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Recent Investigation of Drought Severity in Southern Part of Nigeria

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Abstract

The tremendous impacts of climate change such as devastating flooding, deforestation, erosion and drought are becoming more increasingly evident, particularly, in southern part of Nigeria. This paper considered an eight-month initiation and termination sequence in the monthly precipitation data analysis of nine southern Nigerian stations between 1960 and 2012 with the aim of identifying years of drought and major drought events that have occurred in the southern Nigeria using Drought Severity Index based on eight-month cumulative precipitation anomaly (DSI_8). The results revealed that years of extreme drought are most frequent at Ibadan and Warri and least at Enugu and Benin. Mild drought occurred most in Osogbo, Ondo and Benin and least in Calabar. Enugu and Benin were wettest followed by Calabar and Ikeja. On the decadal scale, extreme drought occurred most in 1970-1979 and 1980-1989 decades. The 1960-1969 was the wettest decade while the current decade (2010-…) was observed to be witnessing wetness. Mild drought was found to be predominant in the region with 44.12% average occurrence. With the on-going wetness of the current decade, measures such as national programme on flood control have been delineated to forestall any possible negative impacts.

Key words: Drought severity index; Precipitation anomaly; Extreme events: Southern Nigeria.

1.0 Introduction

Extreme weather events due to climate change are major challenges facing the entire world. All parts of Nigeria are directly or indirectly affected by environmental problems such as deforestation, drought, desertification, climate change, rain and windstorms, flood, and erosion among others which are caused either by unsustainable human activities, nature, or both, leading to environmental hazards or disaster [1]. However, some of these problems are more pronounced in specific geographical regions of the country. While drought and desertification are major environmental problems associated with northern Nigeria,deforestation, flood and erosion are the main environmental issues affecting the southern and eastern parts of the country [2,3]. The coastal nature of the Southern region (including deltas, especially those affected by storms and storm-induced floods) increases its vulnerability to climate change effects of flood and erosion. Climate change magnifies the severity of natural disasters in terms of intensity and frequency in Nigeria which therefore makes the understanding of the intensity and frequency of such change of paramount importance as it is being considered and examined in this research. By definition, no universally accepted classification scheme has been developed to define drought which may be classified in terms of meteorological, hydrological, agricultural and socio-economic conditions. However, the review of the definitions of drought in [4] and [5]gave about 150 definitions of drought which are basically grouped into the above 4 groups. In summary drought is a condition of insufficient moisture caused by a deficit in precipitation over some time period. It is a cumulative departure from normal or expected precipitation, that is, the climatological mean. This cumulative precipitation deficit may be made manifest in the reduced stream flows, reservoir level or increased depth to the ground water table after several months. It should be noted that drought occurs in both arid and humid regions but it is often associated only with arid, semi-arid, and sub-humid by drought monitors and analysts. The response of arid and humid biomes to drought was reported in [6] and it was stated that biomes from both arid and humid areas respond to drought in short time scale and while those from arid regions can rapidly adapt to changing water availability the ones from the humid regions cannot. Serious hydrological imbalances that have adverse effects on land resource production system are caused by drought and the implications could be more devastating in the humid areas. In the sub-humid and semi-arid regions biomes respond to drought at long time scale

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and plants withstand water deficit more effectively than in the other regions. The southern Nigeria is vulnerable to drought impacts and resilience could not be developed if the drought situation in the area is not investigated. A substantial part of the humid south-south (costal) Nigeria was affected by drought between 1979 and 2008 based on less than 50 % precipitation for three consecutive months compared with the average for the whole period [7]. Drought events are often characterized by: severity expressed by a drought index, time of onset and duration, areal extent and frequency of occurrence. The association of drought to the semi-arid (northern) part of Nigeria has led to a lot of considerations and studies on the subject in the area. Intensities, recurrence and the effects of drought in the northern Nigeria have been severally reported, particularly in [8, 9, 10]. The devastating consequences of drought make this study necessary in the southern Nigeria which is a humid area. However, quite a few number of drought event analyses of the area have been carried out with no sufficient analyses of the dominant drought intensity of the area on a decadal scale. The drought situation over the whole country has been assessed in [11] using the sign of the normalized standard deviation of rainfall in each station between 1941 and 1983. Seasonal rainfall forecast for southern Nigeria has been carried out with few other related works but no proper assessment of drought intensity of the area has been done[12]. However, this study has been designed with the aim of identifying years of drought in each of the stations, major drought events that have occurred and dominant drought intensity in the region on a decadal scale usinga much simpler Drought Severity Index (DSI) that uses monthly accumulated precipitation deficitin the recent time (1960-2012).

2.0 Study Area

The southern Nigeria covers the coastal area extending from the Benin border in the west to the Cameroun border in the east (Fig. 1) The climateis humid in the south and also humid strip along the coast with rainfall averages over 2000 mm. Rainfall commences at the beginning of the raining season around March/April from the coast (in the south), spreads through the middle belt, reaching its two peaksin June/July and September. The northern part receives less rainfall which starts in May/June and ceases in September/October with peak in August. The retreat on the other hand starts from the north [13].

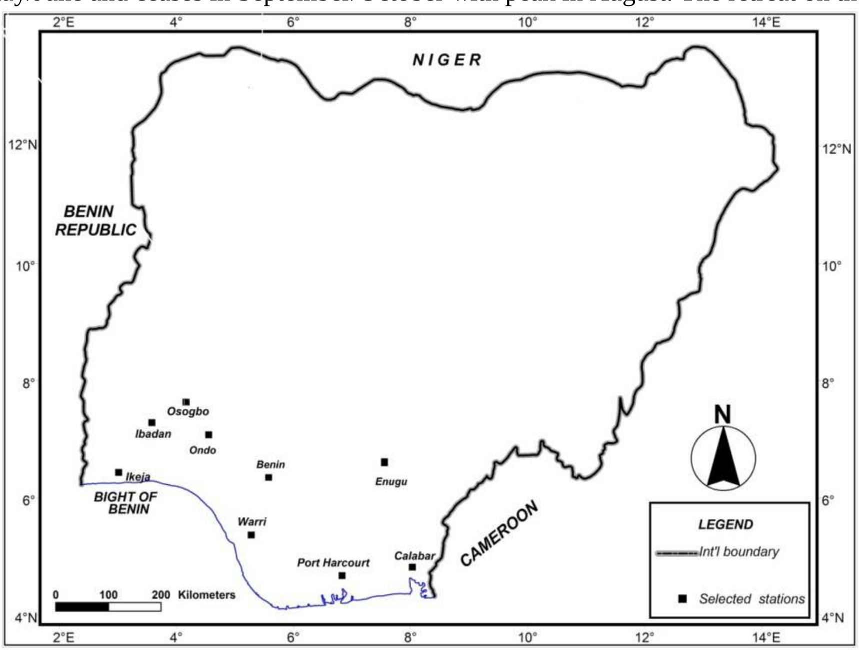

Figure 1: Locations of the stations in the study area

The south-western and the north-eastern winds influence the country's weather. The south-western winds are full of moisture and blusters from the Atlantic Ocean whereas the north easterlies are dry and dust-laden winds that primarily blow from the Sahara desert. The Inter-tropical Convergence Zone (ITCZ) is the region of low pressure around the earth where the northerly and southerly winds meet. The two winds are contrasting as the southerly is wet while the northerly is dry. So the areas below the ITCZ usually experience rainfall while the areas above it are dry. The rainy seasons therefore come into existence due to the fluctuations of the ITCZ position over Nigeria. The position of the ITCZ fluctuates seasonally and the different ITCZ zones affect different areas of the country at various times. Between January/February and August, the ITCZ migrates northward and there is a corresponding shift northward of the area of rainfall activity, and from the end of August when the ITCZ is at its most northerly position, theweather of the most southerly directed zone of the ITCZ migrates a short distance inland causing a period of reduced rainfall in the coastal area, a phenomenon known as the 'little dry season' or the 'July/August break'. During this period the southwesterlies become deflected into westerlies which bring little or no rain.

