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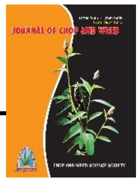

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Research Article

Assessment of agricultural drought in the Red Lateritic Zone of West Bengal using Palmer Drought Severity Index

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ABSTRACT

With an objective to characterize drought conditions in the Red Lateritic Zone of West Bengal, an investigation was undertaken to compute the frequency of different categories of agricultural drought and their temporal dynamics using the Palmer Drought Severity Index (PDSI), for the period 1951-2020. For this, gridded data on daily rainfall, minimum temperature and maximum temperature were obtained from IMD Gridded dataset and information on AHC (mm/mm depth; Grid based) was obtained from a FAO developed software named Harmonized World Soil Database. An investigation over the entire study location showed that there is a prolonged drought period in Bankura, Birbhum and Purulia combining MLD/MOD/SD/ED from 1960-1969 and 2006- 2011. Among the districts, Birbhum (5.2%), Purulia (4.39%), Bankura (10.69%) recorded maximum frequency for extreme, severe and moderate drought, respectively. During the entire study period, there was no uniform increasing or decreasing temporal trend of PDSI in this zone, however, some distinct increasing or decreasing spans were identified.

***Keywords*:** Agricultural drought, gridded weather data, PDSI and temporal trend

Drought is the hazardous climatic phenomena that cannot be described by any universal definition (Bhunia *et al, 2019.*). Drought occurs when there is a prolonged absence or marked deficiency of rainfall for a long period of time. Drought is mainly categorized into three types, *viz*., Meteorological Drought, Hydrological Drought and Agricultural Drought, among which meteorological drought is very difficult to avoid. Drought in India has caused millions of deaths over the 18^{th}, 19^{th} and 20^{th} centuries. A favorable southwest monsoon is a dominant factor for Indian agriculture such that, a favorable southwest monsoon is critical to securing irrigation water for Indian crops. The variations in the number of rainy months and rainy days and soil moisture limitation are common. Severe drought periods lasting for weeks, sometimes adversely affect crop growth and yield even during the main cropping (*kharif*) season. Planning must take into account the impacts of drought at various scales in a country like India, where the agricultural sector plays a significant role in the economy. Drought indices are a useful tool for characterizing the drought severity and providing a single number that can be used to identify a dryness or wetness character of a region. To monitor the drought severity, we used Palmer drought Severity Index (PDSI). Drought monitoring based on only rainfall is insufficient to provide the actual scenario, thus we used PDSI which incorporates both rainfall and temperature considering soil moisture condition. This index has proven the most effective index in determining long term drought. Pandey *et al.* (2014) assess drought severity and also compared different drought indices to be the best drought indicator in various regions of Jharkhand for a period of 22 to 35 years. The comparative study reveals that Aridity Index (Ia) seems to be the most accurate method for drought severity assessment Pai *et al.* (2011) used Percent of Normal Precipitation (PNP) and Standardized Precipitation Index (SPI) to study district-wide drought climatology over India for the southwest monsoon season using long times series (1901-2003) of 458 districts southwest monsoon rainfall data over the country. Their study showed that the district-wide climatology based on PNP was biased by the aridity of the region, whereas, district-wide drought climatology based on SPI was not biased by aridity.

Red Lateritic Zone (RLZ) of West Bengal occupies 10-13.4% cultivated area of the state of West Bengal. Within this zone, Purulia, Birbhum, Bankura and Paschim Medinipur jointly contribute one-third of the cultivated area (Chatterjee *et al*., 2013).

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This region experiences a semi-arid climate, as distinguished by hot summer, dry and cool winter, with an average annual rainfall ranging between 1100 and 1400mm. Soil of this zone is coarse in texture, well drained and having ferruginous concentration of honeycomb type at a soil depth of 150 to 300 mm.

The soil is acidic with pH value ranging between 5.5 and 6.2, having poor organic matter content and micronutrient status. Soil fertility with respect to nitrogen and phosphorus and water holding capacity are both poor in status (Murmu *et al*., 2016). Though total annual or seasonal rainfall in any district of this zone can be considered sufficient for one or two rainfed crops but crops mostly suffer from early, mid-season or late season drought because of poor distribution of rainfall.

