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Analysis of Meteorological Drought: The Scenario of West Bengal

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A B S T R A C T

Drought occurs due to the relative scarcity of rainfall and varies with respect to occurrence, duration, intensity and extent of the affected area on a spatio-temporal scale. It has far-reaching impact on water resource availability, crop production, ecosystem and a host of social and economic activities. Using Indian Metrological Department (IMD) rainfall data, the authors have attempted an insightful analysis of meteorological drought in the state of West Bengal that has primarily an agro-based economy.

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Introduction

Being the most important environmental problems affecting our earth, drought has been ranked by Hass (1978) as the 'third most costly geophysical phenomena' (Oladipo, 1993). Based on its nature, droughts may be divided into four different categories, viz., meteorological, hydrological, agricultural and socio-economic (Mishra and Singh, 2010). Of these, the meteorological drought signifies the paucity of rainfall over a region for a considerable period of time. Climatic conditions / factors like high temperature and high wind can only worsen its intensity. It should also be noted that a detailed analysis of drought also requires understanding of several other factors like, soil moisture, potential evapo-transpiration, vegetation condition, surface and ground water levels, and etc..

Existing literature on drought largely talks about drought intensity and frequency in various regions like Nebraska in US (Oladipo, 1985), Colorado in US (McKee *et al*, 1993), Sabah and adjacent parts of northern Borneo (Walsh, 1996), Sahel in northern Africa (Agnew and Chappell, 1999), northern China (Zhiew *et al*, 2003) and Aravalli in India (Bhuiyan *et al*, 2006).

A number of different indices have been formulated to quantify the nature of drought. These include Rainfall Anomaly Index (RAI), Palmer Drought Index (PDI), Bhalme and Mooley Drought Index (BMDI), Surface Water Supply Index (SWSI), Standardized Precipitation Index (SPI), Reclamation Drought Index (RDI) etc. Mishra and Singh (2010) have provided a neat review of commonly used drought indices along with their relative advantages and limitations.

Study Area

Physiographically, West Bengal is unique containing almost all the physical features. It has three distinct meteorological seasons, viz., summer (March-May), rainy season (June-October) and winter (November-February). During the hot and dry summer, it experiences localized thunderstorms associated with strong winds and short duration rain. Rainfall is largely due to the south-west monsoons.

The Indian eteorological Department (IMD) M long period data (1900-2005) shows increasing trend in the annual frequency of severe tropical cyclones that crossed West Bengal coast. About 2.65 million ha of land in the state is prone to flood (Attri and Tyagi, 2010). IMD has divided this state into two meteorological sub-divisions, viz., Sub-Himalayan West Bengal (SHWB) and Gangetic West Bengal (GWB). In order to get a holistic and real spatial analysis of drought, the geographically well-distributed 15 meteorological / rain gauge stations have been taken into consideration (Table-1 and Fig.1)

Objectives

The main objective of this study is to analyze meteorological drought in West Bengal on a spatio-temporal scale, particularly to understand the prevalent rainfall dynamics, to examine the seasonal variation in the occurrence and intensity of drought, and to trace the periodicity of droughts.

Database and Methodology

Monthly rainfall data for each station for the period, 1973 – 2005 has been collected from IMD Data Centre, Pune. However, due to lack of data, the monthly rainfalls of Balurghat and Sagar Islands have been taken for the period, 1969 – 2001, and that of Purulia for the period, 1970 – 2002. Climatological Tables, showing long period normal rainfall data (1961-1990) have been obtained from the IMD, New Delhi. For understanding rainfall dynamics, 'coefficient of variation' has been used. Besides, to calculate drought intensity, 'percentage of rainfall departure' (IMD) and 'standardized precipitation index' (SPI) have been used. IMD defines 'meteorological drought' as 'a situation when the seasonal monsoon (June-September) rainfall is less than 75% of its long-term average value' (Attri and Tyagi, 2010). Hence, 'percentage of rainfall departure' variable has been considered to identify the drought categories (Table 2). Due to non-availability of data for all stations, the study has been restricted within 2005.

Table-1: Meteorological/Rain Gauge Stations of Study Region

Meteorological Sub-division	Meteorological/Rain Gauge Stations
Sub-Himalayan West Bengal (SHWB)	Darjeeling, Cooch Behar, Jalpaiguri, Balurghat and Malda
Gangetic West Bengal (GWB)	Berhampore, Shantiniketan, Bankura, Purulia, Bagati, Krishnanagar, Uluberia, Midnapore, Sagar Islands and Alipore

Source: Climatological Tables of Observatories in India, 1961-1990, 6th Ed., IMD.

Table-2: Drought Categories

Percentage Rainfall Departure	Condition
99.99-90	Normal rainfall
89.99-74	Deficient
73.99-50	Moderate Drought
<50	Severe Drought

Source: Pai *et.al.* (2010)

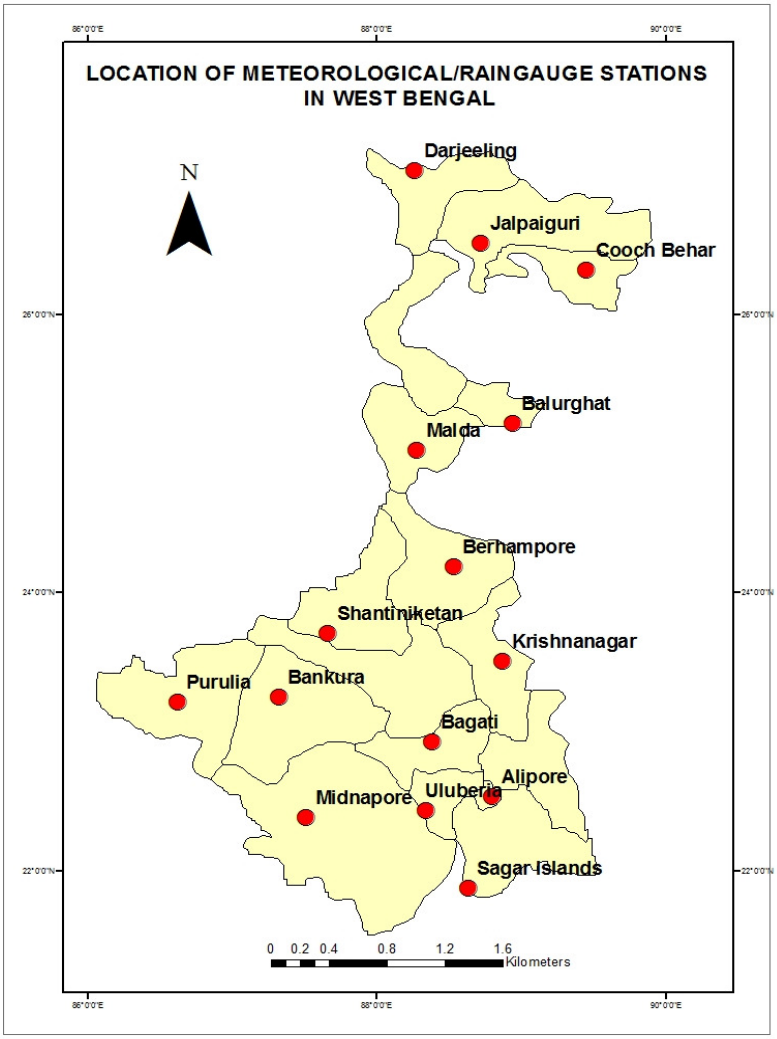

Fig. 1

For a particular station, SPI is calculated on the basis of long term rainfall record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed to a normal distribution so that the mean SPI for the location and desired period is zero (Mishra and Singh, 2010).

$$SPI = (a - b) / c$$

where, a = individual Gamma cumulative distribution value, b = mean, c = standard deviation

It can be calculated for various time scales; however, different length of rainfall record and use of different probability distribution yield varying results in SPI (Mishra and Singh, 2010). For the present study, the following drought categorization has been taken into consideration (Table – 3).

Table-3: Drought Categories according to SPI values

SPI values	Drought Category
0 to -0.99	Mild Drought
-1.00 to -1.49	Moderate Drought
-1.50 to -1.99	Severe Drought
<= -2.00	Extreme Drought

Source: McKee *et al* (1993)

Analysis

(a) Rainfall Dynamics

As in West Bengal rainfall mostly depends on vagaries of south-west monsoon, its spatio-temporal variation is very prominent. IMD long period normal data (1961-1990) reveals that annual average rainfall is highest in Cooch Behar (288.9 mm) and lowest in Krishnanagar (98.9 mm). Although, extreme northern and southern parts (adjacent to Bay of Bengal) of the state receive more rainfall, the central and western parts receive less rainfall.

Coefficient of variation, a relative measure of dispersion, is computed to get seasonal and annual variability of rainfall for all stations. During pre-monsoon (February-May) and post-monsoon season (October-January), most of the stations report high variability of rainfall. During pre-monsoon season, rainfall variability is quite high in Berhampore, Sagar Islands, Purulia, Malda and Darjeeling. In monsoon season (June-September), all the stations (excluding Krishnanagar) report less than 36% variability. However, in post-monsoon season, some stations like Krishnanagar, Midnapore, Purulia, Jalpaiguri, Darjeeling, Malda and Balurghat exhibit higher rainfall variability. In general, few stations like Krishnanagar, Balurghat, Malda and Sagar Islands report higher rainfall variability (Fig.2).

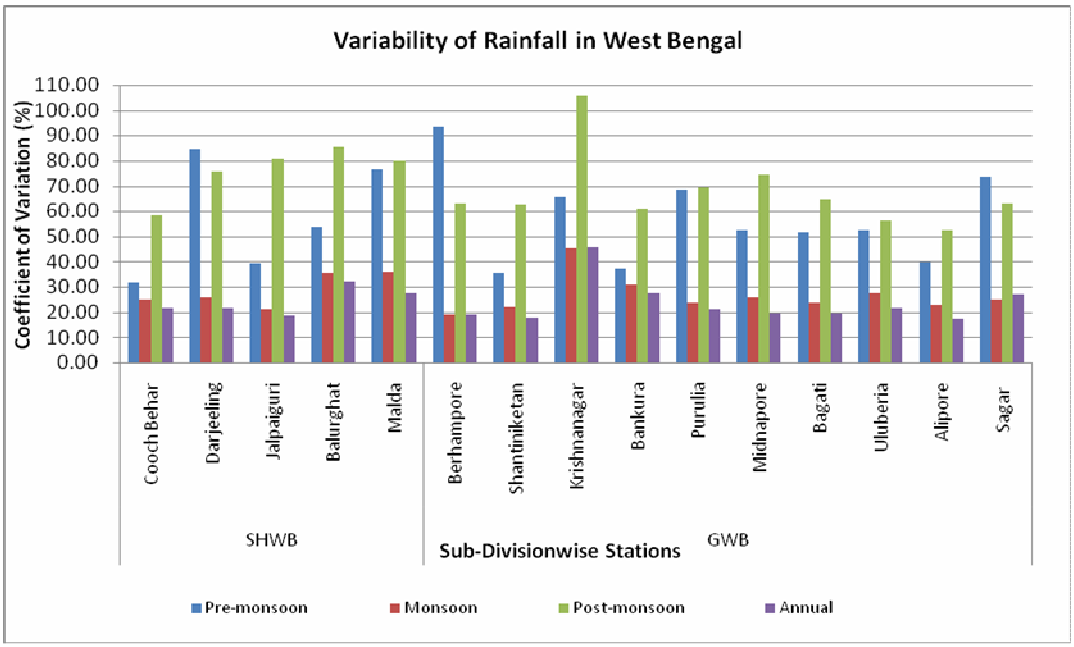

Fig. 2

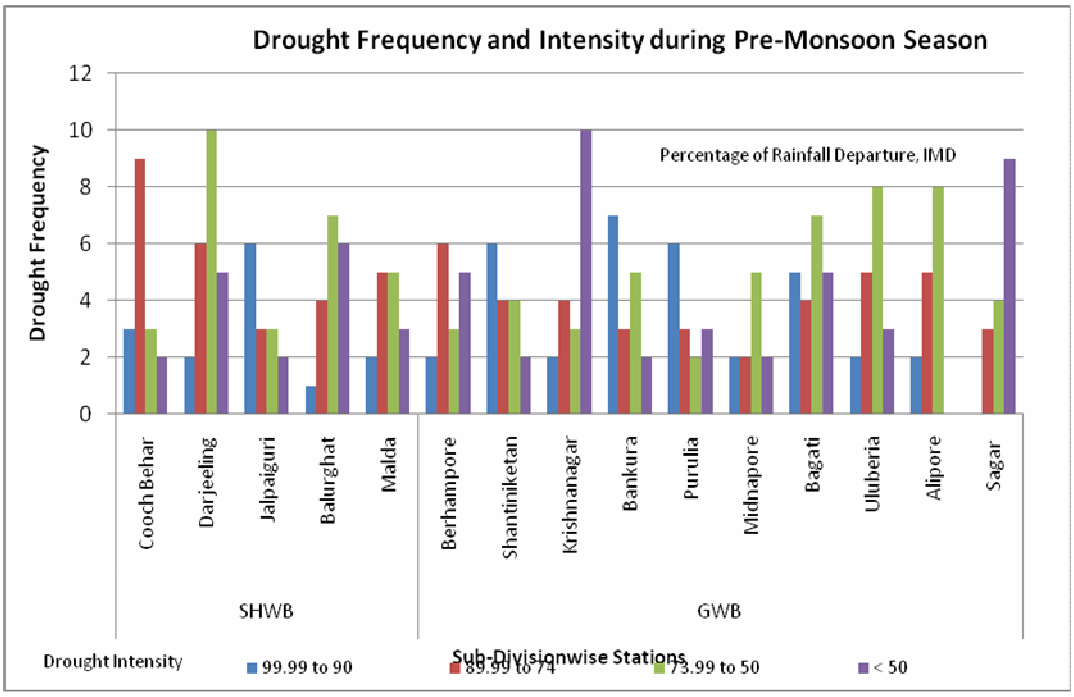

Fig. 3

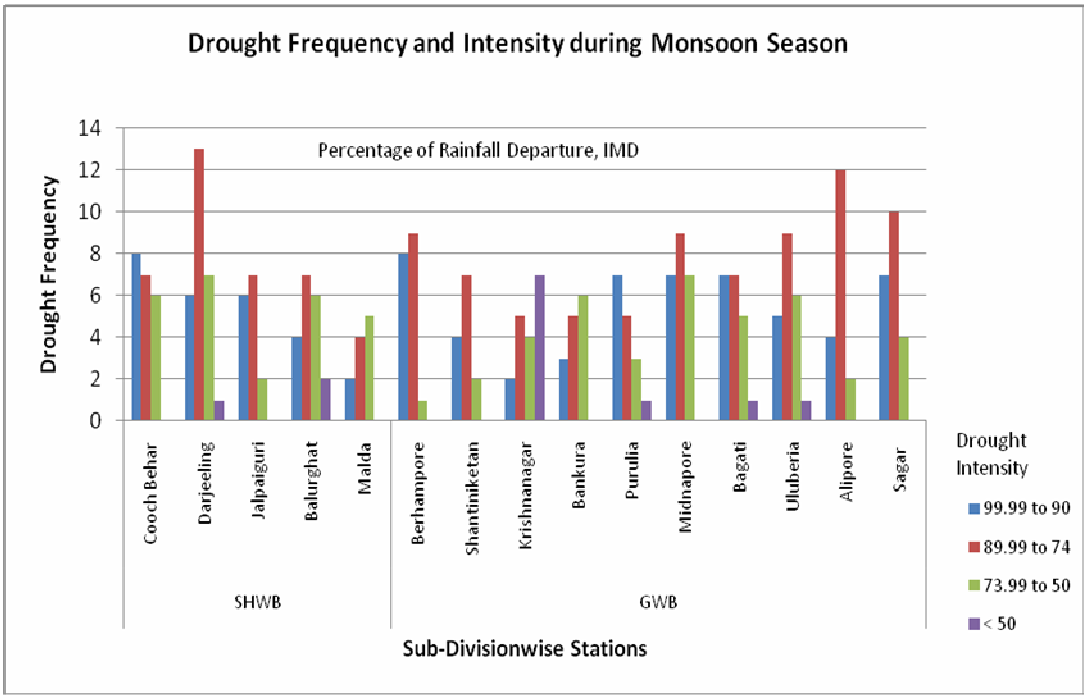

Fig. 4

(b) Drought Frequency and Intensity — *analyzing rainfall departure*

Rainfall dynamics is very helpful in assessing meteorological drought. During pre-monsoon season, Balurghat, Darjeeling, Malda, Krishnanagar, Berhampore, Sagar Islands and Bagati have experienced higher number of 'severe droughts'. In this season, 'moderate drought' frequency is found to be higher in Darjeeling, Balurghat, Alipore, Uluberia and Bagati. On the other hand, Jalpaiguri, Shantiniketan, Bankura and Purulia show normal rainfall condition during this season (Fig.3).

However, monsoon season is characterized with variable rainfall across the state. 'Normal rainfall' occurred in Cooch Behar, Jalpaiguri, Berhampore, Purulia, Midnapore and Bagati. However, higher number of years of 'deficient rainfall' has been experienced in Darjeeling, Berhampore, Uluberia, Alipore and Sagar Islands. Only Krishnanagar has experienced higher number of 'severe droughts' in this season (Fig.4).

In post-monsoon season, meteorological drought appears more prominently. Higher frequency of severe droughts has been reported in Darjeeling, Balurghat, Berhampore, Krishnanagar, Malda and Sagar Islands. Moderately higher frequency of 'severe droughts' has been observed in Bankura, Purulia, Malda and Jalpaiguri. Malda, Balurghat, Jalpaiguri, Berhampore and Krishnanagar also report higher frequency of 'moderate droughts' (Fig.5).

It should be noted that Krishnanagar has the unique experience in higher frequency of 'severe droughts' in all three seasons. Apart from this, Balurghat has experienced higher frequency of 'moderate droughts' in all three seasons. The seasonal data also reveals that Darjeeling, Malda, Berhampore, Uluberia and Sagar Islands have reported higher frequencies of high intensity (severe and moderate) droughts. Here, we must remember that rainfall variability is quite higher in Krishnanagar, Balurghat, Malda and Sagar Islands (Fig.2).

