World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:7, No:3, 2013

# Analysis of Meteorological Drought Using Standardized Precipitation Index – A Case Study of Puruliya District, West Bengal, India

Moumita Palchaudhuri, Sujata Biswas



***Abstract*—**Drought is universally acknowledged as a phenomenon associated with scarcity of water. The Standardized Precipitation Index (SPI) expresses the actual rainfall as standardized departure from rainfall probability distribution function. In this study severity and spatial pattern of meteorological drought was analyzed in the Puruliya District, West Bengal, India using multi-temporal SPI. Daily gridded data for the period 1971-2005 from 4 rainfall stations surrounding the study area were collected from IMD, Pune, and used in the analysis. Geographic Information System (GIS) was used to generate drought severity maps for the different time scales and months of the year. Temporal SPI graphs show that the maximum SPI value (extreme drought) occurs in station 3 in the year 1993. Mild and moderate droughts occur in the central portion of the study area. Severe and extreme droughts were mostly found in the northeast, northwest and the southwest part of the region.

***Keywords*—**Standardized Precipitation Index, Meteorological Drought, Geographical Information System, Drought severity.

## I. Introduction

DROUGHT is one of the major environmental disasters, which have been occurring in almost all climatic zones and damage to the environment and economies of several countries has been extensive. Drought damages are more pronounced or prominent in areas where there is a direct threat to livelihoods. In drought management, making the transition from crisis to risk management is difficult because little has been done to understand and address the risks associated with drought.

Droughts are occurring in different regions of the world with increased frequency and severity. In India, large parts of the country perennially reel under recurring drought. Over 68% of the total area is vulnerable to drought. The 'chronically drought-prone areas' is around 33% and receive less than 750 mm of rainfall, while 35%, classified as 'drought-prone' receive rainfall of 750-1,125mm. The major drought years in India were 1877, 1899, 1918, 1972, 1987 and 2002 [1]. There are a number of classifications for drought. One of the classifications is according to its physical aspects namely, Meteorological, Hydrological and Agricultural. According to the India Meteorological Department (IMD), meteorological drought occurs when the seasonal rainfall received over an area is less than 75% of its long-term average value. If the rainfall deficit is between 26-50%, the drought is classified as 'moderate', and 'severe' if the deficit exceeds 50%. Agricultural drought occurs when there is insufficient soil moisture to meet the needs of a particular crop at a particular point in time. And Hydrological drought is a deficiency in surface and sub-surface water supply. It is measured as stream flows and also as lake, reservoir and groundwater levels. The problems of drought-prone regions in India vary in magnitude, temporally and spatially. Hence drought risk assessment is the necessity to cope up with this devastating drought which affects the society a lot.

Drought indices are one of the very important tools to monitor and to assess drought, because they simplify complex inter-relationships between many climate parameters. There is extensive literature on the quantification of drought by using various indices, models and water balance simulations [2]-[7]. Precipitation has been used to develop a variety of indices, because it is a key variable to study meteorological drought. Among the meteorological indices, the Palmer Drought Severity Index (PDSI) and Standardized Precipitation Index (SPI) are more commonly used. The SPI has certain advantages over others such as use of rainfall data alone and also its variable time scale, which allows it to describe drought conditions important for a range of meteorological, hydrological and agricultural applications [8].

The impact of rainfall deficiency on water resources varies markedly on a temporal scale for different water storage components of the hydrologic system. While soil moisture responds to precipitation anomalies on a relatively short scale, groundwater, stream flow, and reservoir storage reflect longer-term precipitation anomalies. T. McKee in 1993 [8] developed the Standardized Precipitation Index (SPI) to quantify the precipitation deficit for multiple time scales, reflecting the impact of precipitation deficiency on the availability of various water supplies. They calculated the SPI for 3, 6, 12, 24, and 48 - month scales to reflect the temporal behavior of the impact.

Several studies used SPI for real time monitoring and analysis of drought. SPI was applied to monitor the intensity and spatial extension of droughts at different time scales in South Africa [9]. Drought severity and its characteristic in Thessaly region, Greece, were examined using SPI and the

Moumita Palchaudhuri is with Department of Civil Engineering, Budge Budge Institute of Technology, Kolkata, 700137, India. She is now a Research Scholar at the Bengal Engineering & Science University (BESU), Shibpur, Howrah, 711103, India.

Sujata Biswas is an Assistant professor at the Bengal Engineering & Science University (BESU), Civil Engineering Department, Shibpur, Howrah, 711103, India (e-mail: sujata@civil.becs.ac.in).

study indicated that moderate and severe drought is common in Thessaly region [10]. SPI was used by [11] to map the spatial extents of drought hazards in different time steps for western part of Bangladesh. O. Yildiz in 2009 [12] determined the characteristics of meteorological droughts in the Hirfanli Dam Basin, a semi-arid region in Turkey using SPI as a measure for drought severity. Gupta et al. in 2010 [13] carried out a study on temporal and spatial analyses of meteorological drought using SPI and hydrological drought based on theory of runs. In this paper an attempt has been made using to analyze spatial pattern of meteorological drought using SPI which can examine the characteristic of drought and can give an indication of drought at various levels of severity.

## II. Study area

The area under study covers Puruliya district, West Bengal. Puruliya district is one of the nineteen districts of West Bengal state in eastern India. The town of Puruliya is the administrative headquarters of the district. Puruliya lies between latitude 22° 36’ and 23° 30’ N, and longitude 85° 45’ and 86° 39’ E. The geographical area of the district is 6259 km². Rainfall defines the climate of the district. Southwest monsoon is the principal source of rainfall in the district. Average annual rainfall varies between 1100 and 1500 mm. The relative humidity is high in monsoon season, being 75% to 85%. But in hot summer it comes down to 25% to 35%. Temperature varies over a wide range from 7°C in winter to 46.8°C in the summer. Recorded highest temperature is 54°C. Puruliya is the one of the administrative districts of the state chronically affected by drought conditions [1]. This phenomenon affects very notably the agricultural activities in this region and this is the main reason for selecting Puruliya for this study.

District Block Boundary Map of Puruliya, West Bengal was collected from Survey of India (SOI) (1:2,50,000 scale). The map was geo-referenced with the help of SOI toposheets of the district. Fig 1 shows the block boundaries and raingauge stations surrounding Puruliya district which was generated using ArcView GIS software. The coordinates of the four stations are given in Table I.

TABLE I
Location of the Station Points

| Stations | Coordinates |
|---|---|
| 1 | 23.5 N & 86.0 E |
| 2 | 23.5 N & 86.5E |
| 3 | 23.5 N & 87.0 E |
| 4 | 23.0 N & 86.0 E |

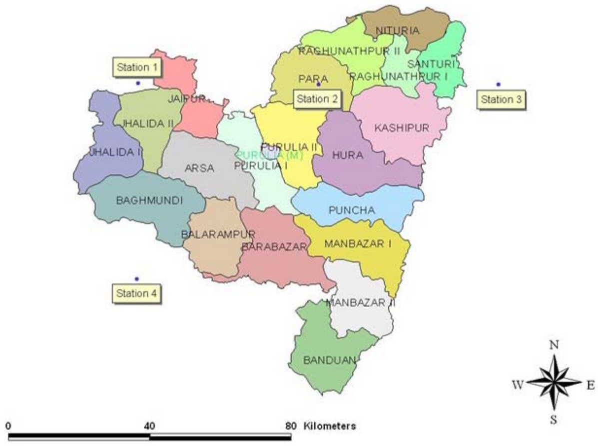



Fig. 1 Map showing Block boundaries and raingauge stations of Puruliya district of West Bengal

## III. Methodology

Daily gridded precipitation data for the period of (1971 – 2005) at the four stations surrounding Puruliya district, West Bengal (shown in Fig. 1) were collected from IMD, Pune. The monthly precipitation data were used as input for the calculation of SPI.

The SPI is computed by fitting an appropriate probability density function to the frequency distribution of precipitation summed over the time scale of interest (usually 3, 6, 12, and 24 months). This is performed separately for each time scale and for each location in space [14].

