Spatial analysis of rainfall variability and rainfed rice crop using GIS Technique in West Bengal (India)

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1. Introduction

West Bengal’s climate varies from tropical savannah in the southern portions to humid subtropical in the north. In early summer brief squalls and thunderstorms known as “Kal-Baisakhi” often arrive from the north or northwest. Monsoons bring rain to the whole state from June to September. West Bengal receives the Bay of Bengal branch of the Indian Ocean monsoon that moves in a northwest direction. However, the Darjeeling Himalayan Hill region experiences a harsh winter, with occasional snowfall at places. The southern parts of West Bengal actually sweat it out with humidity for most time of the year, while the northern and northeastern parts of West Bengal are chilly and cool. Monsoon plays havoc in the region, while the northern and northeastern parts of West Bengal are chilly and cool. The southern parts of West Bengal receive considerable amount of rainfall every year. The average annual rainfall is found to be about 1750 mm ranging from 2500-3500 mm in the Duars and Terai regions to 1200-1800 mm in the plains. 75-80% of the rainfall is recorded during the four months of the monsoon season (June to September). Dry weather prevails during four to five months (November to March) with inadequate rainfall for crop production. Erratic and scattered showers fall between March and May which gradually increase in frequency and intensity and merge into the monsoon. Consequently, sowing of Jute and Aus rice during mid-April and often May is not possible when there is a delay in the onset of monsoon and thus raising only one crop a year is possible under rainfed conditions. Soil of the zone is course textured, shallow and sandy derived weathered debris of the rocks. Soils are subjected to severe wind erosion and have usually boulders with high permeability and low water holding capacity. Some of the flat areas are subjected to floods and are also affected by salinity (Singh, 2010).

As in other states, farmers in West Bengal also have to adjust the cropping system and crop management practices to the limitations imposed by the variability of rainfall. They have developed the farming system, which they practice, by trial and error. The past experience provides them with very broad information on rainfall, floods and water stress. However, for modern agriculture it is not enough. Without proper knowledge of variability of rainfall and other agro meteorological conditions, effective crop management and schedule of supplemental irrigation cannot be undertaken. The variability experienced at the onset and end of the rainy seasons undoubtedly affects the farmer’s cropping strategies. The length of the growing seasons for rainfed crop in any region is precisely determined by the time between the first useful rainfall and end of the useful rainfall, although drought can occur during the middle of these periods. Agricultural practices and operations are planned accordingly to the frequency and quantum of rainfall in the region (Singh, 2010).

The choice of crops and cropping systems is mostly governed by LGP (Ramakrishna et al., 1987, 1985 & 1980). Ramana Rao (1997) has worked the cropping strategies on agro ecological conditions when LGP varied between 75 to 180 days. The beginning, end and total duration of rainy season and frequency of dry spells for rain gauge stations in Andhra Pradesh have been computed and utilized for crop planning in Andhra Pradesh (Victor et al., 1991). The results have been utilized for agricultural planning purposes. Similarly, the rainfall variability and its effect on rained crop yields at Hyderabad were studied by Ramana Rao et al. (1993) and they have found negative aberration in the rainfall contributing to the fall in crop yields. The concept of water requirement satisfaction index (WRSI) was used to quantify the crop yield under rainfed conditions by Victor et al. (1988) and Raman et al. (1971). They have found an exponential relationship between the yield and water availability. Rainfall probability analysis for sustainable crop production and strategies for costal Orissa have been reported by Kar (2002). For rainfed agriculture system, Frere and Popov (1979) suggested a technique based on crop water balance using climate data. They have studied the relationship between WRSI and the relative yields of sorghum crop for Botswana region (FAO, 1986). Rainfall probability analysis for sustainable crop production and strategies for Bihar have been reported by Singh et al. (2005, 2007, 2008 and 2009) by analyzing 30 years data. Singh et al. (2009) has worked out the spatial analysis of Mandal-wise rainfall variability for drought in Anantapur District of Andhra Pradesh in India using the GIS software. Keeping in the view was in this paper spatial analysis of rainfall and rainfed rice of West Bengal.