(c) Drought Frequency and Intensity— *analyzing SPI Occurrence*

During the study period, wet and dry conditions have varied seasonally. In case of Cooch Behar, monsoon season has experienced less number of

droughts as compared to pre-monsoon and post-monsoon season. In contrary, Midnapore has reported higher number of droughts in monsoon season as compared to pre-monsoon and post-monsoon seasons. To capture such time- bound nature of droughts, it is judicious to compute seasonal as well as annual frequency of droughts for each station.

During pre-monsoon season, Jalpaiguri, Darjeeling, Balurghat, Cooch Behar, Malda, Darjeeling, Purulia and Uluberia have reported higher number of droughts. This frequency is relatively low in Krishnanagar, Midnapore and Bagati. In monsoon season, Malda, Berhampore, Uluberia, Alipore etc stations have shown higher frequencies of drought. However, majority of stations in SHWB sub division have reported lower frequencies of drought. During post-monsoon season, Jalpaiguri, Alipore, Shantiniketan, Krishnanagar and Bagati have reported higher number of droughts. On the other hand, Darjeeling, Berhampore and Bankura have experienced lower number of droughts. In overall sense, Jalpaiguri, Darjeeling, Cooch Behar, Berhampore, Krishnanagar, Alipore, Bagati and Sagar Islands Islands have reported relatively higher number of droughts. In contrary, Balurghat, Shantiniketan and Uluberia have experienced relatively lower number of droughts (Fig.6).

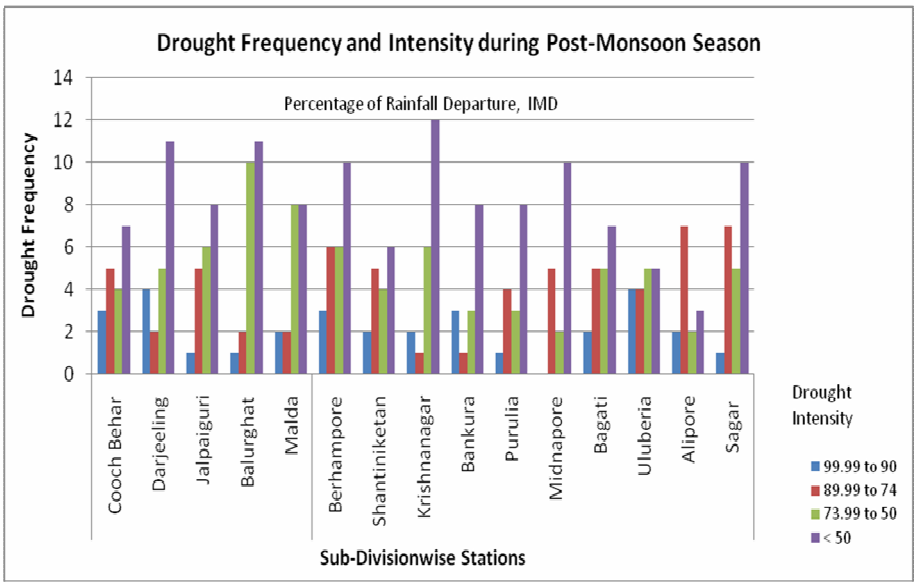

Fig. 5

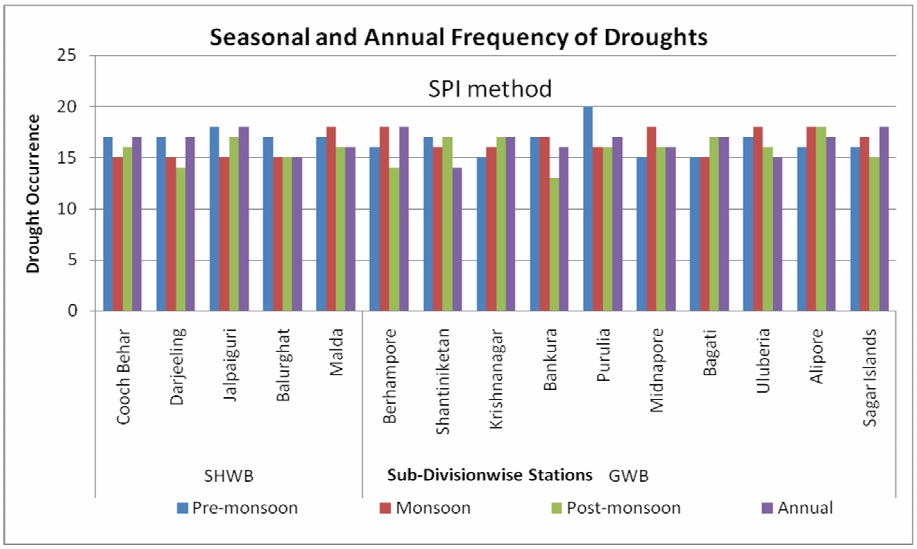

Fig. 6

Frequency and Intensity

Relatively higher number of severe droughts has taken place in Berhampore, Bankura, Shantiniketan, Krishnanagar and Uluberia during pre-monsoon season. In monsoon season, few stations like Uluberia, Bagati, Purulia and Malda have reported higher number of years of severe droughts. During post-monsoon season, this critical situation has happened in Berhampore, Bagati, Bankura, Uluberia and Alipore. Based on average annual rainfall data of the whole time period, the SPI values show relatively higher number of droughts in Bankura, Purulia and Balurghat. Except Sagar Islands and Berhampre, each station of the state has reported two years of severe drought. Thus, every station has reported at least one year of moderate drought in all three seasons. Annually speaking, Berhampore, Santiniketan, Cooch Behar and Jalpaiguri have experienced relatively higher number of moderate droughts. Relatively higher number of moderate droughts has occurred in Balurghat, Bagati and Sagar Islands during pre-monsoon season. During monsoon season, Cooch Behar, Alipore, Darjeeling and Berhampore have such higher number of gloomy experiences. In post-monsoon season, Midnapore, Purulia and Krishnanagar report relatively higher number of moderate droughts (Table-4).

Spatial changes in drought pattern have been captured through drought intensity maps of 1974, 1988 and 2001. The spatial distribution of drought phenomena has a diversified picture in West Bengal. There is northward transition from dry to moist conditions. In 1974, the southern part of West Bengal has been more drought affected as compared to the North Bengal region. Surrounding areas of Bankura and Uluberia are affected by severe drought. Malda and Alipore stations are moderetly drought affected. In the northern part, drought has not ocurred at all (Fig. 7).

But in 1988, the situation has changed quite significantly. Severly drought affected zones have been shifted to the extreme side of Western Bengal. Purulia and Krishnanagar has emerged as severly drought affected areas. Between Purulia in one side and Alipore, Shantiniketan, Sagar Islands, Uluberia on other, a reltively moist zone has appeared. In the central part of West Bengal (at Malda and Balurghat), another transition zone of mild and moderate drought has prevailed. In northern part of the state, Darjeeling has experienced mild drought but the nearby stations of Jalpaiguri and Cooch Behar has moist conditions (Fig. 8).

In 2001, there is a total change in the spatial pattern. Almost equal intensity of drought is observed in the state, except extreme northern and central parts. Darjeeling, Shantiniketan, Berhampore, Cooch Behar, Alipore has come out as moderate to severe drought affected areas (Fig. 9).

In SHWB meteorological sub-division, Balurghat (4), Malda (2) and Jalpaiguri (2) have reported higher number of severe drought years. In GWB sub-division, Purulia (3) and Alipore (3) exhibit higher number of severe drought years. Berhampore (8), Shantiniketan (6) and Jalpaiguri (6) have experienced higher number of moderate droughts (Table-5).

(d) Periodicity of Drought

If drought occurs continuously for years, the water balance situation gets hampered, thereby affecting water resources, natural vegetation and crops. But if the drought is intermittent, then other rainfall-led wet years keep soil moisture recharged. That's why periodicity of drought is important. It has been observed that Balurghat and Krishnanagar have continuous ten years drought period.

Even, Krishnanagar, Bankura and Puruliya have poor experiences of five-year prolonged drought. Continuous Four-year

drought has happened in Bankura, Midnapore, Uluberia and Sagar Islands. Even Jalpaiguri has experienced such four-year prolonged drought twice (Table-6).

Table-4: Seasonal Drought Frequency and Intensity according to SPI values

		Pre-monsoon			Monsoon			Post-monsoon			Annual		
Sub-Division	**Stations**	*Mi*	*Mo*	*Se*	*Mi*	*Mo*	*Se*	*Mi*	*Mo*	*Se*	*Mi*	*Mo*	*Se*
SHWB	Cooch Behar	11	3	3	7	7	1	9	4	3	9	6	2
	Darjeeling	13	1	2	7	7	1	6	5	3	12	3	2
	Jalpaiguri	12	4	2	8	5	2	9	5	3	10	6	2
	Balurghat	9	7	1	8	5	2	8	5	2	8	3	4
	Malda	12	3	2	12	3	3	12	3	1	9	5	2
GWB	Berhampore	9	3	4	10	7	1	7	3	4	10	8	0
	Shantiniketan	11	3	3	9	5	2	11	4	2	6	6	2
	Krishnanagar	7	5	3	9	5	2	9	6	2	10	5	2
	Bankura	10	3	4	10	5	2	5	5	3	9	3	4
	Purulia	15	3	2	10	3	3	8	6	2	10	3	4
	Midnapore	8	5	2	11	5	2	8	8	0	9	5	2
	Bagati	7	6	2	7	5	3	10	4	3	10	5	2
	Uluberia	11	3	3	11	3	4	9	4	3	8	5	2
	Alipore	8	8	0	10	8	0	14	1	3	12	3	2
	Sagar Islands	8	6	2	11	5	1	9	4	2	12	5	1