This causes rainfall to increase eastward over southern Nigeria during the July – August period [14, 15].Apart from the large-scale southward displacement of the ITCZ, drought occurrence can also be attributed to factors which inhibit rainfall activity below (i.e. to the south of) the ITCZ.There are tele-connections between the Tropical oceans sea surface temperature anomalies and rainfall [16]. Pacific El Nino is the warm phase of El Nino Southern Oscillation (ENSO) while La Nina is the cold phase of ENSO. During the warm phase of ENSO, the east –west (Walker) circulation at the Pacific Ocean, the north-south (Hadley) circulation at the western Pacific, and the Atlantic Hadley circulation weaken. However, the Hadley circulation at the eastern Pacific isstrengthened. Pacific Ocean El Nino is accompanied with warming in the North Atlantic Ocean [17]. The combined effect of the sea surface temperature (SST) anomalies in the two oceans is associated with drought in West Africa [17].The Atlantic Nino is the warming of the equatorial eastern Atlantic while the Atlantic Nina is cooling of the same area with respect to climatology. The Atlantic Walker circulation weakens and extends eastward during the peak phase of the Atlantic Niño. However, the Atlantic Hadleycirculation is strengthened [18]. Usually the region where the Walker and Hadley circulations are strong are associated with enhanced rainfall while their weakness regions are associated with reduced rainfall. The Atlantic Nino enhances rainfall at the Guinea coast so Atlantic Nina would enhance drought over the area [19]. Cooling of equatorial Atlantic Ocean also has the potentials to reduce rainfall at the Guinea coast [19].

3.0 Data and Methods

3.1 Data

Monthly precipitation data were obtained from the archives of the Nigerian Meteorological Agency (NIMET) Oshodi, Lagos covering nine selected southern stations between 1960 and 2012. Homogeneity analyses were performed on the data using the Buishand range test, Standard Normal Homogeneity test (SHNT), Von Neumann ratio test and Student t-test at 95% significance level to ascertain the accuracy and the reliability of the data in each of the stations. These tests are mathematically expressed in equations 1, 2, 3, and 4 respectively.

3.2 Statistical Data Analyses

3.2.1 BuishandRange Test

In this test, the adjusted partial sums are defined as:

$$S_0^* = 0 \; and S_k^* = \sum_{i=1}^{k}(Y_i - \overline{Y}) \; k = 1, \dots, n \ldots\ldots\ldots\ldots \quad (1)$$

When the series is homogeneous, then the value of S_k^* will rise and fall around zero.The year *k* has break when S_k^* has reached a maximum (negative shift) or minimum (positive shift). Rescaled adjusted range, *R* is obtained by

$$R = \frac{\max\limits_{0\le k\le n} S_k^* - \min\limits_{0\le k\le n} S_k^*}{s}$$

The $R/\sqrt{n}$ is then compared with the critical values given in [20]

3.2.2 Standard Normal Homogeneity Test

The SNHT is based on the T(k) statistic that compares the mean of the first k observationswith the mean of the remaining n-k observations:

$$T(k) = k\bar{z}_1^2 + (n-k)\bar{z}_2^2 \; k = 1, \dots, n \ldots\ldots\ldots\ldots \quad (2)$$

where

$$\bar{z}_1 = \frac{1}{k}\sum_{i=1}^{k}\frac{(Y_i - \overline{Y})}{s} \; and \; \bar{z}_2 = \frac{1}{n-k}\sum_{i=k+1}^{n}\frac{(Y_i - \overline{Y})}{s}$$

The year *k* consisted of break if value of *T(k)*is maximum. To reject null hypothesis, the test statistic,

$$T_0 = \max_{1\le k<n} T(k)$$

isgreater than the critical value, which depends on the sample size, n[21].

3.2.3 Von Neumann Ratio Test

The von Neumann ration N is defined as the ratio of the mean square successive (year to year) difference to the variance [22]:

$$N = \frac{\sum_{i=1}^{n-1}(Y_i - Y_{i+1})^2}{\sum_{i=1}^{n}(Y_i - \overline{Y})^2} \ldots\ldots\ldots\ldots \quad (3)$$

When the sample is homogeneous the expected value is N = 2.

3.2.4 The Student's T-tests

The t-test statistics [23, 24], which has a student's distribution, is defined as:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{s}\sqrt{\frac{n_1 n_2}{n_1 + n_2}} \ldots\ldots\ldots\ldots \quad (4)$$

where n_1 $_{and}$ n_2 are the sample sizes, $\bar{X}_1 and \bar{X}_2$ are the respective sample means and s is the sample variance, calculated as

$$s = \sqrt{\frac{n_1 S_1^2 + n_2 S_2^2}{n_1 + n_2 - 2}}$$

The general problem of drought risk assessment has led to the development of several drought severity indices which are based on precipitation [25]. The two most commonly used of these indices are the standardized precipitation index (SPI) [26] which transforms monthly precipitation time series into a standardized normal distribution and the drought severity index (DSI) which uses accumulated monthly precipitation anomalies concept of [27] as described below. The latter was used to develop the drought severity index in this study; the index values were standardized and the drought occurrences are categorized using the modified SPI classification(Table 2). The DSI was used in [28] to analyze drought risk in southwest England. The same has been used to examine UK water resource drought [29, 30] and changes projected by the PRUDENCE models on a European scale [31]. This type of index requires little rainfall data and can be easily interpreted by users and has been highly recommended [32]. It was concluded in [33] that simple indices that require rainfall as the input perform comparatively well when compared to some more complicated indices.

Table 2: Modified Standardized Precipitation Index (MSPI)

MSPI Values	Categories
DSI = 0	Wetness(Non-drought)
$0 < DSI \leq 0.99$	Mild drought
$0.99 < DSI \leq 1.49$	Moderate drought
$1.49 < DSI \leq 1.99$	Severe drought
$DSI \geq 2$	Extreme drought

The monthly precipitation and monthly precipitation anomaly with respect to the 1961-1990 mean are the only input to the drought severity index analysis. The DSI_8 uses an eight-monthly initiation and termination rule appropriate for the description of rainfall behaviour of the study area. It is described thus: The precipitation anomaly in month t is X_t. If X_t is negative and the precipitation in the preceding 8-month period i.e. X_{t-1}, X_{t-2}, X_{t-3}, X_{t-4}, $X_{t-5,}$ $X_{t-6,}$ $X_{t-7,}$ X_{t-8} is also lower than its mean, then a drought sequence is initiated in month t, assigning DSI_8 a positive value proportional to the precipitation deficit in month t. If the month t+1is then considered and the precipitation deficits in months t and t+1 are –X and –Y mm respectively, then DSI_8 for month t+1 equals X+Y if the mean monthly precipitation total for the preceding eight months has not been exceeded. If the precipitation anomaly is positive in month t+1 then the drought sequence can continue provided the eight-monthly mean total has not been exceeded with DSI_8 = X-Y. Termination of a drought occurs when the monthly mean total has been exceeded and DSI_8 is assigned a value of zero. To make comparison between sites, the DSI values are then standardized by dividing the absolute deficit by the station's mean-annual precipitation which is then multiplied by -100. The final index value expresses the accumulated deficit as a percentage of mean-annual precipitation.

4.0 Results and Discussions

The decade 1960-1969 was a wet decade with 23.64% average occurrence of wetness. This was followed by a mild drought at 17.09%. Severe and extreme drought also had 10% and 6.15% occurrence respectively while drought was moderate at 5.77% occurrence (Fig. 2). Extreme drought was predominant at an average of 30.77% occurrence during the 1970-1979 and 1980-1989 decades. Also on the average, severe drought occurred at 20% intensity while moderate, mild and wetness had 23.08%, 18.80% and 11.80% respectively during the two decades.

For the decade, 1990-1999, both severe and moderate droughts dominated the region with an average percentage occurrence of 25% each. The decade experienced wetness at 22.73% while extreme and mild occurred at 16.92% and 17.59% respectively. Mild drought was the dominant drought intensity during the 2000-2009 decade with 23.12% average occurrence. It was followed by wetness at 21.82% occurrence. Severe, moderate and extreme droughts were present at 20%, 15.38% and 12.31% occurrence respectively. The result also showed that the current decade (2010 - …) is witnessing wetness which seems to be building up at an average percentage occurrence of 8.18%.