Computation of the SPI involves fitting a gamma probability density function to a given time series of precipitation, whose probability density function is defined as:

$$g(x)=\frac{1}{\beta^{\alpha}\Gamma(\alpha)}x^{\alpha-1}e^{-x/\beta} \tag{1}$$

where $\alpha > 0$ is a shape parameter, $\beta > 0$ is a scale parameter, and $x > 0$ is the amount of precipitation. $\Gamma(\alpha)$ is the gamma function, which is defined as:

$$\Gamma(\alpha)=\int_{0}^{\infty} y^{\alpha-1}e^{-y}dy \tag{2}$$

Fitting the distribution to the data requires $\alpha$ and $\beta$ to be estimated. Edwards & Mckee in 1997 [15] suggest estimating these parameters using the approximation of [16] for maximum likelihood as follows:

$$\alpha=\frac{1}{4A}\left[1+\sqrt{\left(1+\frac{4A}{3}\right)}\right],\ \beta=\frac{\bar{x}}{\alpha},\ with\ A=\ln\bar{x}-\frac{\sum \ln x}{n} \tag{3}$$

where n is the number of observations. Integrating the probability density function with respect to x yields the following expression G (x) for the cumulative probability:

$$G(x)=\int_0^x g(x)dx=\frac{1}{\beta^\alpha \Gamma(\alpha)}\int_o^x x^{\alpha-1}e^{-x/\beta} \quad (4)$$

Substituting t = x ⁄ β, (4) is reduced to:

$$G(x)=\frac{1}{\Gamma(\alpha)}\int_0^x t^{\alpha-1}e^{-t}dt \quad (5)$$

It is possible to have several zero values in a sample set. In order to account for zero value probability, since the gamma distribution is undefined for x = 0, the cumulative probability function for gamma distribution is modified as:

$$H(x)=q+(1-q)G(x) \quad (6)$$

Finally, the cumulative probability distribution is transformed into the standard normal distribution to yield the SPI. Following the approximate conversion provided by [17], it results:

$$z=SPI=-(t-\frac{c_0+c_1t+c_2t^2}{1+d_1+d_2t^2+d_3t^3}),\, t=\sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \quad (7)$$

$$for\ 0< H(x) < 0.5\ and$$

$$z=SPI=+(t-\frac{c_0+c_1t+c_2t^2}{1+d_1+d_2t^2+d_3t^3}),\, t=\sqrt{\ln\left(\frac{1}{(1.0-H(x))^2}\right)} \quad (8)$$

$$for\ 0.5< H(x) <1.0\ where\ c_0=2.515517, c_1=0.802853, c_2=0.010328, d_1=1.432788, d_2=0.189269, d_3=0.001308.$$

Drought intensity classification into various categories with different values of SPI is given in the following Table II [8]. Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation.

In this study, SPI program developed by the National Drought Mitigation Centre, University of Nebraska-Lincoln (http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx), is used is used to compute time series of drought indices (SPI) for each station in the basin and for each month of the year at different time scales (3, 6, and 12 months).

TABLE II
CLASSIFICATION OF SPI VALUES

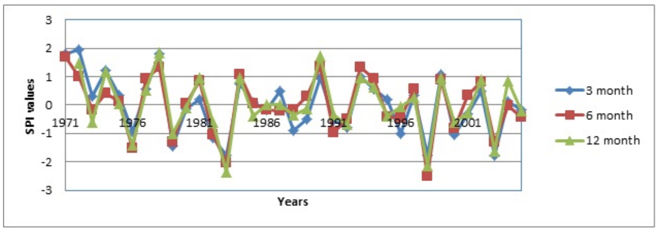
| SPI values | Drought Category |
|---|---|
| 0 to −0.99 | Mild drought |
| −1 to −1.49 | Moderate drought |
| −1.5 to −1.99 | Severe drought |
| ≤ −2 | Extreme drought |

## IV. RESULTS AND DISCUSSION

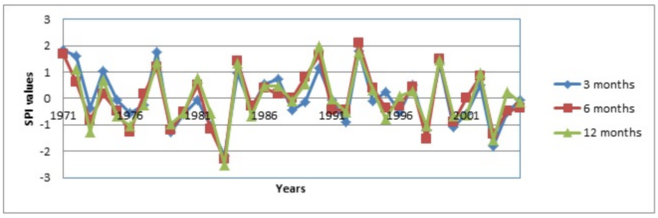
The study produced the maps of drought severity at 3, 6 and 12 months time steps, in the Puruliya district of West Bengal, India. Month of September was chosen for calculating SPI for 3, 6 and 12 month time step as July to September is normally wet season for the study area. Month of September was chosen for the calculation as negative SPI values in the wet season will indicate drought throughout the year.

Fig. 2 shows SPI values for three different time scales namely 3 months, 6 months and 12 months for the four stations.

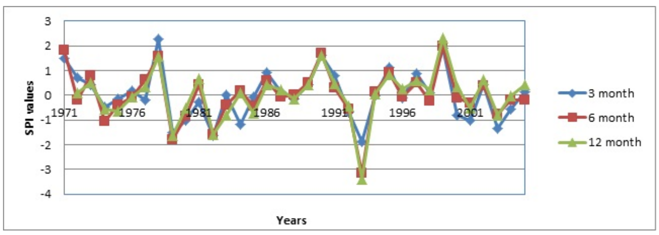
Results show that for station 1 the maximum SPI value (-2.52) is for 6 months timescale in the year 1998. For 3 and 12 months timescale the SPI value is maximum in the year 1998 (-1.76) and 1983 (-2.36) respectively. For station 2, the maximum SPI value was found in 1983 and the values are -2.17, -2.3, -2.52 for 3, 6, 12 months timescale respectively. For station 3, the maximum SPI value was found in 1993 and the values are -1.9, -3.14, -3.4 for 3, 6, 12 months timescale respectively. For station 4, the maximum SPI value (-2.24) is for 6 months timescale, in the year 1982. For 3 and 12 months timescale the SPI values are maximum in the year 1979 (-1.89) and (-2.47) respectively.



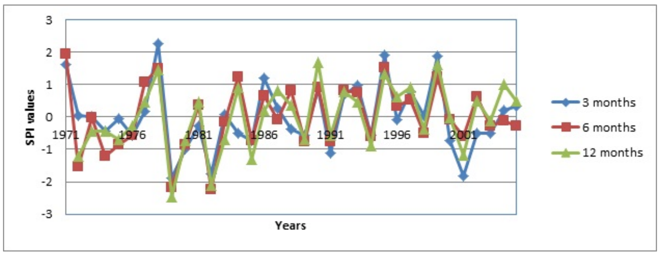

(a)




(b)




(c)




(d)

Fig. 2 Variation of SPI for the month of September (1971 - 2005) (a) station 1, (b) station 2 (c) station 3 (d) station 4

Fig. 3 shows the areal extent (as percent of the total basin area) of the drought categories in the month of September during (1971–2005) based on 12-months timescale. It is also observed that more than 50% of the study area is under the influence of drought in the years 1975, 1976, 1980, 1982, 1983, 1985, 1988, 1991, 1992, 1995, 1998, 2000 and 2001 (SPI < 0). This represents nearly 37% of the years during the analysis period (1971–2005) are struck by drought events. The years 1975, 1980, 1985, 1988, 1991, 1992, 2000, and 2001 mark the most critical drought years in the basin with more than 75% of the total area under drought, coinciding with historical drought years in the study area. Considering all the severity classes per year, 1976, 1979, 1980, 1982, 1983, 1985, 2001, 2003 are the worst years with nearly 100% of the total area under extreme drought.

As indicated earlier that monthly precipitation data were used as input to SPI calculation. The output from the SPI program was used as input to the ArcView GIS to generate drought severity maps for the basin at multiple time scales and for each month of the year. Maps which are shown in Figs. 2 and 3 are for the month of September. The spatial distribution of the drought categories over the study area was obtained by assigning each rain gauge station an area of influence (thiessen polygon).

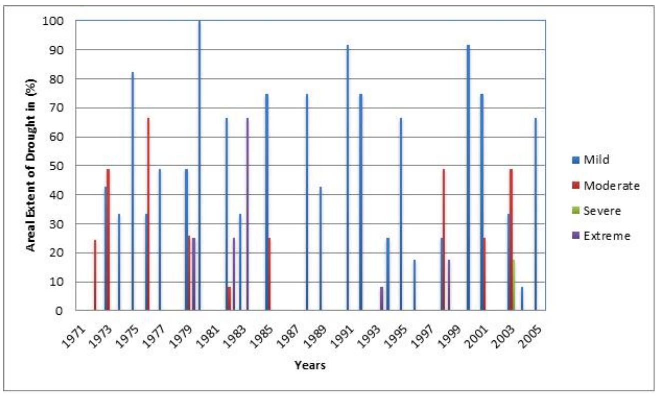



Fig. 3 Areal Extent of drought severity in the Puruliya district based on 12-month SPI for September

Fig. 4 shows drought occurrences at different categories and time-steps over the study area. The drought occurrences were calculated based on percentage occurrence of each event (within each category) for each station with respect to total number of observations over the study area in the same category and timescale. Table III shows percentage of drought occurrence at multiple time scales and drought categories in Station 1. Similar calculations were also done for all the stations of the study area.

TABLE III
DROUGHT OCCURRENCE IN STATION 1

| SPI Classes | Drought Category | Drought occurrences (%) | | |
|---|---|---|---|---|
| | | 3 - months | 6 - months | 12 - month |
| ≤ −2 | Extreme | 0.00 | 5.714 | 5.882 |
| (−1.99, −1.5) | Severe | 8.57 | 2.857 | 2.941 |
| (−1.49, −1) | Moderate | 8.57 | 8.571 | 5.882 |
| (−0.99, 0) | Mild | 28.57 | 31.429 | 38.235 |

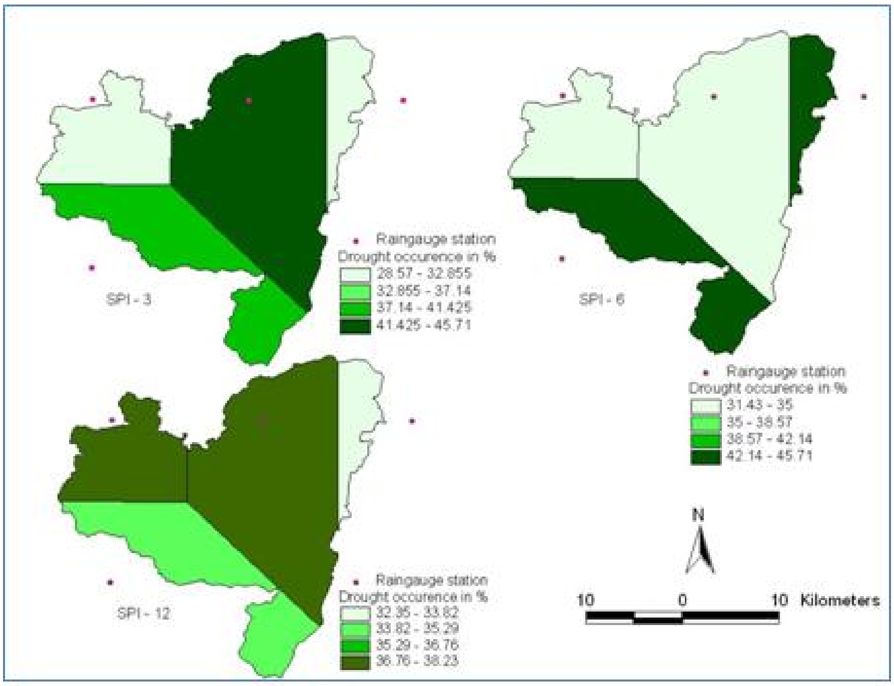



Fig. 4 (a) Spatial Extent of mild drought occurrence for the month of September

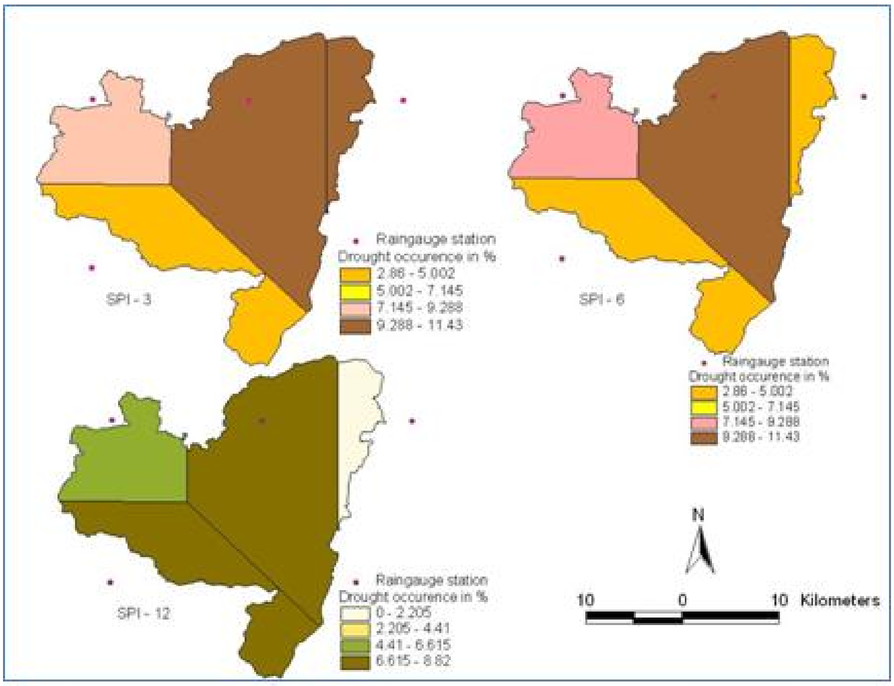



Fig. 4 (b) Spatial Extent of moderate drought occurrence for the month of September

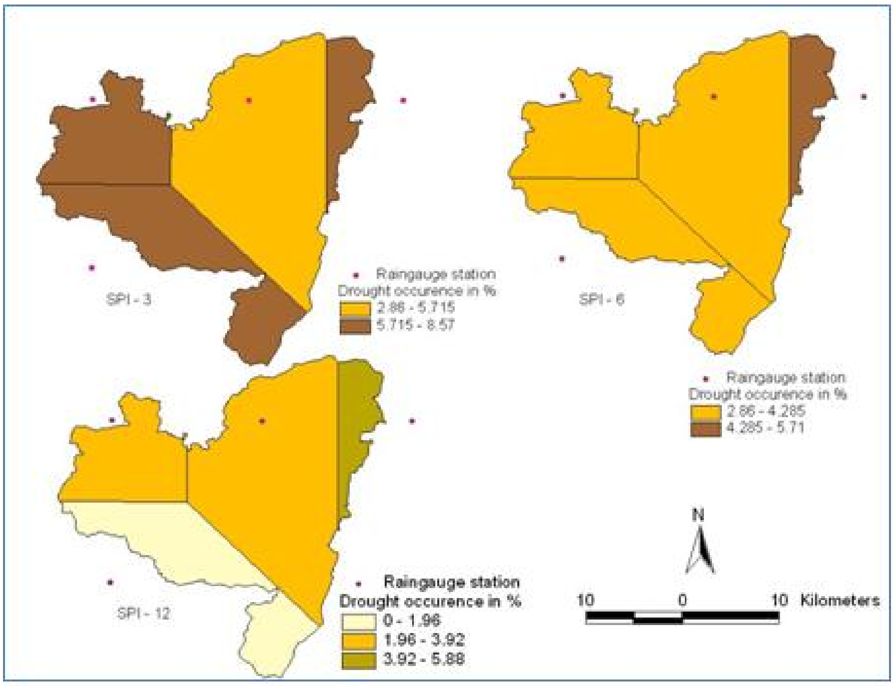



Fig. 4 (c) Spatial Extent of severe drought occurrence for the month of September

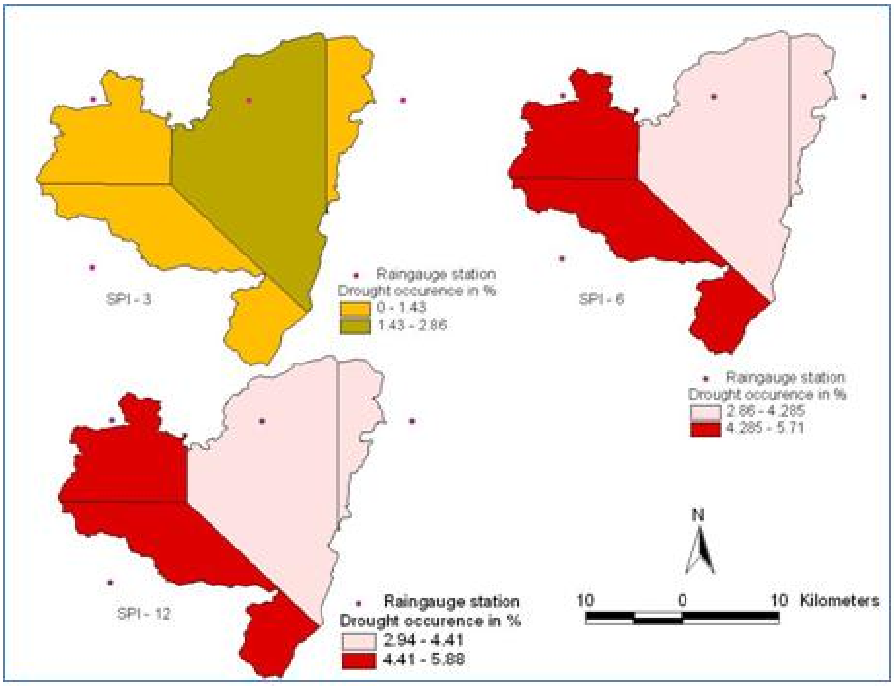



Fig. 4 (d) Spatial Extent of extreme drought occurrence for the month of September

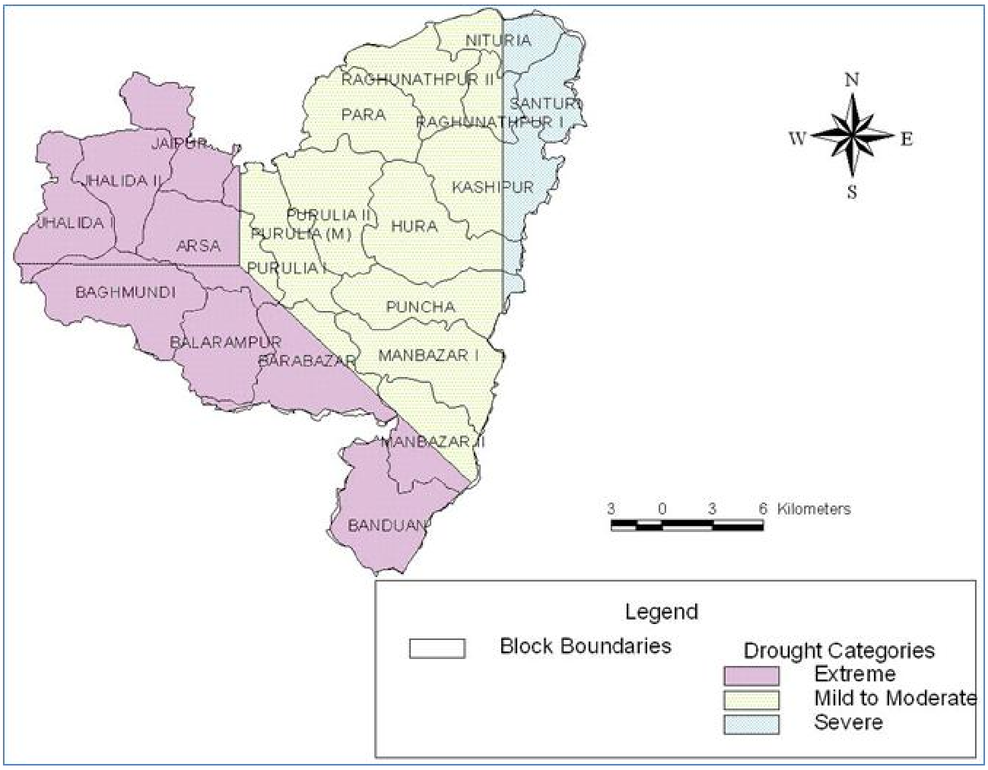



Fig. 5 Study area showing drought severity

Mild and moderate droughts (Fig. 4) occur in the central portion of the study area (Puruliya I, Puruliya II, Manbazar I, Raghunathpur II, and Para are the blocks which falls under the central portion of the study area). The northeast part of the study area is prone for severe drought, but less prone for extreme droughts. Extreme drought occurs in northwest and southwest part of the study area. Hence the entire study area can be labeled as drought prone area (Fig. 5).

## V. CONCLUSION

The analysis of spatial pattern of drought using spatial SPI and temporal SPI from rainfall data is useful to determine the spatial distribution and characteristics of drought in the Puruliya District, West Bengal, India. GIS helps to generate drought severity maps for the different time scales and months of the year. Temporal SPI graphs show that the maximum SPI value (extreme drought) occurs in station 3 in the year 1993. From the areal extent graph, 1976, 1979, 1980, 1982, 1983, 1985, 2001, 2003 are the worst years with nearly 100% of the total area under extreme drought. Mild and moderate droughts occur in the central portion of the study area. The northeast part of the study area is prone for severe drought and extreme drought occurs in northwest and southwest part of the study area. Hence from the drought severity maps it can be shown that the entire study area can be labeled as drought prone area. It is found that SPI is a good indicator of the drought characteristics like severity and spatial extent. There exists no relation between the droughts of short and longer time scales as well as among the severity classes of each time period.

## ACKNOWLEDGMENT

The authors would like to thank the India Meteorological Department (IMD), Pune, for providing the precipitation data.

## REFERENCES

[1] "Drought in India", *Poorest Areas Civil Society (PACS) Programme,* 2008.

[2] W. C. Palmer, "Meteorological Drought", *U.S. Weather Bureau Manuscript* No. 45 58pp February, 1965.

[3] W.M. Alley, "The Palmer Drought Severity Index as a measure of hydrological drought", *Water Resources Bulletin* Vol. 21 p105 - 114, 1985.

[4] T. Karl, F. Quinlan and D.S. Ezell, "Drought termination and amelioration: its climatological probability", *Journal Clim Appl Met* Vol. 26 p1198 - 1209, 1987.

[5] Z. Sen, "Probabilistic formulation of spatio-temporal pattern", *Theor Appl Climatological* Vol. 6 p197 - 206, 1998.

[6] X. Lana, C. Serra and A. Burgueno, "Spatial and temporal characterization of annual extreme droughts of Catalonia (North Spain)", *Int J Clim* Vol. 18 p93 - 110, 1998.

[7] K. Stahl and S. Demuth, "Linking stream flow drought to occurrence of atmospheric circulation pattern", *Hydrol Sci Journal* Vol. 44(5) p665 - 680, 1999.

[8] T. B. McKee, N. J. Doesken and J. Kleist, "The Relationship of Drought Frequency and Duration to Time Scales", *Proceeding of the Eight Conference on Applied Climatology* 17-22 January, Anaheim, California, 1993.

[9] M. Rouault and Y. Richard, "Intensity and Spatial Extension of Drought in South Africa at Different time Scale", *Water SA* Vol. 29(4) October, 2003.

[10] A. Loukas and L. Vasiliades, "Probabilistic analysis of Drought spatiotemporal characteristics in Thessaly region, Greece", *Natural Hazards and Earth System Sciences* Vol. 4 p719 - 731, 2004.

[11] S. Shahid and H. Behrawan, "Drought risk assessment in the western part of Bangladesh", *Nat Hazards* Vol. 46 p391 - 413, 2008.

[12] O. Yldz, “Assessing temporal and spatial characteristics of droughts in the Hirfanli dam basin, Turkey”, *Scientific Research and Essays* Vol. 4 (4) p249 - 255, 2009.
[13] D. C. Edossa, M. S. Babel and A. D. Gupta, “Drought Analysis in the Awash River Basin, Ethiopia”, *Water Resour Management* Vol. 24 p1441 - 1460, 2010.
[14] P. Angelidis, F. Maris, N. Kotsovinos and V. Hrissanthou, “Computation of Drought Index SPI with Alternative Distribution Functions”, *Water Resour Manage* Vol. 26 p2453 - 2473, 2012.
[15] D. C. Edwards and T. B. McKee, “Characteristics of 20th century drought in the United States at multiple timescales”, *Climatology Report Colorado State University, Fort Collins*, No. 97-2, 1997.
[16] H. C. S. Thom, “A Note on the Gamma Distribution”, *Monthly Weather Review* Vol. 86(4) p117 -122, 1958.
[17] M. Abramowitz and A. Stegun, “Handbook of mathematical formulas, graphs, and mathematical tables”, *Dover Publications Inc* New York, 1965.