Analysis of onset, persistence and termination of agricultural drought, i.e., insufficiency of moisture in soil to satisfy the water requirement of crop at various growth stages, can be an important task for crop planners for leveraging optimum use of natural water resources. There is an urgent need to characterize the moisture stress condition as well to assess the pattern of their temporal change in the event of any perceived climate change. Thus, it will be worthwhile to study the drought condition of the Red Lateritic Zone of West Bengal using PDSI which will help us identifying much needed adaptation measures to ensure future proof crop production strategy.

MATERIALS AND METHODS

For the purpose of estimating the monthly time series of PDSI for the studied location of West Bengal, monthly climatic dataset on precipitation and temperature for the historical period was necessary. For this purpose, daily gridded rainfall data ($0.25^o \times 0.25^o$), gridded daily maximum and minimum temperature data ($1^o \times 1^o$) for the period 1921-2020 were obtained from IMD portal (https://www.imdpune.gov.in/cmpg/Griddata- accessed on 27 March, 2023) and subsequently processed for different temporal periods. For this study, information on the available water holding capacity of soil (mm per mm depth; grid based) was collected from harmonized world soil database developed by FAO. (FAO et al., 2009)

Palmer (1965) introduced an index that combines precipitation, temperature and soil moisture content as predictor variables to compute the magnitude of agricultural drought conditions. The Palmer Drought Severity Index (PDSI) computation starts with monthly climatic water balance using historic records of precipitation and temperature. A two-layer soil moisture storage approach is applied with upper layer containing 25.4 mm of available moisture (at field capacity stage) and rest of the available moisture (depending on soil texture) in the underlying layer. When both upper as well as underlying layer reach maximum moisture capacity, runoff takes place. Four different potential values, such as potential evapotranspiration, potential recharge, potential runoff and potential loss were computed. Four climatic coefficients, *viz*., α (coefficient of evapotranspiration), β (coefficient of recharge), γ (coefficient of runoff) and δ (coefficient of loss) were estimated to compute CAFEC (Climatically Appropriate for Existing Condition) precipitation, which were compared with actual precipitation (difference is considered as d) to estimate water deficiency. To get the final index (Z), d is multiplied with a weighting factor K (estimated from climatic record). Finally PDSI of a given month (i) is represented as $PDSI_i = 0.897 \times PDSI_{i-1}/3 \times Z_i$. (Palmer, 1965)

Daily rainfall, maximum temperature and minimum temperature data obtained from IMD Gridded dataset for Bankura, Birbhum, Paschim Medinipur and Purulia (1951-2020) were used in monthly PDSI estimation. Daily maximum temperature and minimum temperature data were first used to estimate PET using Hargreaves and Samani (1985) method. Daily rainfall and PET data were then summarized on a monthly basis for input in the PDSI model. The model was implemented in R-Studio (RStudio Team, 2015) using “scPDSI” package (Zhong *et al*., 2018) downloaded in R-Studio environment. Finally, drought categories were identified using Table 1.

Time series of study parameters were smoothed using Locally Weighted Scatter Plot Smoothing method (Lowess) (Cleveland, 1981) using ggplot2 function of R-Statistical Programme, to understand the nature of trend in a better way.

Table 1: Palmer drought index based drought categories (Palmer, 1965)

Index value	Characters of recent weather
4.00 or more	Very much wetter than normal
3.00 to 3.99	Much wetter than normal
2.00 to 2.99	Moderately wetter than normal
1.00 to 1.99	Slightly wetter than normal
0.50 to 0.99	Incipient wet spell
0.49 to –0.49	Near normal
--0.50 to –0.99	Incipient drought
--1.00 to –1.99	Mild drought
--2.00 to –2.99	Moderate drought
--3.00 to –3.99	Severe drought
--4.00 or Less	Extreme drought