Thematic maps for all the basic parameters and their derivatives have been prepared for the entire study area using GIS package. The analysis has helped in identified the regions where immediate attention is needed. The fertility status of the soils in all the states and the regions of low and high fertility at different blocks in the state have been identified (Katyal et al., 1996b & 1997).
West Bengal is an important rice growing state in the country where the crop is grown in all the three seasons, kharif (Amam). Mostly the crop is grown under irrigated conditions in the state. For the study purpose, seven districts, viz., Purulia, Midnapur, Bankura, Birbhum, Burdwan, West Dinajpur and Malda have been identified as rainfed rice growing districts.

2. Materials and method

The daily rainfall data (different districts and blocks of whole state of West Bengal) have been collected from IMD, Pune and rice yield data have been collected from Bureau of Economics and Statistics, West Bengal Government. Drought years were segregated on the basis of their severity following the procedure adopted by Subrahmanya and Sastri (1969); Sastri et al. (2006); Subrahmanya et al. (1965); Singh, (2005) and Singh and Rathore (2008). The levels of classification are given below:

| Departure of crop water deficit index value from the median | Drought intensity |
|-----------------------------------------------------------|------------------|
| 0 to 1/\(\sigma\)                                        | Mild             |
| 1/\(\sigma\) to \(\sigma\)                               | Moderate         |
| \(\sigma\) to 2\(\sigma\)                               | Severe           |
| >2\(\sigma\)                                             | Disastrous       |

where, \(\sigma\) is the standard deviation of the crop water deficit index values. The same criteria were adopted for determining phenophasic crop water deficit index and to estimate corresponding yield levels for different categories of drought years. A week receiving more than 50 mm rainfall is taken as wet week and less than 50 mm rainfall is taken as dry week. Based on the historical data of weekly rainfall, initial probabilities were worked out for each station as mention below:

\[
P(W) = \frac{F(W)}{n} \quad \text{and} \quad P(D) = \frac{F(D)}{n}
\]

where,

- \(P(D)\) - probability of occurrence of a dry week.
- \(P(W)\) - probability of occurrence of wet week
- \(F(D)\) - frequency of occurrence of a dry week.
- \(F(W)\) - frequency of occurrence of wet week in \(n\) years
- \(N\) - Number of years data.

Similarly, the conditional probabilities are calculated by formulae:

\[
P(D/D) = \frac{F(D/D)}{F(D/D) + F(W/D)} = \frac{F(D/D)}{F(D)}
\]

\[
P(W/W) = \frac{F(W/W)}{F(W/W) + F(D/W)} = \frac{F(W/W)}{F(W)}
\]

\[
P(D/W) = \frac{F(D/W)}{F(W/W) + F(D/W)} = 1 - P(W/W)
\]

\[
P(2D) = PD_{W1}.PDD_{W2}
\]

\[
P(3D) = PD_{W1}.PDD_{W2}.PDD_{W3}
\]

\[
P(2W) = PW_{W1}.PWW_{W2}
\]

\[
P(3W) = PW_{W1}.PWW_{W2}.PWW_{W3}
\]

where,

- \(P(D/D)\) - Probability of occurrence of dry week provided the last week was a dry week.
- \(P(W/W)\) - Probability of occurrence of wet week provided the last week was a wet week.
- \(P(D/W)\) - Probability of occurrence of a dry week provided the last week was a wet week.

2.1. Weekly MAI

Considering the soil moisture, weekly rainfall and weekly PET of individual stations, the AE was computed following Thornthwaite water balance technique. By using weekly AE and weekly PET (Penman, 1948), the weekly MAI and probability of expedience of weekly moisture availability were calculated by Thornthwaite et al., 1955 & 1957.
**TABLE 1**

Distribution of stable rainfall week (R>50 mm) in different selected stations of West Bengal

| Districts         | Stations         | No. of stable rainfall weeks | Start from (Week No.) | End on (Week No.) |
|-------------------|------------------|------------------------------|-----------------------|-------------------|
| Midnapur (W)      | Midnapur         | 15                           | 25                    | 38                |
| South 24 Pgs      | Alipur           | 17                           | 23                    | 39                |
| Darjeeling        | Darjeeling       | 19                           | 23                    | 40                |
| Darjeeling        | Kalimpong        | 18                           | 23                    | 40                |
| Coochbehar        | Coochbehar       | 23                           | 18                    | 40                |
| Murshidabad       | Baharampur       | 15                           | 24                    | 37                |
| North 24 Pgs      | Dum-Dum          | 17                           | 23                    | 39                |
| Nadia             | Krishnagar       | 12                           | 24                    | 36                |
| Jalpaiguri        | Jalpaiguri       | 23                           | 18                    | 40                |
| Purulia           | Purulia          | 14                           | 25                    | 39                |
| Burdwan           | Burdwan          | 14                           | 24                    | 37                |
| South Dinajpur    | Balurghat        | 15                           | 22                    | 40                |
| North Dinajpur    | Raiganj          | 16                           | 22                    | 38                |
| Malda             | Malda            | 17                           | 24                    | 40                |
| Midnapur (E)      | Contai           | 17                           | 24                    | 40                |
| Bankura           | Bankura          | 15                           | 24                    | 39                |
| Birbhum           | Shantiniketa     | 15                           | 24                    | 39                |
| Hooghly           | Bagati           | 15                           | 23                    | 39                |
| Howrah            | Howrah           | 14                           | 23                    | 39                |

**TABLE 2**

Earliest week for sowing of rainfed upland rice at some selected stations of West Bengal at different probability levels

| Districts         | Station           | Standard meteorological week number at probability levels (%) |
|-------------------|-------------------|--------------------------------------------------------------|
|                   |                   | 10   | 25   | 50   | 75   | 90   |
| Midnapur (W)      | Midnapur          | 12   | 15   | 18   | 20   | 22   |
| South 24 Pgs      | Alipur            | 13   | 16   | 18   | 19   | 22   |
| Darjeeling        | Darjeeling        | 12   | 13   | 15   | 17   | 18   |
| Darjeeling        | Kalimpong         | 13   | 14   | 16   | 18   | 19   |
| Coochbehar        | Coochbehar        | 13   | 14   | 16   | 17   | 19   |
| Murshidabad       | Baharampur        | 15   | 16   | 19   | 21   | 23   |
| North 24 Pgs      | Dum-Dum           | 14   | 16   | 18   | 19   | 22   |
| Nadia             | Krishnagar        | 13   | 15   | 18   | 19   | 21   |
| Jalpaiguri        | Jalpaiguri        | 13   | 14   | 16   | 18   | 19   |
| Purulia           | Purulia           | 14   | 17   | 20   | 23   | 24   |
| Burdwan           | Burdwan           | 12   | 15   | 18   | 20   | 22   |
| South Dinajpur    | Balurghat         | 14   | 16   | 18   | 21   | 21   |
| North Dinajpur    | Raiganj           | 15   | 17   | 19   | 21   | 22   |
| Malda             | Malda             | 15   | 18   | 19   | 21   | 23   |
| Midnapur (E)      | Contai            | 12   | 16   | 19   | 21   | 23   |
| Bankura           | Bankura           | 14   | 16   | 19   | 23   | 24   |
| Birbhum           | Shantiniketa      | 13   | 16   | 18   | 20   | 23   |
| Hooghly           | Bagati            | 13   | 16   | 17   | 19   | 24   |
| Howrah            | Howrah            | 13   | 14   | 18   | 21   | 23   |
Figs. 1(a-c). Mean productivity (t/ha), coefficient of variability and stability yield index of kharif rice crop in West Bengal

Figs. 2(a&b). Spatial variability in productivity of rice crop in (a) Purulia and (b) Midnapur districts of West Bengal

Figs. 3(a&b). Coefficient of variability in productivity of rice crop in (a) Purulia and (b) Midnapur districts of West Bengal

\[ MAI = \frac{AE}{PE} \]

where,

- MAI = Moisture Availability Index (Weekly),
- AE = Actual Evapotranspiration (Weekly)
- PE = Potential Evapotranspiration (Weekly)

For determination of Actual Evapotranspiration following two conditions have been considered

(i) If \( P > PE \), then \( AE = PE \)

(ii) If \( P < PE \), then \( AE = P + \Delta S \)

where,

- \( P \) = precipitation, \( \Delta S \) = Change in soil moisture

2.2. GIS methodologies

For the preparation of various thematic maps using GIS package, base maps with correct coordinates are essential. The map was digitized manually on the
computer screen. The errors obtained during the process of digitization were removed. The map has been projected to real coordinates through geo-processing techniques. The attribute table, which is created by default, contains the identity of each polygon (blocks). The names of the blocks in the maps entered against identified blocks to facilitate to enter the different parameters that are required to be analyzed. The analysis can be carried out either from the data available in the attributes table or from the same data available in excel format. With the help of GIS, the drought prone regions have been identified (Singh et al., 2009).

2.3. Spatial Interpolation using Spatial Analyst of Arc View 3.2a

Interpolation assumes that the phenomenon being predicted is closely approximated by the mathematical function used. The unknown values are then calculated according to this function. The choice of an approximate model is therefore essential in order to obtain reasonable results. Surface interpolation uses a defined or selected set of all the samples to estimate each of the output grid’s cell values (Singh, 2010 and Katyal et al., 1996b & 1997).

3. Results and discussion

3.1. Districts-wise of West Bengal

The water losses from the rice field in the form of evapotranspiration and percolation are assumed to be around 6 to 7 mm/day during the kharif season. It amounts to about 50 mm/week, which is considered as a stable rainfall period without stress. From the averages of weekly rainfall of all the district headquarters, period of stable rainfall weeks have been computed and depicted in Table 1. Also the start and end of such period has been worked out and presented in the same table. It is observed from the table that the duration of stable period varied from 12 weeks in the Nadia district to 23 weeks in Coochbehar district adjacent to high rainfall region in Assam and Bangladesh. In the northeastern districts, which comprise Darjeeling, Coochbehar and Jalpaiguri it varied between 18 to 23 weeks and in the rest of the districts it varied from 12 to 17 weeks. The start of the season in the state is early in the northeastern districts (18 week) and ends in 40th week whereas it is around 25th week in Purulia and Midnapur which are typical rainfed areas and ends around 38th and 39th weeks (Singh et al., 2008, Chowdhury, 1981 & 1998).

For direct sowing of rice under upland conditions, cumulative amount of rainfall of 75 mm is required for taking up sowings. Using the above criteria, the earliest week of sowing of upland rice at different probabilities of the selected rain gauge stations have been analyzed in Table 2. It is observed from the Table 2 that sowing of upland rice could be started as early as 15th week at Darjeeling followed by 16th week in Coochbehar and Jalpaiguri once in two years (50% probabilities). For southern and western districts, sowing could be taken up in 18th-19th week while it would be in 20th week in Purulia. When the probability increased to 75 per cent, a delay of one to two weeks in commencement has been observed in all the stations. However, the delay in commencement was around three weeks in Purulia according to Victor et al. (1991). These would provide a basis for preparing management strategies for reducing risks involved in rainfed situation.

3.1.1. Crop productivity pattern

From the mean rice crop productivity, the coefficient of variability and the sustainability index (Mean - Sd. Dev. / highest value) in respect of the blocks in season (kharif) have been computed. Using GIS, the mean productivity maps, coefficient of variability and SYI maps for the Aman season have been prepared [Figs. 1(a-c)]. As the study is confined to rainfed rice system, the maps for Aman season (kharif) are only presented (Katyal et al., 1996b & 1997).

The Fig. 1(a), which shows the mean productivity during kharif season indicated that highest productivity
values of 3 to 3.5 t/ha is noticed in the block of central districts of Burdwan, Bankura, Birbhum, Hoogly districts. Perhaps, irrigation facilities in these districts might have helped in arriving at such high productivity rates. Low productivity of 1 to 1.5 t/ha have been noticed in two to three blocks of South 24-Paraganas and in Jalpaiguri districts. The productivity levels of northern districts, viz., Jalpaiguri, Coochbehar, West Dinajpur, South 24-Paranagas vary from 1.5 to 2.0 t/ha.