Source: Compiled from SPI values by the authors *Note*: *Mi*- Mild, *Mo*- Moderate, *Se*- Severe

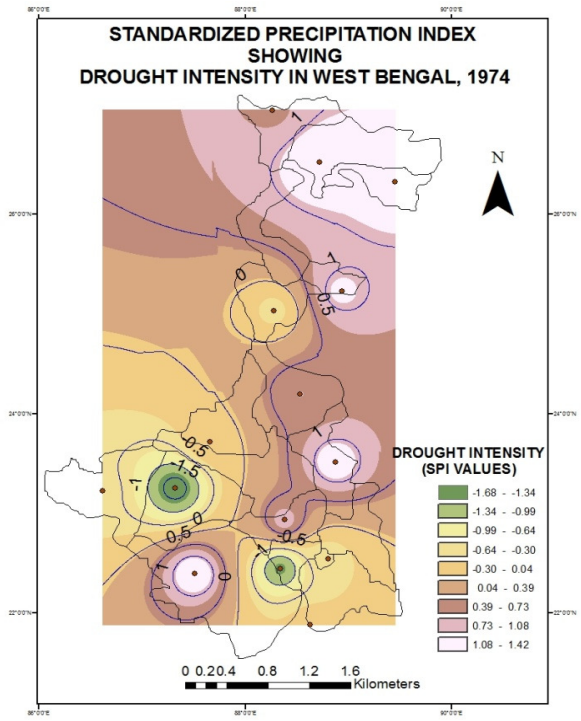

Fig. 7

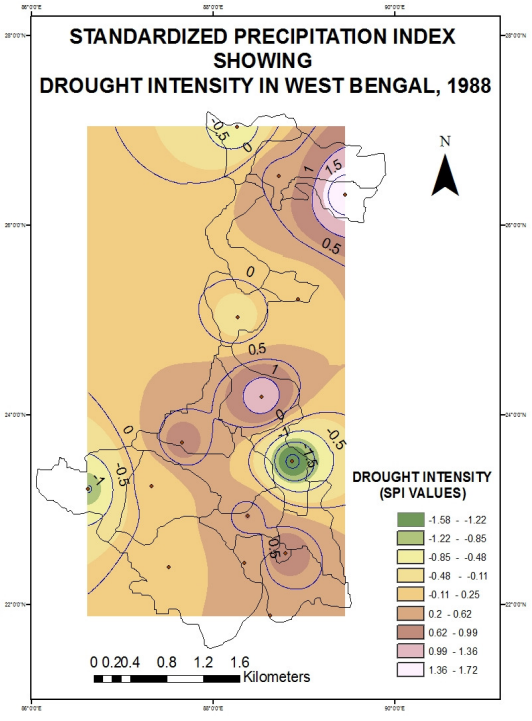

Fig. 8

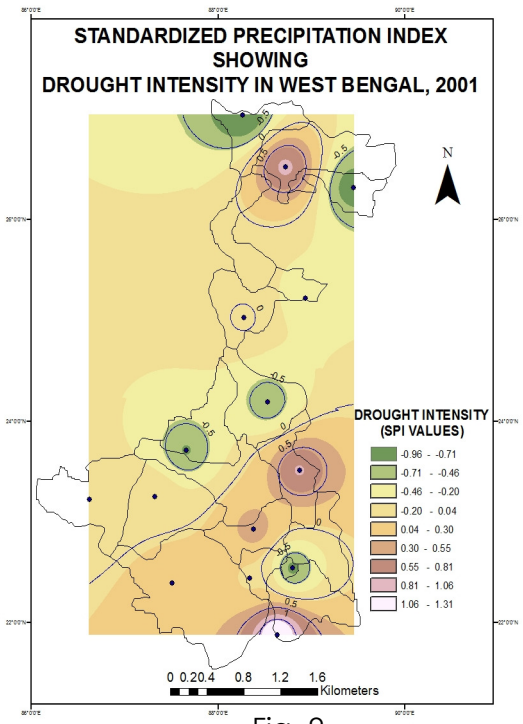

Fig. 9

Table-5: Drought Years with various intensities (SPI value)