RESULTS AND DISCUSSION

Temporal variability and duration of drought intensity

Temporal distribution of monthly values of PDSI were plotted for all 4 districts of the RLZ of West Bengal and presented in Fig.1. The figure shows the onset, persistence and termination of different categories of drought and wet condition over the study period. Negative values indicate drought condition while positive value represent wet condition. A closer observation of Fig.1 could identify some of the prominent long duration drought with combinations of MLD (Mild drought), MOD (Moderate drought), SD (Severe drought) and ED (Extreme drought). Bankura showed one prolonged drought combining MLD/MOD/SD/ED during January 1960 to March 1969 and another prolonged drought combining MLD/MOD/SD/ED during October 2006 to February 2011. Similarly, Birbhum also showed prolonged drought combining MLD/MOD/SD/ED during January 1960 to March 1969 with a slight 6 month wet period from January 1962 to June 1962 and another 27 month prolonged drought during September 2008 to November 2010. Paschim Medinipur showed comparatively shorter and a moderate drought period from September 1960 to October 1966. Purulia showed a shorter drought period combining MLD/MOD/SD/ED during October 1907 to April 1910 and another prolonged drought period from January 1961 to August 1970 with the maximum intensity and a 9 month wet period in between. Similar study was carried out by Zoljoodi and Didevarasl (2013) in Iran using PDSI and correlate it with soil moisture, temperature and precipitation to evaluate spatio-temporal variability of drought events from 1951-2005. They revealed that the most extreme drought spell lasted 4 years from 1999-2002 and there is an increased drought severity throughout Iran during this period. Their study also found strong correlation of PDSI with soil moisture while poor correlation with other variables.

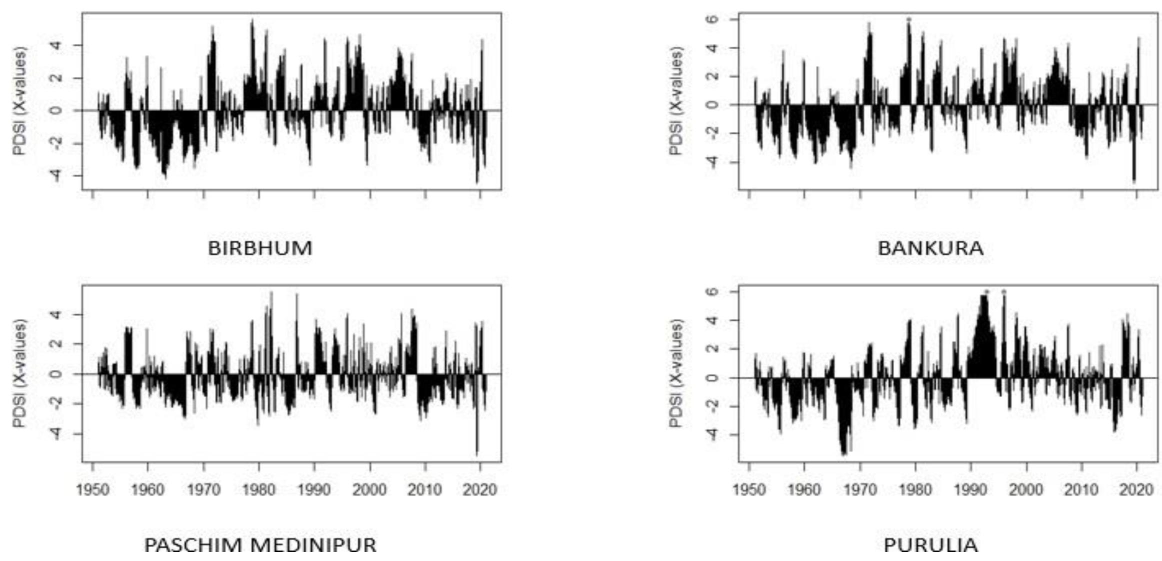

Fig.1: March of PDSI in different districts of Red Laterite Zone over the study period

Frequency of different categories of drought

Following the drought classification of Palmer (1965), various categories of drought were computed month-wise and station-wise and their frequencies were presented in Table 2 through Table 5.

