STUDIES ON AGROCLIMATIC CHARACTERIZATION OF RICE WHEAT GROWING REGIONS OF BIHAR STATE AND IMPACT OF DROUGHT ON CROP PRODUCTION

PRAGYAN KUMARI

DIVISION OF AGRICULTURAL PHYSICS
INDIAN AGRICULTURAL RESEARCH INSTITUTE
NEW DELHI – 110 012
INDIA

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STUDIES ON AGROCLIMATIC CHARACTERIZATION OF RICE WHEAT GROWING REGIONS OF BIHAR STATE AND IMPACT OF DROUGHT ON CROP PRODUCTION

By

PRAGYAN KUMARI

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Approved by :

Chairman : 5/5/2000
(Dr. C.V.S. Sastri)

Members : 9/9/2K
(Dr. N.V.K. Chakravarty)

9/2/2K
(Dr. N.T. Yaduraju)

(Mr. Mahesh Kumar)

Dr. C.V.S. Sastri
Principal Scientist

Division of Agricultural Physics
I.A.R.I., New Delhi-110 012

CERTIFICATE

This is to certify that the thesis entitled **"Studies on Agroclimatic Characterization of Rice Wheat growing regions of Bihar state and Imapct of drought on crop production "** submitted to the Faculty of Post –Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfillment of the requirements for the degree of **Doctor of Philosophy** in **Agricultural Physics** by **Mrs. Pragyan Kumari,** is a genuine record of bonafide work carried out by her under my guidance and supervision. No part of this study reported here, has so far been submitted anywhere for publication or for any other degree or diploma in any other form.

The assistance and help received during the course of this investigation have been duly acknowledged.

Place: New Delhi
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(C.V.S. Sastri)
Chairman
Advisory Committee

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(Pragyan Kumari)

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INTRODUCTION

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Agricultural meteorology mainly concerns with the understanding of the impact of changing environmental parameters on growth and yield of agricultural crops and establishing the interrelationships quantitatively. To convert the knowledge of physical environment into a reliable means for making decisions with respect of crop production forms a critical problem in agrometeorology. The climate is the primary factor controlling the distribution of crops and agricultural pattern in a particular geographical area. Weather has a great role to play in almost all the agricultural activities from the initial preparatory tillage to the harvesting and storage of produce. It is considered as a limiting factor in the matter of the time of sowing/transplanting, scheduling of irrigation, timing of fertiliser application etc. A sound knowledge of climatic factor and understanding of the complex processes of interaction between climate and biological processes of the plant are essential for a scientific approach to farming.

A precise understanding of agroclimatic conditions is a prerequisite for efficient crop planning in any given region. Agroclimatic characterisation meant for judicious crop planning and management that leads to higher production involves generation of information in respect of length of the possible cropping seasons and its variability both under rainfed and irrigated conditions. Water availability period for crop growth, irrigation requirements of the different crops and weather hazards like drought, floods, heat waves, cold waves, strong winds, hails frost etc that will restrict crop production. Farmers have to adjust the cropping system and crop management practices to the limitations imposed by the environment. They have developed the farming system, which they practice, by trial and error of generation. No doubt 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 agroclimatic conditions effective cropping pattern and schedule of supplemental irrigation can not be planned.

The two universal environmental risks in agricultural production are adverse temperature and inadequate water supply. In tropical, sub tropical, semi arid and arid climate the management of inadequate water supply for crop production needs more attention than other factor of environment depending upon the nature of the soils, distribution of rainfall, temperature, and intensity of the solar radiation during the cropping seasons. The variability experienced in the onset and end of the rainy seasons, undoubtedly affects the farmer cropping strategies. The length of the growing seasons for rainfed crops in any region is precisely determined by the time between the first useful rainfall and the end of the useful rainfall, although droughts 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. Agricultural and hydrological operations are disrupted badly due to large-scale drought conditions caused by delayed sluggish or week activity of monsoon in any year.

Drought is a general term implying a deficiency of precipitation of sufficient magnitude so as to interfere with some phase of economy. Depending on the purpose of the study the drought can broadly be divided into Meteorological drought, Hydrological drought and Agricultural drought. Agricultural drought is marked by the prolonged water deficit in the soil when the plants are damaged due to insufficient water supply. The magnitude of damage caused to the crops is higher when the drought conditions persists over a period of time particularly during critical phases of crop growth. Knowledge of occurrence of drought and its persistence over fairly long periods of time and information on the intensity of drought during different intervals of time constitute an important aspect of drought analysis, which is very essential for crop planning as discussed earlier.

The success or failure of crop particularly under rainfed conditions is closely linked with the rainfall patterns. Simple criteria related to sequential phenomenon like dry and wet spells could be used for analysing rainfall data to obtain specific information for crop planning and carrying out agricultural operations (Sastry 1976). For planning purposes it is important to know the sequence or persistence of dry, wet periods. Markov chain probability model has been found suitable to describe the long-term frequency behaviour of wet or dry weather spells (Gabriel and Neuman 1962, Victor and Sastry 1979). The Markov chain conditional probability model has been accepted as fully justified in the analysis of weekly rainfall data and a number of research workers have demonstrated its practical utility in agricultural planning, both for a long term and short term period such as a week. When applied to periods like a week, this model enables the determination of probability of occurrence of dry or wet weather during a particular week depending on the weather conditions during the preceding week.

Basic requirement for a study of rainfed is the rainfall pattern and water availability periods. