# Application of Multi-Variant Statistical Drought Indices on Characterization and Quantification of Drought Conditions and its Effects on Agriculture in Mubi Area, North-East Nigeria

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***Abstract***

*This present research work aimed to apply multi-variant statistical drought indices on characterization and quantification of drought conditions and its effects on agriculture in Mubi area, North-east Nigeria. Five different drought indices were adopted namely; Rainfall Seasonality Index (RSI), Rainfall Decile Index (RDI), Percent Normal Precipitation (PNP), Threshold Level Method (TLM) and Rainfall Anomaly Index (RAI) and also effectiveness test of the indices was also assessed. The rainfall data was obtained from Adamawa state university, Mubi Agro-meteorological station from the 2004-2020 and also data on causes and effects of drought were derived using questionnaires where One Hundred and Eighty (180) farmers were randomly selected and subjected to descriptive statistical analysis. The results obtained revealed that the suitable index for drought identification in the area is in order of TLM >RDI, >PN>RSI >RAI. Meanwhile, for the quantification >PN > RSI >TLM> RSI > TLM >RAI. In addition, the highly effective indices with ETV > 0.4 are PN, RSI and TLM with three combinations, RSI and TLM for double indices. Among the single index the PN, RSI and RDI are found to be highly effective respectively. In addition, deforestation (45%) and overgrazing (30 %) are the major causes of drought scenarios in the area that occurred mostly in 2009-2014 affecting crop yields (35 %) and pest and diseases outcrop (20 %). The farmers' uses early maturing crops (35 %) and early planting (20 %) are found to major mitigation strategies adopted in the area. Thus, the adoption of the highly effective identified indices (PN, RSI and TLM and RSI and TLM) should therefore be adopted in the region towards understanding the drought conditions for sustainable agricultural production and mitigation strategies. Farmers in the area should be train on the drought mitigation.*

***Keywords:*** *Agriculture, Drought, Indices, Mubi and Statistical*

## INTRODUCTION

Drought is a hazardous natural event that is associated with below-average water availability in the hydrological cycle due to climate variability. Unlike other natural hazards (e.g. floods), drought has a very complex development pattern (onset, impacted area, severity, recovery) that cannot be easily understood (Beyene, *et al.*, 2014). Over the past decades, different drought indices have been suggested in the literature (Christoph *et al.*, 2017). By representing drought as a single numeric value, drought indices greatly facilitate analysis and comparison over time and space (Okpara and Tarhule, 2015).which are used in combination with an appropriate threshold, all relevant drought characteristics, namely onset, drought magnitude, intensity and cessation, can be derived (Yevjevich, 1967: Dracup, 1980; Agnew, 2000; Paulo and Pereira, 2006). A drought index value is typically a single number, far more useful for decision-making than raw data. Although none of the major indices is inherently superior, some indices are better suited for certain regions or uses than others. For example, the Palmer Drought Severity Index (PDSI) is useful for large areas of uniform topography and is widely used by the U.S. Department of Agriculture to determine when to grant emergency drought assistance (Michael , 2007). However, there are no physical arguments to prefer one method over the other for drought identification (Beyene *et al.*, 2014). Therefore, one possibility to tackle the variety of drought indices, their shortcomings and their underlying ad hoc assumptions is to assess a number of indices and combine them in a monitoring system as, e.g., suggested by the Drought Monitor for the United States (Svoboda *et al.*, 2002).

In addition, considering that each index calculates drought differently, it is often useful to compare several indices using the same regional data (Okpara and Tarhule, 2015). To achieve that, (Yevjevich *et al.*, 1978) proposed eight quantitative criteria, namely, (i) Characteristics, statistical properties and variability of droughts indices, (ii) Detailed analysis of a major historical drought, (iii) Indices adaptation to the local climate, (iv) Unbounded index values, (v) Spatial invariability, (vi) Flexible time scale, (vii) Data requirements and availability, and (viii) Interpretability. Similarly, it is a well-known fact that drought indices assimilate data on rainfall, snowpack, stream flow, and other water supply indicators into a comprehensible big picture (Michael, 2007). Thus, Drought is often detected after it has already well developed (Sheffield and Wood, 2012). Comparative studies of drought indices have been carried out in many regions or river basins and none of the methods currently in use can be considered universal, or absolutely correct. The selection of a method in a given area depends on available data and on the capability of a method to estimate in the best possible way the occurrence of drought in time and space, and its variability (Morid *et al.*, 2006).

## STATEMENT OF THE PROBLEM

Drought is one of the most natural hazards affecting agricultural and socio-economic activities of an area .Obviously, Mubi area in the past decades was known to have received high to moderate rainfall evenly distributed than any other part of the state after Ganye and Tongo region respectively. Conversely, in recent decade and currently the area and the environs is faced with devastating drought episodes that imposed serious damage on farming and other socio-economic activities. However, some research have been conducted using single drought index towards identification and quantification of drought conditions which each method gives almost different results and complicates the concept of understanding drought in the area. Thus, understanding drought characteristics, severity, duration and incidence is a prerequisite and panacea of planning, management and mitigation strategies of drought effects on agricultural and environmental development in the area.

At the same time, it is apparent that no any scientific attempt of research work that have been published in the study area using multiple-variant of drought indices towards evaluating drought phenomenon affecting the area. It is against this backdrop, this research work aimed to apply multi-variant statistical drought indices on characterization and quantification of drought conditions and its effects on agriculture in Mubi area, North-east Nigeria

## OBJECTIVESE OF THE STUDY

1. To assess the spatial and temporal variability of drought condition in the area using different indices
2. To identify the most effective drought index suitable in the area
3. To classify and quantify long term drought scenarios in the area
4. To evaluate the perception of peasant farmers on the causes and severity of seasonal drought in the area
5. To identify the effects of drought on agricultural production in the study area

## MATERIALS AND METHOD

### Study Area

Mubi land area lies between latitudes 9°30' and 11° north of the equator and longitudes 13° 00' and 13°45' east of the Greenwich Meridian at an altitude of 696 m above sea level. It is situated in the northern savannah ecological zone of Nigeria. It has a land area of 4,728.77 km$^2$ and a population of 759,045 people in 2003 (Adebayo, 2004). The climate of the study area is characterized by alternating dry (November to March) and wet (April to October) seasons. The mean annual rainfall ranges from 700 mm to 1,050 mm. The seasonal maximum temperature of 37.0°C occurs in April and minimum of 12.7°C in January. Maximum relative humidity is 90% and minimum is 50% (Adebayo, 2004). The vegetation is of typical Sudan savannah type, which implies grassland interposed by shrubs and few trees mostly acacia (*Acacia albida*), locust-beans (*Parkia biglobosa*) and Eucalyptus trees (*Eucalyptus spp*) among others (Adebayo, 2004, Tekwa and Usman, 2006).

