IJAAR PUBLISHING®

International Journal of Advanced Academic Research | ISSN: 2488-9849
Vol. 9, Issue 11 (November, 2023) | www.ijaar.org

ASSESSING THE EFFECTIVENESS OF SPI AND PDBM INDICES IN METEOROLOGICAL DROUGHTS DETECTION; A COMPARATIVE APPROACH.

BY:

LAWAN BULAMA[1], EJEH LAWRENCE UDEH[2], ADAMU IBRAHIM[3], FATIMA MUHAMMAD ALAMAI[4] AND MUSTAPHA ALIBE[5]

[1, 2, 3, 4]DEPARTMENT OF GEOGRAPHY, FEDERAL UNIVERSITY GASHUA, YOBE STATE.

[5]DEPARTMENT OF GEOGRAPHY, UMAR IBN IBRAHIM EL-KANEMI COLLEGE OF EDUCATION, SCIENCE AND TECHNOLOGY, BAMA, BORNO STATE.
ALIBE1234@YAHOO.COM

[1]Corresponding Author:
e-mail: Comradelawanbulama@gmail.com
08065029050.

ABSTRACT

This study conducts a detailed analysis of the comparative performance of two meteorological drought detection indices, namely the Standardized Precipitation Index (SPI) and the Percentage Deviation Below Mean Index (PDBM). The research focuses on a 60-year dataset (1956-2015) of annual rainfall records from meteorological stations in North-east Nigeria, provided by the Nigerian Meteorological Agency (NIMET) Oshodi. The stations utilized for this analysis include Nguru, Maiduguri, Bauchi, Yola, Gombe, and Jalingo. Rainfall data from these stations were aggregated and averaged to create a unified rainfall series for the sub-region. This combined dataset was subjected to SPI and PDBM analyses to comprehensively assess three key meteorological drought properties: frequency, duration, and magnitude, over a 12-month time scale. To illustrate the variation in drought magnitudes, SPI anomaly graphs were generated, and a bar graph was constructed to compare the performance of the two indices. The results revealed significant disparities between the two indices. Notably, SPI detected a larger number of drought events compared to PDBM, with 30 drought events identified by SPI as opposed to 17 by PDBM. SPI effectively detected various intensities of drought, including mild, moderate, severe, and extreme droughts, while PDBM primarily identified slight-intensity droughts. Furthermore, SPI captured drought events of higher magnitude, detecting four severe and three extreme droughts, while PDBM failed to identify any high-intensity droughts. These findings contribute to the existing body of knowledge on drought research, offering valuable insights for decision-makers and researchers. The study's conclusion highlights the superior performance of the SPI model in meteorological drought detection and recommends a review and enhancement of the PDBM model.

KEYWORDS: Meteorological, Drought, SPI, Frequency, Intensity.

Bulama, L., Udeh, L.E., Ibrahim, A.; Alamai, M.F. & Alibe, M. (2023). Assessing the Effectiveness of SPI and PDBM Indices in Meteorological Droughts Detection; A Comparative Approach. *International Journal of Advanced Academic Research*, 9(11), 1-11.

1.1 Introduction

Climate change and its attendance challenges such as droughts**,** floods, global warming etc. are things of concern to researchers and policy makers all over the globe. It has been in the public domain and discourse but locally and globally for some couple of decades now. One of the unequivocal indicators of climate change is the change in rainfall pattern giving some places little rain while other places too much rain. Areas that received little rainfall drought occurrence while areas that received too much rainfall may experience flood.

An analysis by climate scientists at the National Centre for Atmospheric Research (NCAR) in the United States (2012) hinted that drought is the second most geographically extensive hazard after floods covering 7.5 per cent and 11 per cent of the global land area each. The land area, population and GDP loss affected by drought amount to 970 million km^2, \$57.3 billion and \$108.6 billion US dollars respectively. Rossi *et al*., (2007) put forward that the percentage of Earth's land area stricken by serious drought more than doubled from the 1970s to the early 2000s. Drought is the world's costliest natural disaster causing an average of \$6 - \$8 billion in global damages annually and collectively affects more people than any other natural disaster. Drought from time immemorial has always constituted a threat to mankind (Ayoade, 2015). It has been a matter of serious concern to man since ancient times, and even today, it is an outstanding example of man's helplessness before nature's large-scale and formidable phenomenon. It is ranked as one of the foremost among earth's natural hazards representing the adverse effects due to a shortage of water mainly from rainfall (Jat *et al*., 2010).

Incidences of drought have incessantly occurred over many parts of Northern Nigeria especially in the Arid and semi-arid areas (North-east inclusive), in varying scales of severity, frequency and duration at different years with tremendous concomitant calamity in the form of Lake Chad receding or shrinkage, widespread crop failures, low agricultural yield, lost of livestock, mass starvation (even famines), cessation of economic activities, migration of people and the host of others. The considerable distress arising out of drought occurrences draw the attention of researchers, and national and international agencies to have appropriate and reliable drought indicator with good performance efficiency to quantify drought condition and calamity in our environment. The indicators are called indices such as the Standardized Precipitation Index (SPI), Percentage Deviation Below Mean Index (PDBM), Rainfall Anomaly Index (RAI), Bhalme and Mooley Drought Index (BMDI), etc. Drought indices are essential tools for the characterization and monitoring of drought. They simplify complex climatic functions and quantify climatic anomaly as for its severity, frequency and duration (Tigkas *et al.*, 2015)

The preceding analysis highlights the significance of drought as a prominent consequence of climate change. It also underscores the limited attention that the performance efficiency of indices capturing drought events has received in scientific literature. This underscores the necessity for a thorough comparative assessment of meteorological drought detection performance between the SPI and PDBM models. This study aims to bridge this gap by offering valuable insights to potential users of these indices for drought investigations, thus enhancing the decision-making process in addressing drought-related challenges. .

2.1 Materials and Methods

Several materials were used in this paper and including: 'e-views software (9.0) for the rainfall normality test, Microsoft Excel Worksheet used for the computations and determination of Standardized Precipitation Index (SPI) and Percentage Deviation Below Mean Index (PDBM) values, ARC/INFO GIS 9.3 software and digitizer for map production of the study area.

In the study area, six meteorological stations were considered. Rainfall records spanning a period of 60 climatological years (1956-2015) were fully utilized. The stations and their locations are shown in table 1 below.

Table 1: Meteorological stations used and their geographical locations

S/N	Station	Latitude	Longitude	Elevation (m)
1.	Nguru	12 º 58 ' N	10 º 28 ' E	500
2.	Maiduguri	11 º 51' N	13 º 05 ' E	500
3.	Bauchi	10 º 17 ' N	9 º 49 ' E	700
4.	Yola	9 º 14' N	12 º 28' E	700
5.	Gombe	10 º 29' N	11 º 15' E	700
6	Jalingo	8 º 38 ' N	10 º 46 ' E	600

Source: Nigerian Meteorological Agency Oshodi, Lagos, 2010.

2.1.1 Estimation of Drought Using SPI Index

Standardized precipitation index (SPI) is a widely used empirical index developed in Colorado by McKee *et al*., (1993) for quantification of rainfall deficit and monitoring of drought conditions (Wambua, *et al*., 2015). It is a relatively newer and effective index used by National Drought Mitigation Center for quantitative detection and description of droughts of varying intensities (Hayes, 1999). It is based only on precipitation and can be used to monitor conditions on a variety of timescales. It uses the rainfall parameter as the sole climatological input for the computation. The nature of the SPI allows an analyst to determine the rarity of a drought or an anomalously wet event at a particular time scale for any station with precipitation records, it facilitates the identification of different drought types and is known with computational simplicity and reliable results. It has the attribute of demanding long-term rainfall data and neglecting other variables like temperature (Wambua, *et al.,* 2015; Kamali *et al*., 2017; Mondol *et al.,* 2017).

The SPI is the average cumulative seasonal rainfall of available synoptic stations. It is a number of standard deviations that the observed value would deviate from the long-term mean (Ali, 2010). The SPI calculation for any location is based on the long-term precipitation record for the desired period. This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Lucio *et al.,* 2012).

The study adopted 12-month timescale because of its robustness, reliability, and suitability in meteorological drought analysis (Umar, 2013). Drought occurs when the SPI value reads negative whereas, a positive value indicates no drought. The greater the negative deviation, the more severity the drought (Onchiri *et al*., 2016, Umar, 2023). Following the standard procedure, the monthly rainfall totals were summed to form an annual series for each station. And the annual values for all the stations were aggregated and totalled into a single series and the climatological long-term mean and standard deviation were arithmetically calculated within the Microsoft Excel statistical software. The positive and negative anomalies from the long-term mean (normals) were calculated using the SPI formula for each station.

A SPI value is calculated using the formula below;

$$SPI = \frac{Xik - \bar{X}}{\delta i} \quad \text{.......i}$$

$$\text{Mean} = \bar{x} = \frac{\sum x}{\text{N}} \quad \text{.......ii}$$

Where

$\chi ik =$ Observed rainfall for the station

$\bar{x}$ = Mean rainfall for the station

δi =Standard deviation for the station

The mean of the rainfall can be calculated using the formula as

$$\text{Mean} = \bar{x} = \frac{\sum ix}{\text{N}} \quad \text{.......iii}$$

Where N is the number of rainfall observed

The standard deviation for the rainfall is computed using

$$\delta = \frac{\sqrt{\sum(x-x)^2}}{\text{N}} \quad \text{.......iv}$$

After the computation of the SPI values, the derived positive and negative SPI values were then compared with the threshold SPI values adopted from Mckee *et al.*, (1993) for categorization and classification of the drought intensities as shown in table 2 below.

Table 2: Categorization of SPI values and drought severity levels

SPI VALUES	**DROUGHT CATEGORIES**
0 to -0.99	Mild Drought
-1.00 to -1.49	Moderate Drought
-1.5 to -1.99	Severe Drought
-2.00 or less	Extreme Drought

Source: McKee *et al.,* (1993).

2.1.2 Estimation of Drought Using PDBM Index

Percentage Deviation Below the Mean (PDBM) is a known drought index used for computing drought intensities (Atedhor, 2016). It is applied in the assessment of drought often coupled with the SPI index for comparative performance evaluation (Umar, 2013). It is adapted from Ayoade (2008) who calculated drought conditions based on percentage of departure or deviation from the normal rainfall value. It is parsimonious index with ease of calculation and generally useful and simple to understand by public. It is also challenged for demanding long-term rainfall data (Ayoade, 2008; Umar, 2013; Atedhor, 2016). Refer to Table 3 below for the description of categories of the various drought intensities according to the index. The index is computed using the formula given as:

$$\text{PDBM} = \frac{X_i - \bar{X}}{\bar{X}} \times 100\ \% \qquad \text{.....v}$$

Where:

Xi - is the Annual Rainfall Series

$\bar{X}$ - is the mean of the entire series

Table 3: Categorization of PDBM values and drought severity levels

PDBM Scale	Drought Category
11-25%	Slight Drought
26-45%	Moderate Drought
46-60%	Severe Drought
>60%	Disastrous Drought

Source: Ayoade, (2008)

3.1 Study Area

Geographically, Northeast is located between Latitude 6 ° 30' N and 13 ° 40' 20" N of the equator and Longitude 8 ° 42' E and 14 ° 40' E of the Greenwich meridian. It is bounded by the Niger Republic in the north, Chad, and Cameron in the east. The North-eastern zone has a total landmass of 45, 567 km², representing 40% of the total area of Nigeria (Onah & Tyubee, 2015). And a population total of 19,471086 people (NPC, 2006).

The zone is underlain by the Chad Formation, an extensive deposit of lacustrine origin which has been dated to be Pleistocene (Bumba *et al*., 1991). The landscape is characterized by a vast flat undulating plain in the North and plateau in the South with features of volcanic origin such as conical hills, craters, and escarpments which descend gently in the areas of Bauchi, Gombe, Taraba and Adamawa states. In the northern part, sand dunes are found in Gudumbali, Borno State and in Tulotulo, and Kaska in Yobe State.

Lake Chad basin is the dominant hydrological feature in the area with an average height of 300m above sea level (Waziri, 2009). The basin and its hydrological catchment area span Borno, Yobe, Bauchi, Jigawa, Kano and Plateau states. River Komadugu of Yobe and River Hawul drain the Biu plateau southwards into the river Gongola, and River Taraba forms major hydrology of the state.

The climate of the zone is characteristically marked by two seasons namely: dry and wet seasons. The alternating wet and dry seasons are primarily due to an intermediate position of the country between the Inter-Tropical Discontinuity (ITD) (Udo and Okujagu, 2014). The rainy season starts in June or July, as the Inter-Tropical Discontinuity passes northwards, peaks in August and finishes quite rapidly in September or October. The rest of the year is virtually dry. In the northern fringes of the study area, a long dry season occurs between November and May, characterized by North-east trade wind that brings Harmattan– cold, dry, dusty and hazy wind. During the wet season, the rainfall is patchy and irregular with an average of about 500mm. The dwindling rainfall of the northern fringes results in the occurrences of droughts, famine and pests, drying of rivers, fall in the groundwater level and widespread desiccation of soil (Waziri, 2009).

Two major types of vegetation namely: Savanna and Montane vegetation exist in the zone (Onah and Tyubee, 2015). The Savanna vegetation is categorized into two viz: Sahel and Sudan savanna. A savanna is a grassland area characterized by a varying degree of woody cover. It is an important ecological zone supporting varying groups of wildlife and people (Bibi, 2013). Montane vegetation is situated in the Southeastern border between Nigeria and Cameroon, around Adamawa and Taraba States and in the Western parts of Bauchi State around its borders with Plateau and Kaduna. It is characterized by the presence of a diversity of moss and epiphyte species with uneven canopies, and short deciduous trees (USAID/Nigeria, 2008).

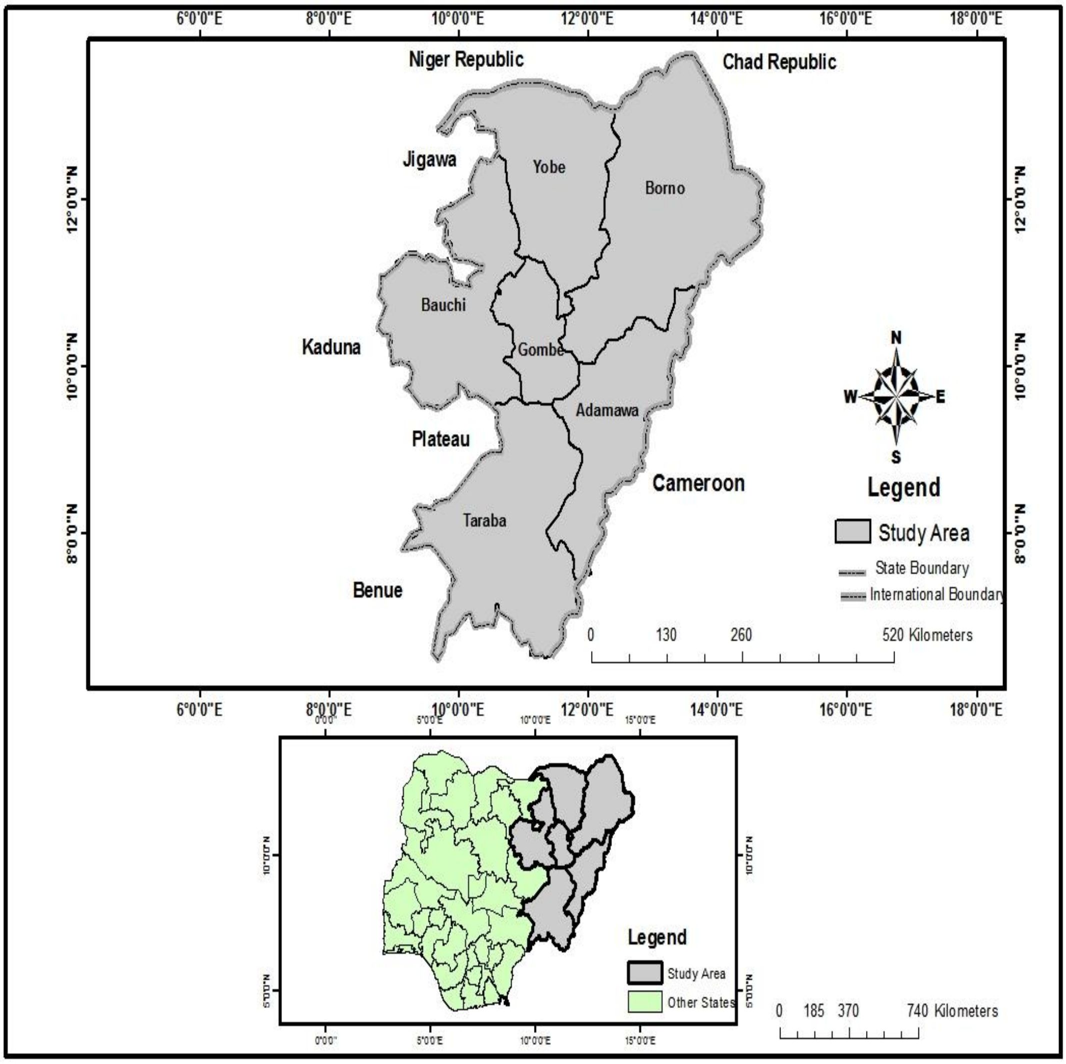

Figure 1: Location of North-eastern Zone of Nigeria.
Source: FUGA GIS Lab., Geography Dept. 2023.

4.1 Results and Discussions

Here the results and discussion are divided into three sections. The first section is on drought scenarios detected using SPI, followed by that of PDBM and then a comparison of the two indices.

4.1.1 Drought Scenarios Detected Using SPI Index (1956 – 2015)

Results obtained revealed the detection of 30 aggregated drought events. Moreover, low-intensity droughts predominantly struck the entire study area with mild and moderate droughts occurring 19 and 5 times respectively. Moreover, the index recorded 4 and 2 incidences of severe and extreme categories respectively. The occurrence of high-intensity drought corroborates with Umar (2013) who discovered severe and extreme drought in the northeastern sub-region of Nigeria. See Table 4 for the frequency of occurrence of various drought intensities over the study area.

Drought duration results revealed high incidences of unsustained drought conditions. Such non-persistent droughts occurred intermittently. For instance, multiple 1-year long occurred 16 times and 2-year long happened 4 times. No cases of 3-year, 4-year, and 5-year long duration were captured by the model. Notably, 1 incidence of above 5-year drought was encountered, stretching between 1957 and 1962. It is pertinent to state that the persistent drought condition was under mild drought intensity. Table 4 below provides details on the duration as captured by the SPI.

The severe drought episodes occurred in 1967 (-1.54 SPI Scale), 1973 (-1.57) and between 1983 (-1.69) and 1984 (-1.71 SPI Value). Moreover, during the study period, the most severe drought of extreme intensity happened in 1966 (-2.29 SPI Values), and 1968 (-3.10 SPI Value). The 1968 drought was the highest magnitude detected with an SPI value of -3.10. A high-magnitude drought of this intensity has the most deleterious effects on agriculture, ecosystems, surface water and groundwater. For more details on severity level see below the SPI anomaly graph in Figure 2.

Table 4: Drought events detected in the study area based on the SPI index (1956-2015)

Zone	Length of Records	Mild	Moderate	Severe	Extreme	Total Drought
North-East Zone	1956-2015	19	05	04(1967, 1973, 1983 &1984)	02(1966 &1968)	30

Source: Author's Computation, 2023.

Table 5: Summary of drought duration over the study area based on the SPI index (1956-2015)

Station	1- Year	2- Year	3- Year	4-Year	5- Year	Above 5-Year
North-east Zone	16	4	-	-	-	1(1957-1962)

Source: Author's Computation, 2023.