3.1.2. Crop variability

The coefficient of variability (CV%) map [Fig. 1(b)] indicates that the variability is low (0-20%) in few blocks of Burdwan, Purulia, Midnapur and Coochbehar. It is interesting to note that all the higher productivity zones are not stable as the variability is high among these blocks. Most of the area in the state can be categorized as under low and medium variability.
Table 6(a)

Rice yields and the corresponding rainfall and its derivatives in different blocks of Jaldha, Purulia district (West Bengal)

| Year | Prod (q/ha) | RF (mm) (season) | Crop duration (week) | Crop duration (week) | No. of dry spells at different crop stages |
|------|-------------|------------------|----------------------|----------------------|------------------------------------------|
|      |             |                  | Beginning | End | A | B | C | D | A | B | C | D | A | B | C | D |
| 1985 | -           | 1041             | 27        | 38  | 100 | 100 | 97 | 88 | 1  | -  | 2  | -  | -  | -  | 1  |   |
| 1986 | 23.36       | 1003             | 25        | 45  | 100 | 100 | 98 | 99 | -  | 1  | 1  | 1  | -  | -  | -  | 1  |
| 1987 | 28.9        | 1274             | 27        | 40  | 100 | 100 | 100| 94 | -  | -  | 1  | 1  | -  | -  | -  | 1  |
| 1988 | 25.91       | 1101             | 24        | 40  | 100 | 100 | 100| 99 | -  | -  | -  | 1  | -  | -  | -  | 1  |
| 1989 | 26.37       | 1072             | 25        | 41  | -   | -   | -  | -  | 1  | -  | 1  | -  | -  | -  | -  | -  |
| 1990 | 13.49       | 1514             | 25        | 41  | -   | -   | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| 1991 | 23.22       | 1027             | 30        | 41  | 100 | 100 | 99 | 78 | -  | -  | 1  | -  | -  | -  | -  | 1  |
| 1992 | 22.9        | 1322             | 23        | 42  | 74  | 100 | 100| 100| -  | -  | -  | -  | -  | -  | -  | -  |
| 1993 | 21.7        | 921              | 25        | 42  | 94  | 100 | 100| 99 | -  | 1  | 1  | 2  | -  | -  | -  | -  |
| 1994 | 28.49       | 1405             | 24        | 43  | 100 | 100 | 100| 100| -  | -  | -  | -  | -  | -  | -  | -  |
| 1995 | 16.14       | 1092             | 25        | 47  | 100 | 100 | 100| 100| -  | -  | 1  | 1  | -  | -  | -  | -  |
| 1996 | 11.28       | 1435             | 26        | 40  | 100 | 100 | 100| 97 | 1  | 2  | -  | 1  | -  | -  | -  | -  |
| 1997 | 23.9        | 1181             | 26        | 42  | 97  | 99  | 99 | 95 | -  | -  | 1  | -  | -  | -  | -  | -  |
| Mean | 22.7        | 1181             | 26        | 42  | 97  | 99  | 99 | 95 | -  | -  | 1  | -  | -  | -  | -  | -  |

A-Seedling Stages, B-Vegetative stage, C-Reproductive stage and D-Maturity Stages

Table 6(b)

Rice yields and the corresponding rainfall and its derivatives in different blocks of Manbazar, Purulia district (West Bengal)

| Year | Prod (q/ha) | RF (mm) (season) | Crop duration (week) | MAI at different crop stages | No. of dry spells at different crop stages |
|------|-------------|------------------|----------------------|-----------------------------|------------------------------------------|
|      |             |                  | Beginning | End | A | B | C | D | A | B | C | D | A | B | C | D |
| 1981 | -           | 920              | 25        | 38  | 96 | 100 | 100| 96 | -  | -  | -  | 1  | -  | -  | -  | 1  |
| 1982 | -           | 593              | 26        | 37  | 80 | 85  | 100| 88 | 2  | 1  | 1  | -  | -  | -  | -  | 1  |
| 1983 | -           | 818              | 27        | 43  | 90 | 100 | 100| 100| 1  | 1  | 1  | 1  | -  | -  | -  | -  |
| 1984 | -           | 1149             | 26        | 39  | 100 | 100 | 100| 98 | -  | -  | 2  | -  | -  | -  | -  | -  |
| 1985 | -           | 895              | 24        | 42  | 100 | 100 | 100| 100| -  | 1  | -  | 1  | -  | -  | -  | -  |
| 1986 | 23.87       | 1071             | 25        | 42  | 98 | 100 | 100| 99 | 2  | -  | 1  | 2  | -  | -  | -  | -  |
| 1987 | 23.57       | 823              | 25        | 40  | 100 | 100 | 99 | 99 | -  | 1  | 2  | 1  | -  | -  | -  | -  |
| 1988 | 31.89       | 1357             | 24        | 42  | 80 | 100 | 100| 98 | -  | -  | 1  | 3  | 1  | -  | -  | -  |
| 1991 | 21.5        | 787              | 25        | 41  | 93 | 100 | 100| 99 | -  | -  | 1  | 1  | -  | -  | -  | -  |
| 1992 | 27.08       | 1258             | 24        | 42  | 100 | 100 | 100| 99 | 1  | 1  | -  | -  | -  | -  | 1  |   |
| 1993 | 21.5        | 1464             | 26        | 40  | 100 | 100 | 100| 92 | -  | 1  | -  | 1  | -  | -  | -  | 1  |
| Mean | 24.55       | 1086             | 25        | 41  | 96 | 99  | 100| 97 | -  | -  | -  | -  | -  | -  | -  | -  |