The frequency of extreme drought varies from 0-7.14% with an average of 1.93%. Among the months, April showed minimum frequency (1.4%) and May showed maximum frequency (2.8%) of extreme drought. Among the district Birbhum showed the highest frequency (5.2%) and Paschim Medinipur showed the lowest frequency (0.23%) of extreme drought. For severe drought the intensity varies from 0-8.57%, for moderate drought the intensity varies from 4.28-18.5% and for mild drought it varies from 10-30%. Among the months, January showed the maximum frequency (3.56%) for severe drought, November showed the maximum frequency (12.12%) for moderate drought and December showed the maximum frequency (21.76%) for mild drought. On the other side, March showed the minimum frequency (2.85%) for severe drought, July showed the minimum frequency (7.1%) for moderate drought and February (16.05%) showed the minimum frequency for mild drought. Among the districts, Purulia (4.39%), Bankura (10.69%), Paschim Medinipur showed the maximum frequency for severe, moderate and mild drought respectively and Paschim Medinipur (0.35%) showed the minimum frequency (26.19%) for severe drought and Birbhum showed the minimum frequency (8.56% and 17.26%) for both moderate and mild drought.

Many previous authors (Bhunia et al. 2019) working with Standardized Precipitation Index (SPI) similarly reported that Purulia was extremely suffered by high magnitude drought events during monsoon period (1966, 2005 and 2010) with highest drought frequency (54%) recorded by Bankura followed by Purulia (50%) and least frequency recorded by Paschim Midnapore. Frequency of extreme drought was recorded highest by Bankura and lowest by Paschim Midnapore in the post-monsoon period also.

Table 2: Frequency (%) of extreme drought years (1951-2020) in different districts of RLZ

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bankura	0	0	1.42	0	1.42	1.42	1.42	0	0	0	0	0
Birbhum	5.71	4.28	5.71	2.85	5.71	4.28	4.28	5.71	4.28	5.71	7.14	7.14
Paschim Medinipur	0	0	0	0	1.42	1.42	0	0	0	0	0	0
Purulia	1.42	1.42	1.42	2.85	2.85	1.42	2.85	1.42	1.42	1.42	1.42	1.42

Table 3: Frequency (%) of severe drought years (1951-2020) in different districts of RLZ

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bankura	2.85	2.85	2.85	4.28	5.71	5.71	4.28	7.14	7.14	5.71	7.14	5.71
Birbhum	4.28	4.28	2.85	2.85	2.85	5.71	4.28	2.85	4.28	2.85	2.85	7.14
Paschim Medinipur	0	0	0	1.42	0	0	0	0	0	1.42	1.42	0
Purulia	7.14	5.71	5.71	5.71	1.42	4.28	2.85	1.42	1.42	1.42	7.14	8.57

Table 4: Frequency (%) of moderate drought years (1951-2020) different districts of RLZ

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bankura	11.4	12.8	10.0	7.14	8.57	12.8	11.4	8.57	7.14	8.57	15.7	14.2
Birbhum	10.0	12.8	8.57	7.14	8.57	4.28	5.71	7.14	8.57	8.57	11.4	10
Paschim Medinipur	12.8	7.14	10.0	5.71	11.4	8.57	5.71	10.0	8.57	10.0	17.1	18.5
Purulia	11.4	12.8	11.4	10.0	10.0	7.14	5.71	12.8	14.2	12.8	4.28	5.71

Table 5: Frequency (%) of mild drought years (1951-2020) different districts of RLZ

District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bankura	18.5	11.4	18.5	22.8	17.1	18.5	14.3	14.3	15.7	21.4	20.0	20.0
Birbhum	15.7	10.0	18.5	25.7	11.4	12.8	14.3	22.8	21.4	20.0	15.7	18.5
Paschim Medinipur	27.1	30.0	31.4	34.3	20.0	20.0	24.3	24.3	28.5	27.1	22.8	24.3
Purulia	17.1	12.8	15.7	14.28	17.1	22.8	18.5	20.0	15.7	18.5	25.7	24.3

A month-wise temporal trend of drought intensity

Temporal pattern of yearly values of monthly PDSI across the *kharif* months and districts were constructed using Loess smoothing algorithm and presented in Fig. 3. It was revealed that PDSI trend was not unimodal across the months and districts. Up to around 1960's, there was an increasing trend of drought intensity (a decreasing value of PDSI), then, up to 1990's there was a decreasing trend of drought intensity (an increasing value of PDSI). From this period onwards PDSI again registered an increasing trend of drought intensity (a decreasing value of PDSI) up to the end of study period (2020).

