes-for-cocoa-production-in-cote-divoire-and-ghana/

[5] Reuters. (2025, May 30). Ivory Coast's mid-crop cocoa output expected to drop around 40% due to long drought, exporters say. Prime News Ghana. https://www.primenewsghana.com/business/ivory-coast-s-mid-crop-cocoa-output-expected-to-drop-around-40-due-to-long-drought-exporters-say.html
[6] Latest. (2024, November 28). Abandoned coffee farms in Côte d'Ivoire may lead to Robusta coffee shortage. Latest News. https://www.latest.com/abandoned-coffee-farms-in-cote-divoire-may-lead-to-robusta-coffee-shortage
[7] McKee, T. B., Doesken, N. J., & Kleist, J. (1993, January 17–22). The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference on Applied Climatology (pp. 179–184). American Meteorological Society.
[8] Naumann, M., Koelpin, M., Beuer, F., & Meyer-Lueckel, H. (2012). 10-year survival evaluation for glass-fiber–supported postendodontic restoration: A prospective observational clinical study. Journal of Endodontics, 38(4), 432–435. https://doi.org/10.1016/j.joen.2012.01.003
[9] Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association, 63(324), 1379–1389. https://doi.org/10.2307/2285891
[10] Henchiri, M., Igbawua, T., Javed, T., Bai, Y., Zhang, S., Essifi, B., Ujoh, F., & Zhang, J. (2021). Meteorological drought analysis and return periods over North and West Africa and linkage with El Niño–Southern Oscillation (ENSO). Remote Sensing, 13(23), 4730. https://doi.org/10.3390/rs13234730
[11] Rahman, G., Jung, M. K., Kim, T. W., & Kwon, H. H. (2025). Drought impact, vulnerability, risk assessment, management and mitigation under climate change: A comprehensive review. KSCE Journal of Civil Engineering, 29(1), 100120. https://doi.org/10.1016/j.kscej.2024.100120
[12] Kouassi, A. M., Kouao, J.-M., & Kouakou, K. E. (2022). Caracterisation intra-annuelle de la variabilite climatique en Côte d'Ivoire. Bulletin de l'Association des geographes français, 99(2), 289–306. https://doi.org/10.4000/bagf.9534
[13] Yao, N. R., Oule, A. F., & N'Goran, K. D. (2013). Etude de vulnerabilite du secteur agricole face aux changements climatiques en Côte d'Ivoire. MEDD–PNUD.
[14] Tefera, M. L., Seddaiu, G., Carletti, A., &Awada, H. (2024). Rainfall variability and drought in West Africa: Challenges and implications for rainfed agriculture. Theoretical and AppliedClimatology, 156(1), 41. https://doi.org/10.1007/s00704-024-05251-8
[15] Soro, G. E., Anouman, D. G. L., Goula, B. I. T. A., Srohorou, B., & Savane, I. (2014). Caracterisation des sequences de secheresse meteorologique à diverses echelles de temps en climat de type soudanais : Cas de l'extrême nord-ouest de la Côte d'Ivoire. Larhyss Journal, 18, 107–124.