A-Seedling Stages, B-Vegetative stage, C-Reproductive stage and D-Maturity Stages
Fig. 5(a). Relation between kharif rice yield and monthly rainfall at Jaldha block in Purulia district

Fig. 5(b). Relation between kharif rice yield and monthly rainfall at Manbazar block in Purulia district
zones except for few blocks in northern districts and rarely in some other places.

3.1.3. Sustainable yield Index

The Sustainable Yield Index (SYI) maps [Fig. 1(c)] delineated the sustainable productivity regions. It is observed from the Fig. 1(c) that highly sustainable regions are mostly high productivity areas in the central parts of the state comprising the districts of Burdwan and few parts in Purulia. Perhaps, better crop management, with extra inputs added with extra-assured irrigation through tube wells might have contributed significantly for sustainable production in these regions. In general, fairly greater area in the state can be categorized under sustainable production zone. Few pockets of unsustainable and highly unsustainable zones have been noticed in Midnapur and also in Bankura and Malda according to Ramakrishna et al. (1987).

3.2. Block-wise analysis

Block wise (micro-level) analysis with respect to two districts, viz., Purulia and Midnapur has been carried out and the results are as follows maps [Fig. 2(a&b) and 3(a&b)]. Though crops statistics data is available for all the blocks over 12-year period (1986-1998).The corresponding rainfall data for all the blocks is not available; hence, block-wise relations between rainfall and productivity could not be carried out. Only single station rainfall at the district of Purulia has been used with the average crop productivity data of the district.

3.2.1. Probabilities of dry spell analysis at different growth stage of Purulia

The probabilities of dryspells of greater than 3 days and above, range of productivity and the fertility status in Purulia district is shown in Table 3. It is seen from the Table 3 that the range of Aman season productivity is highest in the block Manbazar. Generally, the productivity ranges from 1.12 to 3.07 q/ha in the Jalda block to 1.49 to 3.80 q/ha in the Manbazar block. The general fertility status of the soils is mostly categorized as low to medium low indicating the low fertility status of the district. The probabilities of dry spells at various crop stages of the rice crop shows that generally the probabilities are low (less than 40%) indicating assured season over the year (Victor et al., 1991; Singh et al., 2008 and 2009; Chowdhury, 1981 and 1998).

3.2.2. Commencement and cessation period of rainy season in different blocks of West Bengal

The productivity of kharif season rice crop in relation to different periods of commencement and cessation of rainy season has been computed in Tables 4 & 5. Sowings / transplanting on the commencement of season indicated that the productivity of the crop sown between 20-30 June is less than the crop either sown early or after this period. Perhaps, July being the highest rainfall month in the country, sowing in July has helped in better establishment of the crop. Similarly, the cessation of rainy season on the productivity of Aman season rice crop indicates that early withdrawal of the season between 21-30 September has shown drop in productivity compared to the other periods (Victor et al., 1991 and Singh et al., 2008 and 2009). The higher productivity is seen when the monsoon withdrawals between 1st to 20th October. If withdrawal occurs beyond October 20, the productivity decreases considerably. Perhaps, late rains during maturity may cause lodging of the rice crop in addition to shattering of grains due to high winds associated with cyclonic storms. Also the fall in minimum temperature during last week of October will have negative impact on productivity.