		Drought Years		
Sub-Division	**Stations**	***Mild***	***Moderate***	***Severe***
SHWB	Cooch Behar	1976-1981, 1986, 1995, 1997, 2000-2002	1990-1992, 1994,1998	_
	Darjeeling	1973, 1976, 1981-82, 1986-88, 1992, 1994, 1996-97, 2001	2000, 2002, 2005	1998
	Jalpaiguri	1977, 1979, 1982-83, 1990, 1993, 1995, 1997, 2002, 2004	1973, 1976, 1981, 1986, 1992, 2005	1978, 1994
	Balurghat	1970, 1986, 1992-94, 1996, 1998, 2001	1972, 1997	1975, 1995, 1999-2000
	Malda	1974, 1980, 1983-84, 1988-89, 1992, 2003, 2005	1975-76, 1978, 1982, 1994	1979, 1986
GWB	Berhampore	1975-76, 1978, 1981, 1984, 1987, 1989, 2001, 2003-04	1979, 1982, 1985, 1992, 1994, 1997, 1999, 2005	_
	Shantiniketan	1974, 1981, 1983, 1991, 1996, 2001	1976, 1979, 1985, 1987, 2003, 2005	1982, 1992
	Krishnanagar	1978, 1980-81, 1983, 1985-86, 1992-94, 1996	1979, 1982, 1987, 1989	1988, 1990
	Bankura	1974, 1977, 1983, 1986, 1994, 1996, 1998, 2001, 2005	1975, 1976, 1981, 1982, 2000	1979,1 980
	Purulia	1970, 1974-1975, 1980-81, 1989, 1991, 1997, 1999, 2001	1976, 1983, 1988	1972, 1979, 1982
	Midnapore	1973, 1975, 1980, 1982, 1991-92, 1995, 2003-04,	1979, 1996-98, 2000	1976, 1983
	Bagati	1973, 1975-76, 1985, 1987, 1991-92, 1996, 2004-05	1979, 1989, 1994, 1997, 2003	1982-83
	Uluberia	1975-76, 1983-85, 1987, 1992, 1996	1974, 1979-1980, 1997, 2003	1982, 1998
	Alipore	1974-75, 1983, 1985, 1992, 1994, 1996, 2001, 2003-05	1976, 1989, 2000	1979-80, 1982
	Sagar Islands	1969, 1971, 1974, 1980, 1982, 1984, 1987, 1989, 1992, 1996-98	1972, 1976, 1979, 1985, 2000	1970

Source: Compiled from SPI values

Table-6: Drought Periodicity in Years

	SHWB					GWB									
Drought Period (Years)	Cooch Behar	Darjeeling	Jalpaiguri	Balurghat	Malda	Berhampore	Shantiniketan	Krishnanagar	Bankura	Purulia	Midnapore	Bagati	Uluberia	Alipore	Sagar Islands
1	1	4	5	4	5	7	9	1	5	4	2	6	3	5	7
2	2	2	1	0	1	4	1	0	1	1	5	4	1	3	2
3	2	3	1	0	3	1	1	0	0	2	0	1	2	2	1
4	0	0	2	0	0	0	0	0	1	0	1	0	1	0	1
5	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0

Source: Compiled from SPI values by the authors

Conclusion

Drought frequency and intensity analysis shows that the western (Bankura and Purulia) and central parts (Balurghat, Malda and Krishnanagar) are more affected by this hazard. This may be attributed to considerable variability of rainfall. South-West Monsoon (Bay of Bengal Branch) practically provides plenty rainfall in northern and southern parts of the state. However, extreme northern part has also been found to be drought affected in recent years. IMD long period data (1961-1990) shows that Krishnanagar, Malda and Purulia have experienced relatively lower rainfall (< 1333 mm) as compared to Darjeeling and Cooch Behar (> 2500 mm). Fortunately, Darjeeling and Cooch Behar is well endowed with abundant rainfall, glacier-fed fluvial system and grey black Terai soil. Unfortunately, the central and western parts are characterized by shallow and reddish lateritic soil having low moisture retention capacity. Besides, its interior location and rugged undulating terrain have also prompted persistent dry conditions. Thus, even a smaller fluctuation in rainfall would largely affect moisture availability conditions in Krishnanagar, Malda and Purulia as compared to Darjeeling and Cooch Behar. Therefore, an integrated planning approach, addressing regional climatic conditions, soil, natural vegetation, hydrology and topographical characteristics, can help in agricultural and landuse planning.

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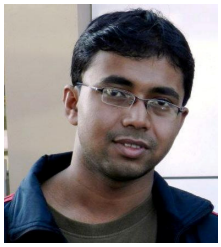

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