SPI Anomaly Over North-east (1956-2015)

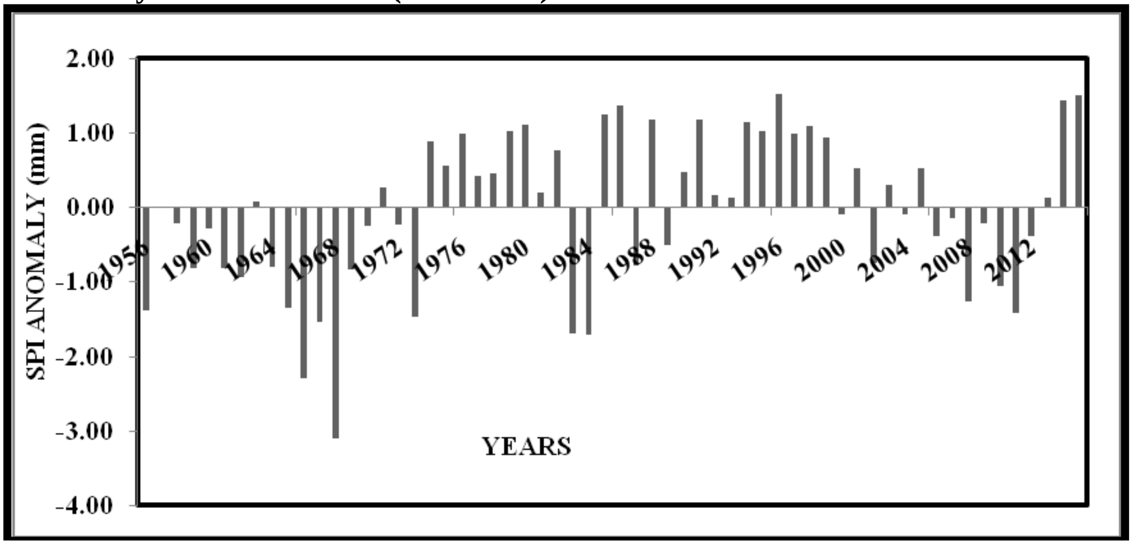

Figure 2: SPI anomaly graph over the North-eastern Zone (1956-2015).
Source: Generated by the Author**,** 2023**.**

4.1.2 Drought Scenarios Detected Using PDBM Index (1956 – 2015)

The result of the analysis reveals the occurrence of 17 total drought events. The drought events are solely of slight intensity as shown below in Table 6. The index demonstrated the capture of only slight magnitude drought throughout the 1956-2015 period of investigation. Moreover, on drought duration, the result confirms the occurrence of several single-year droughts with 5 frequency of occurrence. The 3 cases of 2 years were also recorded by the index. And above all, above 5-year prolonged drought was recorded once. It began from 1994 and stretched up to 1999. It is worthy to state that the longest drought was a prolonged one but not intense in terms of severity. Table 7 below contains the details on duration.

Table 6: Summary of drought events detected in the study area based on PDBM index (1956-2015)

Study Area	**Length of Records**	**Disastrous**	**Severe**	**Moderate**	**Slight**	**Total Drought Years**
North-East	1956-2015	-	-	-	17	17

Source: Author's Computation, 2023.

Table 7: Summary of drought duration over the study area based on the PDBM index (1956-2015)

Station	**1- Year**	**2- Year**	**3- Year**	**4-Year**	**5- Year**	**Above 5-Year**
North-east Zone	5	3	-	-	-	1
Total	5	3	-	-	-	1

Source: Author's Computation, 2023.

4.1.3 Comparison of Drought Events Obtained Using SPI and PDBM Index (1956 – 2015)

Comparatively, the results of the Zonal wise analysis made known the number of drought events captured by SPI is greater than that of the PDBM Index. The SPI was able to detect all the intensities of droughts i.e. mild, moderate, severe and extreme droughts. While the PDBM captures copiously only the slight intensity. Figure 3 below depicts the respective results of the two indices.