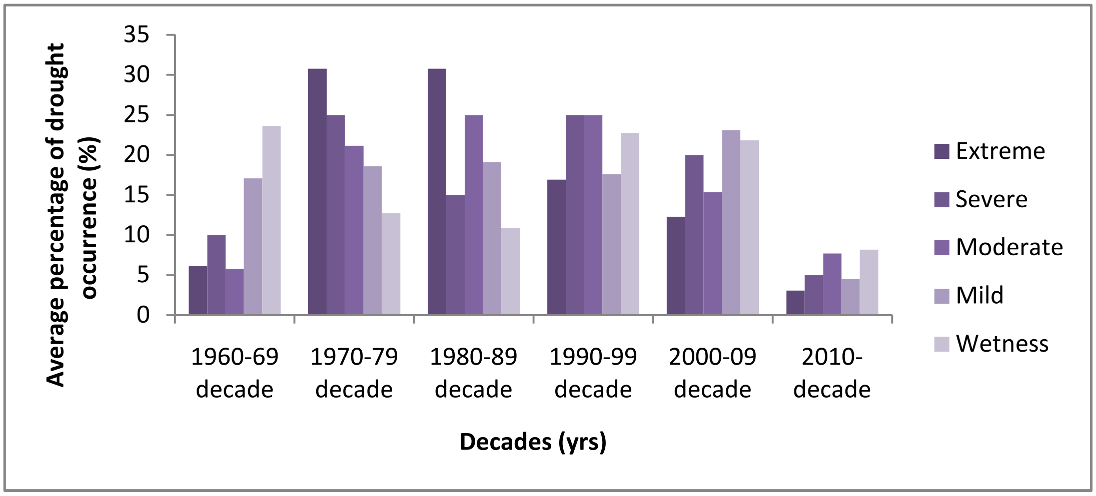

Figure 2: The bar chart representation of the average percentage occurrence of the various degrees of drought in each decade.

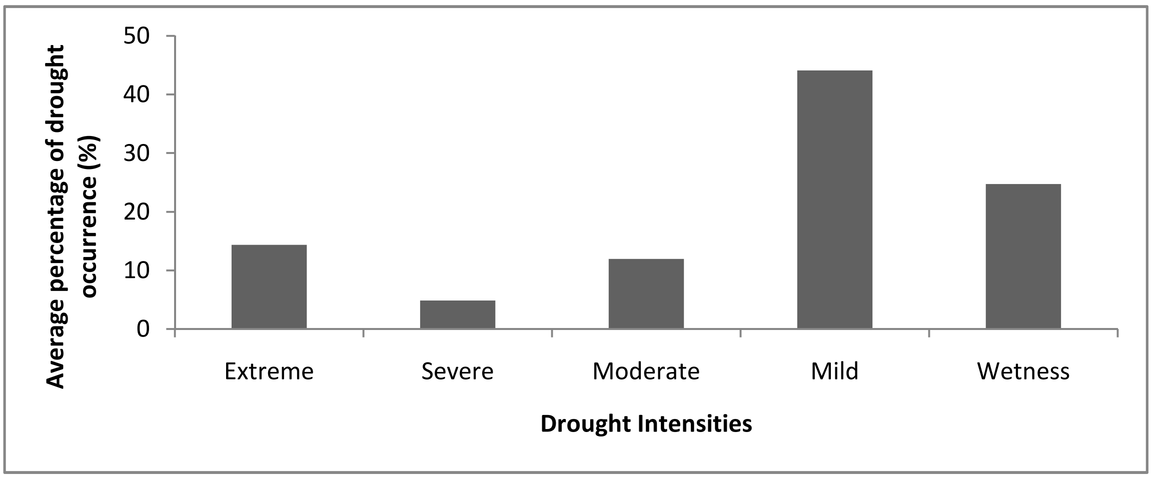

Figure 3: The bar chart representation of the average percentage of occurrence of the various degrees of drought in the study region.

The analyses of the recent severity of drought in the region using Drought Severity Index (DSI) that uses monthly accumulated precipitation deficit has shown that Southern Nigeria witnessed several intensities of drought at different levels of classification. Extreme drought was most frequent at Ibadan and Warri with average 21.15% occurrence each while it was least at Enugu and Benin with 8.51% and 7.69% occurrence respectively. Osogbo had the highest severe drought intensity while Calabar and Enugu did not record any severe drought. Moderate drought was highest at Calabar (19.15%) and Enugu (17.02%) and lowest at Ondo (3.85%) and Benin (7.69%). Osogbo, Ondo and Benin experienced more of Mild drought than other stations at an average percentage occurrence of 50.00% each. This was followed by Warri and Port-Harcourt at 46.25% and 44.44% occurrence respectively. Wetness was most frequent at Enugu (34.04%) and Benin (30.77%), followed by Calabar (29.79%) and Ikeja (29.41%). This is no doubt why there was no severe drought in Enugu while Benin was dominated by mild drought. The strategic location of Calabar and Ikeja within the coastal regions of the study area is also a reason for the dominance of wetness in the area.

In the decadal analyses (Fig. 2), drought was predominantly extreme at 30.77% occurrence each in the decades 1970-1979 and 1980-1989. 1970-1979. 1990-1999 decades had the highest incidence of severe drought at an average percentage occurrence of 25% each. The wettest decade was 1960-1969 at 23.64% occurrence. The reportof [34] also affirms that based on the rainfall variability index and trend analyses, that the 80s and 50s were the driest and wettest decade respectively from 1901 to 2000.