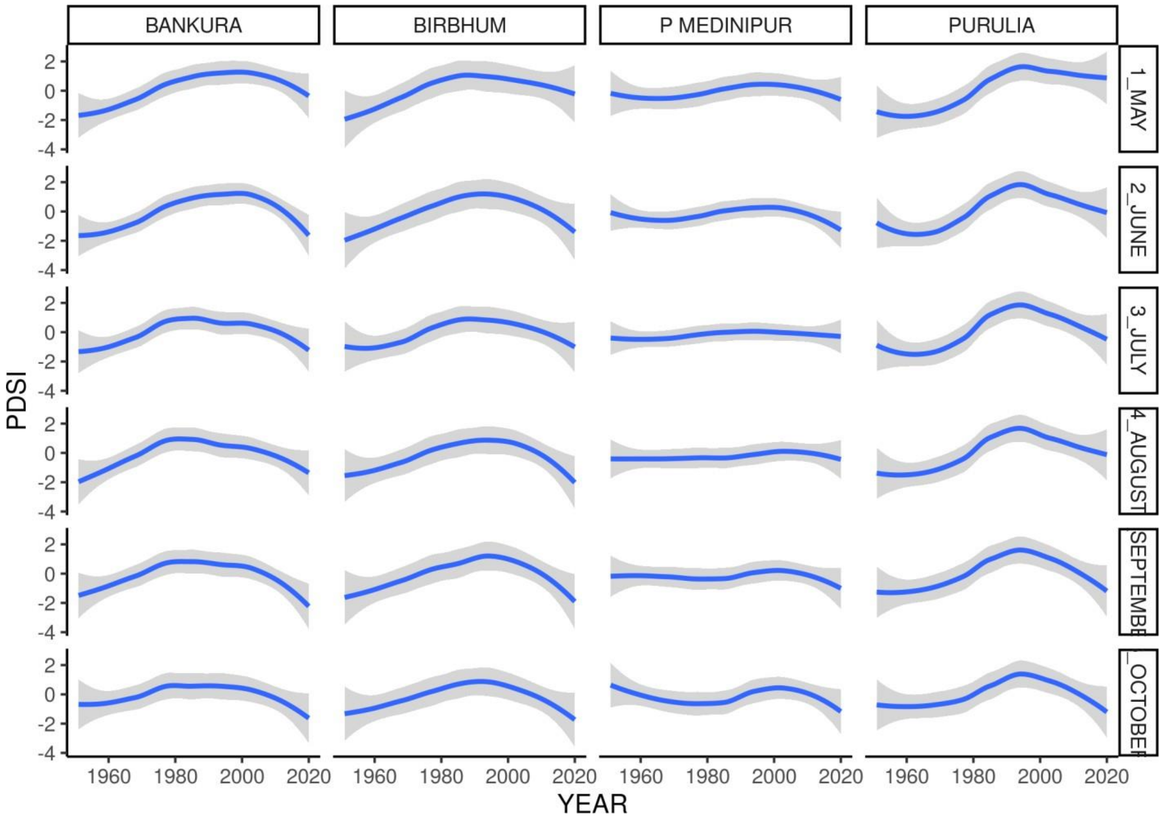

Fig. 3: Trend of PDSI during kharif months in Red Lateritic Zone of West Bengal (1951-2020)

CONCLUSION

An investigation over the entire study location showed that there is a prolonged drought period in Bankura, Birbhum and Purulia combining MLD/MOD/SD/ED from 1960-1969 and 2006-2011. On the other hand, Paschim Medinipur showed comparatively shorter and a moderate drought period from September 1960 to October 1966. Among the districts Birbhum (5.2%), Purulia (4.39%), Bankura (10.69%) recorded maximum frequency for extreme, severe and moderate drought respectively, while among the months, May (2.85%) January (3.56%) and November (12.12%) recorded maximum frequency for extreme, severe and moderate drought respectively. During the entire study period, there was no uniform increasing or decreasing temporal trend of PDSI in this zone, however, some distinct increasing or decreasing spans were identified. However, the temporal trend of monthly PDSI values, mainly during *kharif* season showed an increasing trend of drought intensity for all the districts up to 1960's after that there is a decreasing trend of drought intensity up to 1990's and there after again an increasing trend. Characterization of agricultural drought, in this agroclimatic zone, will help the crop planner to judiciously select crops/cropping system under rainfed agroecosystem.

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