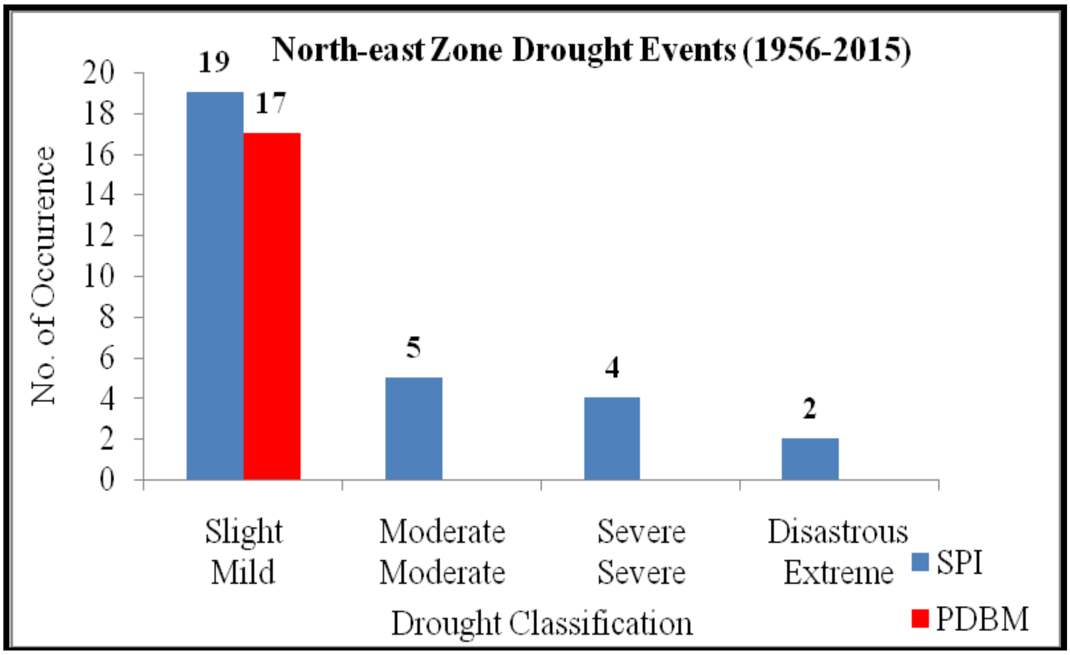

Figure 3: Comparison of drought events captured by SPI and PDBM index (1956-2015) over North-east.

Source: Generated by the Author, 2023.

5.1 Conclusion

This study conducted a meticulous analysis of the performance of meteorological drought detection between the Standardized Precipitation Index (SPI) and the Percentage Deviation Below Mean Index (PDBM) within the North-eastern region of Nigeria over the 1956-2015 period. We utilized annual rainfall data from six meteorological stations in the region.

The investigation revealed distinct variations in the behaviour of SPI and PDBM indices in terms of drought detection. Notably, significant differences were observed in the frequency, duration, and severity of droughts captured by these two indices. SPI consistently outperformed PDBM in the number of drought events it captured. This demonstrated SPI's enhanced capability and applicability in comprehensively identifying and assessing drought events within the study area. Moreover, SPI not only captured a greater number of droughts but also excelled in detecting droughts of higher magnitude and longer duration compared to PDBM. In summary, the findings of this study strongly support the conclusion that SPI is highly effective in the detection and comprehensive capture of meteorological drought within the study area. These results underline the robust performance of SPI in this context.

6.1 Recommendations

The findings derived from this analysis strongly support the recommendation for a comprehensive review, upgrade, redesign, and enhancement of the existing index. This revision is crucial to improve the index's capability to accurately quantify meteorological drought. Furthermore, it is advisable for researchers to consider exploring a broader spectrum of indices, rather than solely relying on the outcomes of a single index. This diversified approach can provide a more comprehensive and accurate assessment of meteorological drought conditions.

References

Atedhor, G. O. (2016). Growing season rainfall trends, alterations and drought intensities in the Guinea Savanna belt of Nigeria: Implications on Agriculture. *Journal of Environment and Earth Science*, ***6*** (3), 5-17.

Ayoade, J. O. (2015). *Introduction to environmental planning and management*. Ibadan: Agbo
Areo publishers, Apata, Pp. 55-70

Ayoade, J. O. (2012). Meteorological hazards and their impacts on the Nigerian urban environment In: Ivbijaro, M. F., & Akintola, F. (eds.), *Sustainable Environmental Management in Nigeria*. Book builders, Ibadan, Nigeria. ***1***(2), 157-177.

Ayoade, J. O. (2008). *Techniques in climatology*. Stirling-Horden publishers Ltd, Ibadan, Nigeria.

Ali, A. (2010). Climate variability and change in the Sahel. In: Yahya, M. M. (ed.), *Climate Change in the Sahel. Special Bulletin of AGRHYMENT Regional Center*. **35**: 1 – 42.