3.2.3. Spatial variability of crop productivity

The spatial variability maps of productivity of different blocks in two districts, viz., Purulia and Midnapur have been prepared and presented in Figs. 2(a&b). Also, the coefficient of variability and the map showing the regions of sustainable and unsustainable productivity have been prepared and presented maps [Figs. 2(a&b)]. It is observed from spatial distributed productive maps [Figs. 2(a&b)] that low yields of less than < 2.0 t/ha has been noticed in the blocks of Neturia, Raghunathpur, Santuri and Balrampur in Purulia and Moina, Bhagwanpur, Contai and Ramnagar in Midnapur.

The rest of the blocks in these two districts have high productivity of greater than 2 t/ha. The coefficient of variability maps [Figs. 3(a&b)] of the districts indicated that interventions for stable productivity is needed in Jalda, Arsha and Manbazar blocks in Purulia districts while many of the blocks in Midnapur showed higher variability according to Raj et al., 2004 and Singh et al., 2009.

The sustainable yield index maps [Figs. 4(a&b)] for both the districts indicated that except in the Arsha block, the productivity is fairly sustainable. There is a need to develop strategies to make the productivity more sustainable through better management techniques.
Similarly, the unsustainable productivity in the blocks of Midnapur needs special attention.

3.3. Rainfed rice yields and rainfall relationship between rice yields and corresponding rainfall and its derivatives at different blocks and different districts

To analyze the variability in productivity in respect of Jaldha and Manbazar where the coefficient of variation value of productivity are on higher side, the moisture adequacy index values at different growth stages and number of dry spells occurring at various stages are shown along with the yield data and seasonal rainfall in Tables 6(a&b). It is observed from the table that the yield has not been affected by the occurrence of dry spell at maturity in both the blocks of Purulia district. Perhaps, the data on different planting systems may help in understanding this feature. Perhaps, more area under low land situation may withstand water stress conditions to a greater length of period. The lowest productivity of 11.28 q/ha in Jaldha and 14.89 q/ha in Manbazar in 1996 can be due to heavy rainfall conditions in June and again in August. Occurrence of low-pressure systems along with monsoon trough may bring in heavy amounts of rainfall in these regions (Victor et al., 1991 and Singh et al., 2008).

The graphical representation of the relationship between rice yields and monthly rainfall (June, July, August and September) at the above two blocks has been depicted in [Figs. 5(a&b)] and the trend line showing the yields has been given in the diagram. It is seen that the correlation coefficients are positive in the month of July for Jaldha block (0.22) and Manbazar block (0.64) in Jaldha and Manbazar block. It is seen from the figures that higher trends have been observed between July and August rainfall and the yield at both the locations. The yield levels have shown small decreasing trend in Jaldha over the years. However, the trend is significant.

4. Conclusions

The rainfall analysis with respect to weekly, monthly, annual rainfall and weekly rainfall probabilities has been carried out for all the stations of the study area. However, duration of dry spells and its probabilities, climatic derivatives like commencement and cessation of rainy season, length of growing period (LGP) and estimates of water balance parameters have been carried out, in respect of all blocks in the identified three districts in West Bengal. The mean productivity pattern of rice crop during kharif season in identified districts was analyzed with respect to occurrence of number of dryspells at different growth stages and average MAI values. It is seen that the correlation coefficients are positive in the month of July for Jaldha block (0.22) and Manbazar block (0.64) in Jaldha and Manbazar block. The rainwater availability maps at different growth stages as against the demand have been worked out for the entire study area. From the block-wise crop data, the statistical parameters like mean, coefficient of variation (CV) and standard deviation (SD) have been worked out. Thematic maps for all the basic parameters and the derivatives have been prepared using GIS package. The spatial variability maps of mean productivity and its changes over 30-year period for the entire study area have been prepared. From the coefficient of variability in productivity, the region where productivity is highly variable has been delineated. This study can be used as a tool for detecting the hazards with regard to water availability during the growth periods. This information can be used by farmers to protect the crop against the damage due to drought by taking alternate measures to mitigate the effect of drought.

This is because of the fact that when the crop phenological calendar will be super imposed upon these sequences, it will provide an insight into the crop water stresses in various phenophase stages. Based upon these conditions, the alternative strategies (for fertilizer application, pesticides etc.) can be recommended to the farmers.

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