### Sources of Data

The research work used the available rainfall data from the year 2004-2020 in identifying and quantifying meteorological drought in the area obtained from Agro-meteorological station of Adamawa State University, Mubi. In addition, data on the causes and effects of drought in the area were obtained through farmer's perception by the use of well-defined questionnaires. Thirty farmers were randomly selected from each of the following six (6) settlements in the area namaely; Muchala, Mayo-Bani, Sebore, Digil, Muvur and Mujilu totaling to one hundred and eighty (180) farmers respectively.

**Method of Data Analysis**

Five (5) drought indices and methods, namely the rainfall seasonality index, threshold level method, rainfall anomaly index, rainfall deciles index, and percent of normal precipitation or precipitation anomaly were selected with respect to rainfall data as a prime indicator in meteorological drought assessment. The methodology of each drought index was presented in the following section. These methods have similar classifications of dryness or wetness, as expressed with a range of numerical values and limit values, and are therefore suitable for simple comparative relationships as depicted on table 1. Meanwhile, data obtained from questionnaires were analyzed using descriptive statistics where frequency and percentages were recorded.

**Rainfall Seasonality Index**

The estimation Seasonality Rainfall Index was proposed by Walsh and Lawer (1981) is used to study the spatial and temporal change in rainfall behavior which contributes in improvement of water and management plans of water resources systems and agriculture in a certain region especially during dry seasons (Hasanain, 2017). The higher the seasonality index of a region the greater the water resources variability and scarcity in time, the more vulnerable the area to desertification (Patil, 2015). It is a known fact that rainfall seasonality is a complicated notion which integrates a numeral of independent components (Walsh and Lawer 198). Therefore, In order to define the seasonal contrasts, the seasonality index (*SI*) (Walsh and Lawer 1981), which is a function of mean monthly and annual rainfall, was computed using the formula:

$$\overline{\boldsymbol{SI}} = \frac{1}{\bar{R}} \sum_{n-1}^{n-12} \bar{X}_n - \frac{\bar{R}}{12} \quad \text{(Eq 1)}$$

The $\overline{\boldsymbol{SI}}$ is defined as the sum of the absolute deviation of mean monthly rainfall from the overall monthly mean divided by the mean annual rainfall.

where $\bar{\boldsymbol{X}}_{\boldsymbol{n}}$ = indicates the mean rainfall of month $\boldsymbol{n}$

and $\bar{\boldsymbol{R}}$ = the mean annual rainfall.

**Threshold Level Method (TLM)**

The second widely applied method is the threshold approach: a drought occurs when the hydrometeorological variable is below a predefined threshold (Beyene , *et al.*, 2014). Threshold level approaches are widely used to identify drought events in time series of hydrometeorological variables. However, the method used for calculating the threshold level can influence the quantification of drought events or even introduce artifact drought events In this study, seven levels were characterized for the methods of variable threshold by the used of calculated annual rainfall data quantile of the study area. These level were (1) ≥ 1050 mm (2) 1000-1050 mm (3) 950-1000 mm (4) 900-950 mm (5) 850-900 mm (6) 800-850 mm and (7) ≤ 800 mm. The levels obtained by these methods were applied to rainfall hydrometeorological variables for characterizing the drought conditions respectively.

**Rainfall Anomaly Index (RAI)**

Rainfall Anomaly Index (RAI) developed by (van Rooy , 1965) was used in depicting periods of dryness and wetness in the area. The use of rainfall anomaly index (RAI) as a single hydro-climatic index for the estimation of wetness and dryness conditions of climatic change for considering the small area, uniformity of the land areas with similar ecological properties or soil properties and limited or unavailability of hydro-meteorological data of any geographical area. In this technique, the precipitation values for the period of study were ranked in descending order of magnitude with the highest precipitation being ranked first and the lowest precipitation being ranked last. The average of the ten highest precipitation values as well as that of the ten lowest precipitation values for the period of study was calculated. The positive and negative RAI indices are computed by using the mean of ten extremes. The formular for calculating positive RAI (for positive anomalies) is given by;

$$\textbf{RAI} = +3\,\frac{P-\overline{P}}{\overline{M}-\overline{P}} \quad \text{(Eq 2)}$$

Let $\overline{M}$ be the mean of the ten highest precipitation records for the period under study, $\overline{P}$ the mean precipitation of all the records for the period, and the **P** precipitation for the specific year.

The formular for calculating negative RAI (for negative anomalies) is given by;

$$\textbf{RAI} = -3\,\frac{\overline{P}-P}{\overline{m}-\overline{P}} \quad \text{(Eq 3)}$$

Let $\overline{m}$ be the mean of the ten lowest precipitation records for the period under study. Then the negative RAI (for negative anomalies) for that year

The arbitrary threshold values of +3 and – 3 have been assigned to the mean of the ten most extreme positive and negative anomalies respectively. The positive or negative sign is related to the positive or negative precipitation anomalies.

**Rainfall Deciles index**

The Rainfall Deciles Index (RDI) is based on the distribution of a longer rainfall observation series into deciles or tenths of distribution. (Palmer , 1965; Tallaksen and van Lanen, 2004). It was developed as an improvement to the percent of normal precipitation or precipitation anomaly. Deciles are calculated based on the number of occurrences arranged from 1 to 10. The lowest values show that the climate is drier compared to average conditions, while greater values point to more humid conditions. All monthly precipitation values in a given period are ranked from the lowest toward the highest, and then the first decile denotes 10 % of the lowest quantity of precipitation; the second decile denotes precipitation values between 10 and 20 %, etc. The median corresponds to the quantity of precipitation having 50 % probability of occurrence within the period under study. Each group is attributed a description of the level of dryness or humidity. The state of humidity marked as "normal" (30-70 %) in the original deciles index has a wider classification into "slightly lower than normal", "normal" and "slightly above normal", which has been simplified and converted into a single category to enable easier comparison with other methods (Smakhtin and Hughes , 2004), as shown on table 1 respectively.

**Percent of normal precipitation**

The percent of normal precipitation (PN) or precipitation anomaly is based on the relationship between the monthly precipitation and an average monthly precipitation in the period under study. It is calculated by dividing actual precipitation by normal precipitation—typically considered and multiplying by 100% (Michael , 2007). This can be calculated for a variety of time scales, including monthly, seasonal, annual, or water year. Normal precipitation for a specific location is considered to be 100%.

**PNP =** $\frac{\text{actual precipitation}}{\text{normal precipitation}} \times \mathbf{100}$**…………………………………**(Eq 4)

**Effectiveness Test Analysis**

The effectiveness of the techniques adopted by the small scale farmers in the study area was analyzed using a 4-point Likert scaling test by Asika, (1991).

**ETV=** $\frac{\Sigma\ \text{Scale-grade x Corresponding Years}}{\textit{Total Number of Years under study}}$**…………………………………………….. Eq (5)**

Where: **ETV**= Effectiveness Test Value, **Σ**=summation, **Scale-grade =** is the number of years of drought indices identified which were depicted on figure 1-4 respectively. **Corresponding Years =** is number of identified years with drought indices, **Total Number of Years under study =** (40 years). The scale-grades were; < 0.2=Not effective (NE); 0.2-0.3 = less effective (LE); 0.3-0.4 =moderately effective (ME), > 0. 4= highly effective (HE). The Effectiveness Test Value (ETV) of < 2.0 was taken as the benchmark, below it any of the conservation techniques was considered as not effective (NE) within a given effective period (EP)

**Table 1. Limit Values for five drought indices**

| **S/N** | **DROUGHT INDICES / RATINGS** | **RDI** | **PN** | **RAI** | **RSI** | **TLM** |
|---|---|---|---|---|---|---|
| 1 | EXTREMELY WET | >90 | **≥ 110** | **≥ 3,00** | ≥1.20 | **≥ 1050** |
| 2 | VERY WET | 80 to 90 | | **2 to 2.99** | 1.00–1.19 | 1000-1050 |
| 3 | MODERATELY WET | 70 t0 80 | | 1 to 1.99 | 0.80–0.99 | 950-1000 |
| 4 | NORMAL | 30 to 70 | 80 to 110 | **0.5 to -0.99** | 0.60–0.79 | 900-950 |
| 5 | MODERATELY DRY | 20 to 30 | **55 to 80** | **-1.00 to -1.99** | 0.4–0.59 | 850-900 |
| 6 | VERY DRY | 10 to 20 | 40 to 55 | **-2.00 to -2.99** | 0.20–0.39 | 800-850 |
| 7 | EXTREMELY DRY | < 10 | **≤ 40** | **≤ -3,00** | ≤ 0.19 | ≤ 800 |

## RESULTS AND DISCUSSIONS

### Characterization of Drought Conditions Using Different Drought Indices

Results on characterized period of drought conditions were presented on table 2-9 accordingly. Extremely wet condition was identified in four years (2012, 2015, 2016 and 2005) using PN indices while using TLM and RSI indices three (2012, 2016 and 2005) years were characterized respectively. The RDI and RAI drought indices did not identify any year with extremely wet condition. This result revealed that the use of PN, RSI and TLM is most favorable than other three combined methods. In addition, very wet condition was characterized in the following years 2004, 2006, 2009, 2014, 2015, 2017, 2018, 2019 and 2020 using RSI while using TLM indices only one years (2015) was recognized to have experience very wet condition. RDI, PN and RAI show no any very wet condition within the period of study. The result characterized RSI and TLM combined indices as most suitable while RSI as the favorable single index for quantify very wet condition. Four (4) years (2007, 2010, 2011 and 2013) of moderately wet condition was characterized using RSI while one year (2014) was characterized using TLM and the other indices (RDI, PN and RAI) shows no any moderate wet condition respectively. Therefore, RSI can be most suitable to quantify the moderate condition. Normal condition of rainfall event was characterized using all the drought indices except RSI. For the RDI seven years ( 2004, 2005, 2006, 2012, 2014, 2015 and 2016) were characterized with normal condition, PN indices characterized thirteen (13) years; 2004, 2006, 2007, 2008, 2009, 2010, 2011, 2013, 2014, 2017, 2018, 2019 and 2020, while RAI recognized normal condition in 2004 and 2020 and TLM indices characterized in 2004, 2006, 2017, 2018, 2019 and 2020 respectively. For the moderately dry condition only TLM indices revealed it in 2009 while the other four indices (RDI, PN, RAI and RSI) shows no such condition. A very dry condition was characterized in five years (2009, 2017, 2018, 2019 and 2020) and TLM indices characterized in the year 2008 only. This result shows that RDI is the most suitable for very dry condition quantification. The PN, RAI and RSI did not show any very dry condition within the period of study. Similarly, RDI characterized five years of extremely dry condition (2007, 2008, 2010, 2011 and 2013) and four years (2007, 2010, 2011 and 2013) were characterized using TLM indices. The other indices (PN, RAI and RSI) did not recognized extremely dry condition within the period of study.

**Table 2. Calculated Values of The Five Drought Indices**

| S/N | YEAR | RDI (mm) | PN (%) | $RAI_{10}$ | RSI | TLM (mm) |
|---|---|---|---|---|---|---|
| 1 | 2004 | 937.40 | 104.56 | 0.00 | 1.07 | 937.40 |
| 2 | 2005 | 1,100.40 | 122.74 | 0.02 | 1.26 | 1,100.40 |
| 3 | 2006 | 933.50 | 104.12 | 0.00 | 1.07 | 933.50 |
| 4 | 2007 | 719.70 | 82.71 | -0.01 | 0.82 | 719.70 |
| 5 | 2008 | 845.00 | 97.18 | -0.00 | 0.97 | 845.00 |
| 6 | 2009 | 896.00 | 99.90 | 0.00 | 1.03 | 896.00 |
| 7 | 2010 | 779.50 | 89.64 | -0.00 | 0.89 | 779.50 |
| 8 | 2011 | 763.80 | 87.84 | -0.01 | 0.87 | 763.80 |
| 9 | 2012 | 1,342.90 | 154.44 | 0.05 | 1.54 | 1,342.90 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 10 | 2013 | 748.80 | 83.52 | -0.01 | 0.86 | 748.80 |
| 11 | 2014 | 964.40 | 107.57 | 0.01 | 1.10 | 964.40 |
| 12 | 2015 | 1004.50 | 112.04 | 0.01 | 1.15 | 1004.50 |
| 13 | 2016 | 1,150.40 | 128.31 | 0.03 | 1.32 | 1,150.40 |
| 14 | 2017 | 930.18 | 103.75 | 0.00 | 1.06 | 930.18 |
| 15 | 2018 | 919.00 | 102.50 | 0.00 | 1.05 | 919.00 |
| 16 | 2019 | 918.50 | 102.45 | 0.00 | 1.05 | 918.50 |
| 17 | 2020 | 928.10 | 103.52 | 0.00 | 1.06 | 928.10 |

**Table 3. Characterization of Extremely Wet Condition Using Drought Indices**

| S/N | RDI | PN | RAI | RSI | TLM |
|---|---|---|---|---|---|
| 1 | NILL | 2012 | NILL | 2012 | 2012 |
| 2 | NILL | 2015 | NILL | 2005 | 2016 |
| 3 | NILL | 2016 | NILL | 2016 | 2005 |
| 4 | NILL | 2005 | NILL | NILL | NILL |

**Table 4. Characterization of Very Wet Condition Using Drought Indices**

| S/N | RDI | PN | RAI | RSI | TLM |
|---|---|---|---|---|---|
| 1 | NILL | NILL | NILL | 2004 | 2015 |
| 2 | NILL | NILL | NILL | 2006 | NILL |
| 3 | NILL | NILL | NILL | 2009 | NILL |
| 4 | NILL | NILL | NILL | 2014 | NILL |
| 5 | NILL | NILL | NILL | 2015 | NILL |
| 6 | NILL | NILL | NILL | 2017 | NILL |
| **7** | NILL | NILL | NILL | 2018 | NILL |
| 8 | NILL | NILL | NILL | 2019 | NILL |
| 9 | NILL | NILL | NILL | 2020 | NILL |

**Table 5. Characterization of Moderately Wet Condition Using Drought Indices**

| S/N | RDI | PN | RAI | RSI | TLM |
|---|---|---|---|---|---|
| 1 | NILL | NILL | NILL | 2007 | 2014 |
| 2 | NILL | NILL | NILL | 2010 | NILL |
| 3 | NILL | NILL | NILL | 2011 | NILL |
| 4 | NILL | NILL | NILL | 2013 | NILL |

**Table 6. Characterization of Normal Condition Using Drought Indices**

| S/N | RDI | PN | RAI | RSI | TLM |
|---|---|---|---|---|---|
| 1 | 2004 | 2004 | 2004 | NILL | 2004 |
| 2 | 2005 | 2006 | 2020 | NILL | 2006 |
| 3 | 2006 | 2007 | NILL | NILL | 2017 |
| 4 | 2012 | 2008 | NILL | NILL | 2018 |
| 5 | 2014 | 2009 | NILL | NILL | 2019 |
| 6 | 2015 | 2010 | NILL | NILL | 2020 |
| 7 | 2016 | 2011 | NILL | NILL | NILL |
| 8 | NILL | 2013 | NILL | NILL | NILL |
| 9 | NILL | 2014 | NILL | NILL | NILL |
| 10 | NILL | 2017 | NILL | NILL | NILL |
| 11 | NILL | 2018 | NILL | NILL | NILL |
| 12 | NILL | 2019 | NILL | NILL | NILL |
| 13 | NILL | 2020 | NILL | NILL | NILL |

**Table 7. Characterization of Moderately Dry Condition Using Drought Indices**

| S/N | RDI | PN | RAI | RSI | TLM |
|---|---|---|---|---|---|
| 1 | NILL | NILL | NILL | NILL | 2009 |

**Table 8. Characterization of Very Dry Condition Using Drought Indices**

| S/N | RDI | PN | RAI | RSI | TLM |
|---|---|---|---|---|---|
| 1 | 2009 | NILL | NILL | NILL | 2008 |
| 2 | 2017 | NILL | NILL | NILL | NILL |
| 3 | 2018 | NILL | NILL | NILL | NILL |
| 4 | 2019 | NILL | NILL | NILL | NILL |
| 5 | 2020 | NILL | NILL | NILL | NILL |

**Table 9. Characterization of Extremely Dry Condition Using Drought Indices**

| S/N | RDI | PN | RAI | RSI | TLM |
|---|---|---|---|---|---|
| 1 | 2007 | NILL | NILL | NILL | 2007 |
| 2 | 2008 | NILL | NILL | NILL | 2010 |
| 3 | 2010 | NILL | NILL | NILL | 2011 |
| 4 | 2011 | NILL | NILL | NILL | 2013 |
| 5 | 2013 | NILL | NILL | NILL | NILL |

**Quantification of Drought Condition Using Different Drought Indices**

Results on the quantified drought condition using different drought indices were shown in Table 10-16. The results revealed that three drought indices ( PN, RSI and TLM) were characterized in the year 2005, 2013 and 2016 under extremely wet condition while two drought indices of RSI and TLM and PN and RSI both revealed the condition in three years (2005, 2012 and 2016) as presented on Table 10 respectively. Very wet condition was quantified with two drought indices ( RSI and TLM ) in the year 2015 while single drought index (RSI) quantified condition in the following years of 2004, 2006, 2009, 2014, 2017, 2018, 2019 and 2020 as depicted in Table 11 respectively. In addition, single drought index of RSI quantified the moderately wet condition in the study for four years (2007, 2010, 2011 and 2013) and also TLM was estimated in the year 2014 as presented in Table 12 accordingly. Furthermore, Table 13 shows the normal condition of precipitation in the area, where four drought indices (RDI, PN, RAI and TLM) quantified the scenario in 2004, three drought indices of RDI, PN and TLM was found in 2004 and 2006 and PN, RAI and TLM was recognized in 2020 respectively. Two drought condition was characterized (TLM and PN) in the following years ; 2004, 2006, 2017, 2018, 2019 and 2020 and single drought index of RDI was quantified in five years (2005, 2012, 2014, 2015 and 2016) and PN was quantified in six consecutive years (2007, 2008, 2009, 2010, 2011 and 2013). Moreover, single drought index of TLM was found to have quantified moderately dry condition in 2009 only as portrayed in Table 14. For the very dry condition RDI was quantified the condition in five years (2009, 2017, 2018, 2019 and 2020) while TLM recognized it in 2008 within the period of the study as depicted in Table 15. Quantified condition of extremely dry event was revealed with two combined indices (RDI and TLM) for the period of four (4) years (2007, 2010, 2011 and 2013) while single index of RDI was quantified the condition in 2008 as shown in Table 16 respectively.

**Table 10. Quantification of Extremely Wet Condition Using Drought Indices**

| S/N | YEARS | DROUGTH INDICES | NUMBER |
|---|---|---|---|
| 1 | 2005 | PN, RSI & TLM | 3 |
| 2 | 2012 | PN, RSI & TLM | 3 |
| 3 | 2016 | PN, RSI & TLM | 3 |
| 4 | 2012 | RSI &TLM | 2 |
| 5 | 2005 | RSI &TLM | 2 |
| 6 | 2016 | RSI &TLM | 2 |
| 7 | 2012 | PN & RSI | 2 |
| 8 | 2016 | PN & RSI | 2 |
| 9 | 2005 | PN & RSI | 2 |
| 10 | 2015 | PN | 1 |

**Table 11. Quantification of Very Wet Condition Using Drought Indices**

| S/N | YEARS | DROUGTH INDICES | NUMBER |
|---|---|---|---|
| 1 | 2015 | RSI & TLM | 2 |
| 2 | 2004 | RSI | 1 |
| 3 | 2006 | RSI | 1 |
| 4 | 2009 | RSI | 1 |
| 5 | 2014 | RSI | 1 |
| 6 | 2017 | RSI | 1 |
| 7 | 2018 | RSI | 1 |
| 8 | 2019 | RSI | 1 |
| 9 | 2020 | RSI | 1 |

**Table 12. Quantification of Moderately Wet Condition Using Drought Indices**

| S/N | YEARS | DROUGTH INDICES | NUMBER |
|---|---|---|---|
| 1 | 2007 | RSI | 1 |
| 2 | 2010 | RSI | 1 |
| 3 | 2011 | RSI | 1 |
| 4 | 2013 | RSI | 1 |
| 5 | 2014 | TLM | 1 |

**Table 13. Quantification of Normal Condition Using Drought Indices**

| S/N | YEARS | DROUGTH INDICES | NUMBER |
|---|---|---|---|
| 1 | 2004 | RDI, PN, RAI & TLM | 4 |
| 2 | 2006 | RDI, PN, & TLM | 3 |
| 3 | 2004 | RDI, PN, & TLM | 3 |
| 4 | 2020 | PN, RAI & TLM | 3 |
| 5 | 2004 | TLM & PN | 2 |
| | 2006 | TLM & PN | 2 |
| | 2017 | TLM & PN | 2 |
| | 2018 | TLM & PN | 2 |
| | 2019 | TLM & PN | 2 |
| | 2020 | TLM & PN | 2 |
| | 2005 | RDI | 1 |
| | 2012 | RDI | 1 |
| | 2014 | RDI | 1 |
| | 2015 | RDI | 1 |
| | 2016 | RDI | 1 |
| | 2007 | PN | 1 |
| | 2008 | PN | 1 |

| | | |
|---|---|---|
| 2009 | PN | 1 |
| 2010 | PN | 1 |
| 2011 | PN | 1 |
| 2013 | PN | 1 |

**Table 14. Quantification of Moderately Dry Condition Using Drought Indices**

| S/N | YEARS | DROUGTH INDICES | NUMBER |
|---|---|---|---|
| 1 | 2009 | TLM | 1 |

**Table 15. Quantification of Very Dry Condition Using Drought Indices**

| S/N | YEARS | DROUGTH INDICES | NUMBER |
|---|---|---|---|
| 1 | 2009 | RDI | 1 |
| 2 | 2017 | RDI | 1 |
| 3 | 2018 | RDI | 1 |
| 4 | 2019 | RDI | 1 |
| 5 | 2020 | RDI | 1 |
| 6 | 2008 | TLM | 1 |

**Table 16. Quantification of Extremely Dry Condition Using Drought Indices**

| S/N | YEARS | DROUGTH INDICES | NUMBER |
|---|---|---|---|
| 1 | 2007 | RDI & TLM | 2 |
| 2 | 2010 | RDI & TLM | 2 |
| 3 | 2011 | RDI & TLM | 2 |
| 4 | 2013 | RDI & TLM | 2 |
| 5 | 2008 | RDI | 1 |

**The Replication of the Combined Drought Indices in the Study Area**

Figure 1-4 described different combination of the applied drought indices within the period of the study. Four (4) combined drought indices were appeared once as shown in Figure 1. Three combined drought indices of PN, RSI and TLM were appeared three times, RDI, PN and TLM appeared two times and PN, RAI and TLM have appeared once as presented in Figure 2. Two combined drought indices of RSI and TLM was repeated four (4) times, followed by PN and RSI replicated three (3) times and PN and TLM and RDI and TLM each appeared once as described in Figure 3 respectively. Single drought index RSI appeared twelve (12) times, RDI eleven (11) times, PN seven (7) times and TLM three (3) times as portrayed in Figure 4 accordingly.

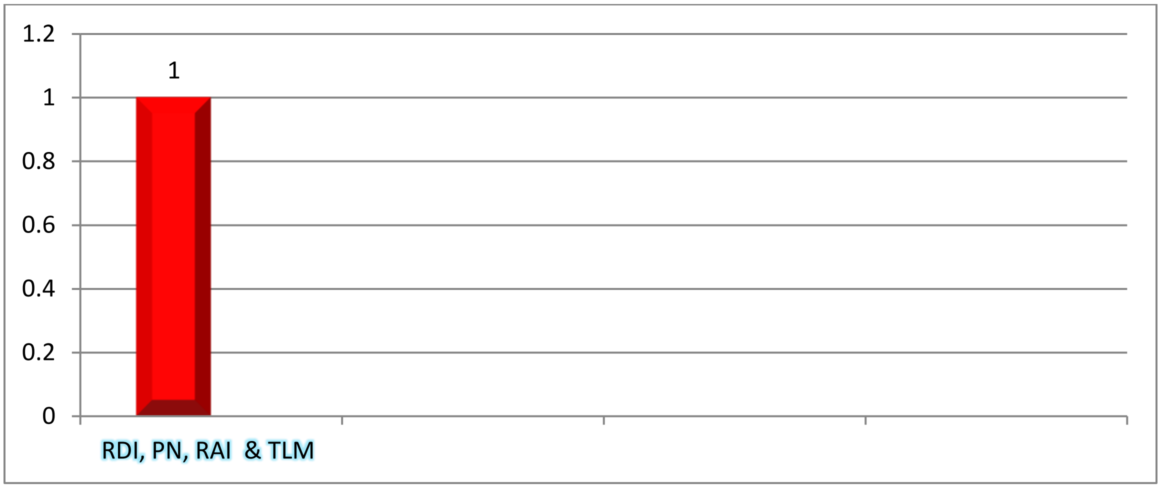


**Figure 1. The characterized and quantified years of four (4) combined drought indices**

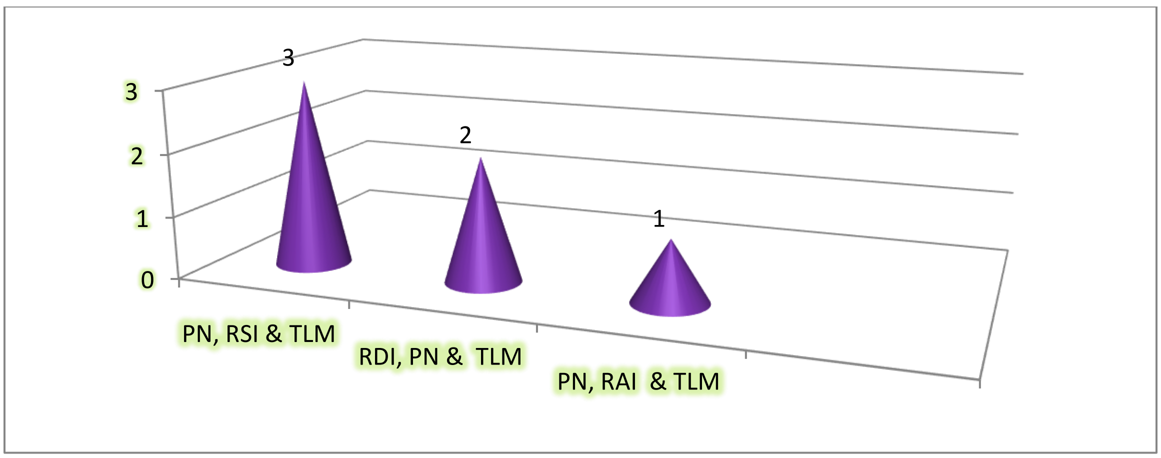


**Figure 2. The characterized and quantified years of three (3) combined drought indices**

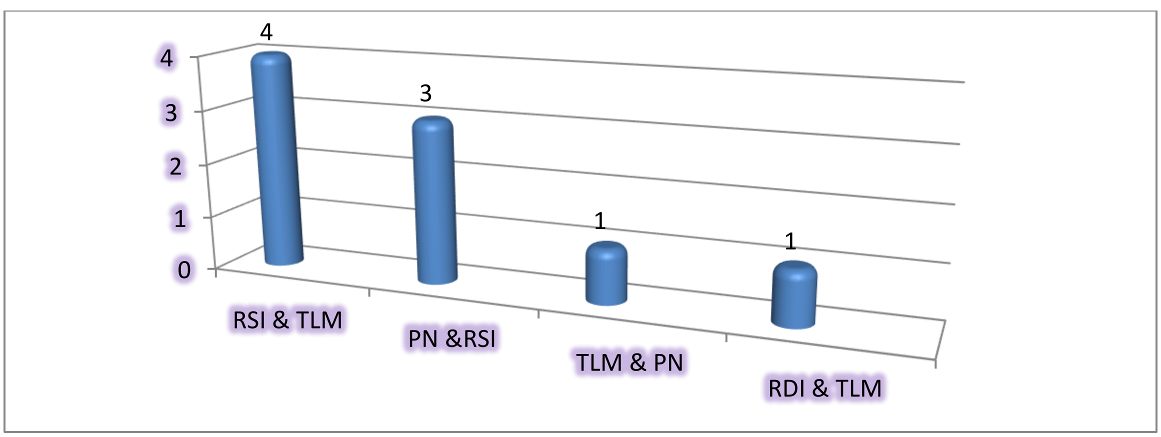


**Figure 3. The characterized and quantified years of two (2) combined drought indices**

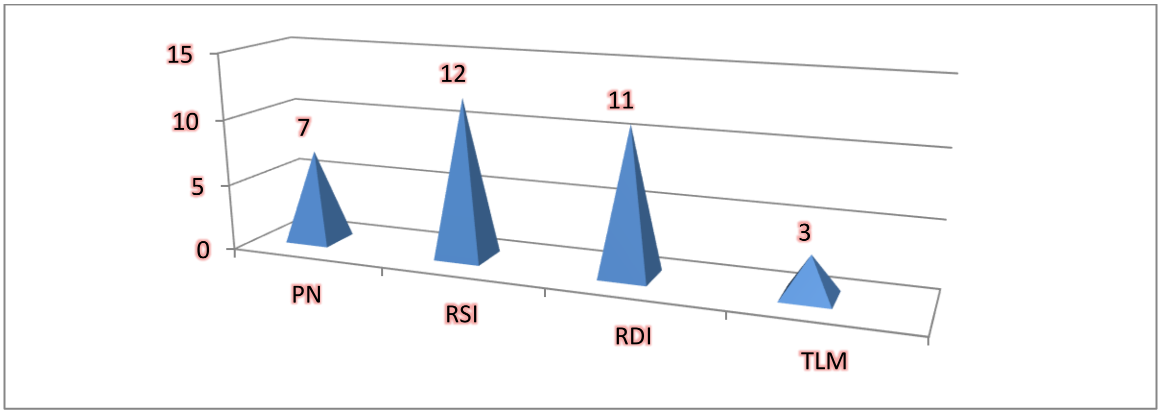


**Figure 4. The characterized and quantified years of single (one) drought index**

**Effectiveness Test Value Analysis for the Characterized and Quantified Drought Indices**

Results on effectiveness Test Value Analysis for the characterized and quantified drought indices were presented in Table 17. There is no combination of all the applied drought indices within the study period in the area. However, four (4) combined indices exist with ETV of 0.23 considered as less effective. Similar finding was reported by Sadiq *et al.*, (2022) who observed that RDI, PN, RAI and TLM were moderately effective. Thus, Lidija *et al.*, (2014) recommended the use four drought indices (SPI, RDI, RAI and PN) in Crotia due to their positive correlation. For the three (3) combined drought indices the PN, RSI and TLM was found to be highly effective having ETV of 0.52 while RDI, PN and TLM was moderately effective (ETV = 0.35) and not effective was observed with PN, RAI and TLM having ETV of 0.17 respectively. This result revealed that the application of PN, RSI and TLM is suitable and recommended than using other three combinations. In addition, two combined drought indices was also recognized where RSI and TLM was rated highly effective with calculated ETV of 0.47 while PN and RSI was moderately effective (ETV= 0.35) and PN and TLM and RDI and TLM were both rated not effective having the same ETV of 0.11 accordingly. This result explained that RSI and TLM indices are suitable in the area when using double indices. Among the single drought indices, PN, RSI and RDI were rated as highly effective with corresponding values 0.41, 0.70 and 0.64 while TLM was found to be not effective (ETV =0.17) respectively. These results are not in conformity with the finding of Sadiq et al., (2022) who observed not effectiveness of single drought index (RDI, RAI, TLM, RSI and PN in Yola area Northern part of Nigeria. However, this result is not in conformity with outcome of Alatise and Ikumawoyi (2007) who stated that RAI is most favourable method in Lokoja area of Nigeria. Generally, there are no physical arguments to prefer one method over the other from drought identification as stated by Beyene *et al.*, (2014).

**Table 17. Results for the effectiveness Test Value Analysis for the identified drought indices**

| Four Combined Drought Indices | Effectives Test value (ET) | Effectiveness Rating (ER) |
|---|---|---|
| RDI, PN, RAI & TLM | 0.23 | Less Effective |
| **Three Combined Drought Indices** | **ET** | **ER** |
| PN, RSI & TLM | 0.52 | Highly Effective |
| RD1, PN & TLM | 0.35 | Moderately Effective |
| PN, RAI & TLM | 0.17 | Not Effective |
| **Two Combined Drought Indices** | **ET** | **ER** |
| RSI & TLM | 0.47 | Highly Effective |
| PN & RSI | 0.35 | Moderately Effective |
| PN & TLM | 0.11 | Not Effective |
| RDI & TLM | 0.11 | Not Effective |
| **Single Drought Indices** | **ET** | **ER** |
| PN | 0.41 | Highly Effective |
| RSI | 0.70 | Highly Effective |
| RDI | 0.64 | Highly Effective |
| TLM | 0.17 | Not Effective |

**Farmer's perception on the causes, severity, effect and mitigation strategies of drought scenario in the study area**

The results on the farmer's perception on the causes, severity level, effects and mitigation strategies of drought in the study area are presented on Table 18. The results on the causes of drought condition in the areas shows that deforestation was perceived as the major cause of drought by most of the framers (40 %) in the area, followed by overgrazing (20 %), bush burning and emissions of greenhouse gases each recorded as 15 % and least causes of drought perceived by the farmers is use of poor cropping methods (5 %) respectively. This result revealed that deforestation is the utmost factor that causes drought in the area this is because tree and vegetation cover are essential for the water cycle as it helps to limit evaporation, stores water and attracts rainfall and also contribute a great deal of atmospheric moisture in the form of transpiration as explained by Yitbarek and Huseyin, (2020).

In addition, perception of farmers on the severity level of seasonal drought condition revealed that normal condition is perceived as the most frequent (40 %), followed by 25 % with moderately condition, very severe (20 %) and extremely severe was perceived by only 15 % respectively. This finding shows that drought condition in the study has ranged from normal to moderate as perceived by the farmers. However, there are trends of rare occurrences of very severe to extremely severe conditions which might have serious effect on agricultural production.

Farmer's perception on the year interval experience drought in the study area presented on Table 18 revealed that the years 2009-2014 is perceived to have frequent (45 %) occurrences of drought followed by the years 2004-2008 (30 %) and 2015-2020 is the lowest (25%) years to have frequent drought respectively. This perception is correlated positively with the calculated drought from the indices which shows that the year 2009, 2010, 2011 and 2013 are the very sever and extremely severe which are within the period of 2009-2014.

Moreover, farmer's perception on the effects of drought on agricultural production in the study area shows that reduction of crop yield is the major (35 %) effect of drought . The manifestation of reduced crop yield as the major direct effect experienced by the farmers due to drought condition in this study is in conformity with the report of Abaje and Magaji (2022) revealed that farmers' perceived decline in crop yields as the most significant impact of drought in Mashi local government area of Kastina State Nigeria. This also agrees with Abubakar *et al.* (2019), Orimoloye *et al.* (2022) and Ayugi *et al.* (2022) that the most immediate effect of drought on the farming sector is a fall in crop production as a result of crops withering and dying. However, the resultant effect of drought-induced decrease in crop yields is shortage of food and consequently hike in the food crops in the market due to limited supply. This also agrees with Orimoloye *et al.* (2022) that drought is the primary cause of grain output shortages relative to consumption, therefore, posing a threat to food security. Generally, the poor crop yields or total crop failure due to drought result in mass poverty and starvation as agriculture is the mainstay of Nigeria's rural economy (Abubakar and Yamusa, 2013). In addition, pest and disease outbreak and loss of pasture and vegetation each was perceived by 20 % of the farmers and the drying of water bodies is perceived by 15 % of the farmers and 10 % is recorded to each of the starvation and dead of livestock, loss of pasture and vegetation and loss of soil fertility.

Based on the farmer's perception on the agronomic mitigation strategies adopted towards drought in the study area shows that use of early maturing crops is considered as the main (35 %) strategy towards mitigation drought in the area. This finding agreed with the recent report of Abaje and Magaji, (2022) who reported that planting of crops with early maturity is a sustainable strategy as perceived by the farmers because it involves the use of scientific innovation of genetically modified varieties that matured in a short period to cope with the short growing season. Early planting was also perceived by 20 % of the farmers in the area. Gana, *et al.*, (2021) revealed that timing of planting is important, as improper timing can exacerbate drought impacts. Planting of trees and late planting methods are perceived by 15 % of the farmers and harvesting of rain water in only 5 %. The use of planting of economic trees (afforestation) which is significant as perceived by the respondents is a sustainable adaptation strategy that helps in reducing land degradation and increases soil-water availability during drought. It also creates a carbon sink and helps in mitigating global warming. Gana, *et al.*, (2021) explained that establishing and restoring forests is important to reverse environmental degradation and provide habitats to affected organisms.

**Table 18. Shows the farmer's perception on the causes, severity level, effects and mitigation strategies in the study area**

| Farmer's perception on the causes drought in the study area | | | |
|---|---|---|---|
| **S/n** | **Causes of Drought** | **Frequency (180)** | **Percentage (100 %)** |
| 1 | Deforestation | 72 | 40 |
| 2 | Overgrazing | 36 | 20 |
| 3 | Bush burning | 27 | 15 |
| 4 | Drying of water bodies | 09 | 05 |
| 5 | Emissions of greenhouse gases | 27 | 15 |
| 5 | Poor Cropping methods | 09 | 05 |
| **Farmer's perception on the severity level of seasonal drought in the study area** | | | |
| **S/n** | **Severity level of seasonal drought** | **Frequency (180)** | **Percentage (100 %)** |
| 1 | Extremely severe | 27 | 15 |
| 2 | Very Severe | 36 | 20 |
| 3 | moderately severe | 45 | 25 |
| 4 | Normal condition | 72 | 40 |
| **Farmer's perception on the year interval experience drought in the study area** | | | |
| s/n | **Years intervals** | **Frequency ( 180)** | **Percentage (100 %)** |
| 1 | 2004-2008 | 54 | 30 |
| 2 | 2009-2014 | 81 | 45 |
| 3 | 2015-2020 | 45 | 25 |
| **Farmer's perception on the effects of drought on agricultural production in the study area** | | | |
| **S/n** | **Effects of Drought** | **Frequency (180** | **Percentage (100 %)** |
| 1 | Reduction of crop yield | 63characterized | 35 |
| 2 | Pest and disease outbreak | 36 | 20 |
| 3 | Starvation and Dead of livestock | 18 | 10 |
| 4 | Loss of pasture and vegetation | 18 | 10 |
| 5 | Loss of soil fertility | 18 | 10 |
| 5 | Drying of water bodies | 27 | 15 |
| **Farmer's perception on the agronomic mitigation strategies adopted towards drought in the study area** | | | |
| s/n | **Mitigation strategies adopted** | **Frequency (180)** | **Percentage (100 % )** |
| 1 | Planting of trees (afforestation) | 27 | 15 |
| 2 | Use of early maturing crops | 63 | 35 |
| 3 | Early planting | 36 | 20 |

| | | | |
|---|---|---|---|
| 4 | Late planting | 27 | 15 |
| 5 | Farmers awareness about the drought | 18 | 10 |
| 6 | Harvesting rain water | 09 | 05 |

## CONCLUSIONS

Drought scenario is considered as one the most hazardous factor threatens the world environment which received much research concerns by relevant agencies in various geographical regions of the world. Such attempt of research was conducted in Mubi areas aimed at characterizing and quantifying the drought events through the use of multi-variant indices and its effects on agriculture. The study revealed that the index preferably to characterized drought condition was in the order of TLM, RDI, PN RSI and RAI. Meanwhile, for the quantification PN, RSI and TLM, RSI and TLM and RSI are considered as most suitable in the area. In addition, the highly effective indices with ETV > 0.4 are PN, RSI and TLM with three combinations, RSI and TLM for double indices. Among the single index the PN, RSI and RDI are found to be highly effective respectively. Deforestation and overgrazing are the major causes of drought scenarios in the area that occurred mostly in 2009-2014 affecting crop yields and pest and diseases infestation. The farmers' uses early maturing crops and early planting are found to major mitigation strategies adopted in the area. Thus, the adoption of the highly effective identified indices (PN, RSI and TLM and RSI and TLM) should therefore be adopted in the region towards understanding the drought conditions for sustainable agricultural production and mitigation strategies. Farmers in the area should be train on the drought mitigation.

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