Generally, the study showed that the southern Nigeria was dominated by mild drought intensity with an average percentage occurrence of 44.12% (Fig. 3). Moderate drought intensity average occurrence stood at 11.94% while severe and extreme droughtsmanifested at the average of 4.85% and 14.37% respectively. The region witnessed wetness at 24.73% occurrence. Although mild drought was found to be predominant, the average percentage of wetness can be consideredto be significant to exert a suppressive influence on the currently predominant drought intensity thereby resulting in extreme events such as flooding and erosion in some coastal parts of the study area. Increase in the frequency and intensity of severe weather events is expected due to climate change. Sea level rise may lead to increasing coastal inundation and flooding of low-lying areas (e.g. Lagos and Port-Harcourt). Beach erosion could pose more threat as a result of ill-designed jetties/groynes which could cause alterations in current directions with the result that erosion could shift to other places as being witnessed on the Bar Beach on Victoria Island, Lagos[35]. Contrary to the long-term decline in rainfall widely reported for the 1970s and 1980s for subtropical West Africa, some areas of Nigeria have experienced a progressive increase in rainfall activities during certain periods. This is the situation over Southern Nigeria (Coastal and Guinea Savanna belts), which experienced progressive increase in August rainfall amount without a corresponding increase in rainfall frequency which translates to a progressive increase in mean rainfall intensity over southern Nigeria thereby affording meteorological explanation for the widespread floods reported for many parts of Nigeria during the 1999 raining season [36].The heavy and moderate rainfall series in whichheavy rainfall contributes 44-52 per cent of the annual rainfall in northern Nigeria and declines in dry years is possiblya contributing factor to the persistence of drought conditions over the region. In contrast to the situation in the north, the moderate and heavy rainfall series over southern Nigeria where heavy rainfall contributes 44-60 per cent of the annual rainfall can be said to depict only evidence of high frequency oscillations which shows a tendency to increase more in wet years [37]. The findings in this study showed that the present decade is witnessing wetness and is expected to witness it the more which confirms the assertion in [37]. The humid biomes of southern Nigeria are likely exposed to dangers due to the resultant impacts of severe and extreme droughts. They have lower response to drought vulnerability when compared with the arid biomes since drought vulnerability is much larger in humid biomes than in arid ones [38]. This might be explained by the more complex relationship between drought and vegetation activity and plant growth in humid areas because they are characterized by water surplus. According to [39], phenological factors such as the period of active leaf flushing and vapor pressure deficit may influence the effect of drought on plants in these areas. Other drought impacts common to southern humid biomes include loss of foliar biomass due to damages to plant tissues [40, 41] in addition to poor tolerance of plants to water stress [42]. Moreover, in humid area such as the southern Nigeria, long-lasting or recurrent droughts may also be too intense to allow for a fast vegetation recovery leading to plant mortality in humid forests [43, 40]. Therefore the predominance of mild drought should be closely watched by relevant agencies.

5.0 Conclusion

Mild drought was found to be the leading drought intensity with a significant percentage of wetness.The current decade is experiencing wetness which tends to worsen as theclimate change impacts persist. The resultant effects of the severe and extreme droughts could also be threatening on the survival of the humid biomes in the southern Nigeria due to its higher drought vulnerability than the arid ones if not properly checkmated. Strategic combat-ready measures should to be put in place against the occurrence of any extreme weather event. Agencies, institutions and facilities for the collection and analyses of meteorological and hydrological information should be strengthened even in the area of information dissemination. A drought monitoring and early warning system should be designed to identify climate and water supply trends and to detect any slight change in the intensity of droughtof the area for mitigation measures and preparedness plans to be put in place. Effective and adequate drainage system should be constructed to free water ways. Appropriate land use that enhances carbon dioxide sequestration, such as afforestation, reforestation and agro-forestry should be encouraged to reduce soil erosion and increase crop productivity for economic development in the region. According to [1], no fewer than 600 gully erosion sites have been estimated in some of the states in the study area such as Abia, Anambra and Imo States. The recent massive landslide in one of the southeastern states is an attestation to the possible climate variability induced changes in erosion intensity [1]. Finally, development of appropriate awareness programmes for formal and informal education to enhance knowledge on climate and environmental issues is also undoubtedly necessary and therefore recommended.

6.0 References

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