Bibi, U. M. (2013).The impact of climate variability and land cover change on land surface conditions in North-eastern Nigeria. Published Ph.D. thesis, University of Leicester, Leicester, UK. Pg. 1-35.

Bumba, J., Kida**,** H**.** M**.** and Bunu, Z. (1991). Exploitation of underground water in Chad Formation-Maiduguri as a case study. In: Gadzarna, N. M., Adeniji, F. A. and Richards, W. S. and Thambyapillay, G. G. R. (eds.), *Arid Zone Hydrology And Water Resources***,** University of Maiduguri Press, Pp. 527.

Jat, M. L., Singh, P., Bhakar, S. R. and Sharma, S. K. (2010). *Drought Management.* Daryaganj, New Delhi, India: Kalyani publishers. Pp. 1-39.

Kamali, B., Kouchi, D. H., Yang, H. and Abbaspour, K. C. (2017). Multi-level drought hazard assessment under Climate change scenarios in Semi-Arid regions: A case study of the Karkheh river basin in Iran. *Journal of Water*, ***9***(2), 1-17.

Lucio, P. S., Molion, L. B., Valadão, C. A., Conde, F. C., Ramos, A. M., Melo, M. L. (2012). Dynamical outlines of the rainfall variability and the ITCZ role over the West Sahel. *Journal of Atmospheric and Climate Sciences*, ***2***(1), 337-350 Retrieved from: http://dx.doi.org/10.4236/acs.2012.23030.

Mondol, A. H., Ara, I. and Das, S. C. (2017). Meteorological drought index mapping in Bangladesh using standardized precipitation index during 1981–2010. *Advances in Meteorology*, ***1***(2), 1-17.

McKee, B. T., Doesken, N. J. and Kleist, J. (1993). The relationship of drought frequency and duration to time scales. Eighth conference on applied climatology, American Meteorological Society, Anaheim, California, Pp. 179-186.

National Centre for Atmospheric Research (NCAR) reports 2012 USA.

National Population Commission (2006). Report of Nigeria's National Population Commission on the 2006 census. *Population and Development Review* ***33*** (1), 206-210

Onah, M. A. and Tyubee, B. T. (2015). Analysis of rainfall-intensity-duration-frequency regime for selected stations in North-eastern Nigeria. *Journal of Meteorology and Climate Science,* ***13***(1), 85-93.

Onchiri, K. M., Ang'awa, F. and Tonui, K. W. (2016). Effects of drought on food production in Asego division, Homabay County – Kenya. *Journal of Geography,* ***3***(3), 1 – 14.

Rossi, G., Vega, T. and Bonaccorso, B. (2007). *Methods and tools for drought analysis and management.* Springer International Publishing, Netherlands, Pg. 2.

Tigkas, D., Vangelis, H., and Tsakiris, G. (2015). DrinC: A software for drought analysis based on drought indices. *Earth Science Informatics,* ***8***(3), 697-709. Available via: http:dx.doi.org/10./007/s12145-014- 0178. 15, April, 2016.

Udo, I. A. and Okujagu, C. U. (2014). Assessment of Inter-tropical convergence zone (ITCZ) impact on precipitation in six locations in Nigeria ***3***(6), 2736- 2739.

Umar, A. T. (2023). *Land, Sea and Air*: *The pillars of Climatic Noise in Nigeria.* The 37th Inaugural lecture, Department of Geography, Usmanu Danfodio University, Sokoto. Pp. 2-35.

Umar, A. T. (2013). Frequency and spatial patterns of droughts in Nigeria. *Journal of Nigerian Meteorological Society,* ***11***(1), 58-72.

USAID/Nigeria, (2008). *Nigeria Biodiversity and Tropical Forestry Assessment.* USA: Chemonics International Inc. 6 - 9.

Waziri, M. (2009). Geography of Borno State: An overview. In: Waziri, M., Kagu, A., & Monguno, A. K. (Eds.), *Issues in the Geography of Borno State.* Adamu Joji Publishers, Kano, ***1***(1), 28-39.

Wambua, R. M., Mutua, B. M., and Raude, J. M. (2015). Spatio-temporal drought characterization for the Upper Tana River Basin, Kenya using Standardized Precipitation Index (SPI). *World Journal of Environmental Engineering,* ***3***(4), 111-20.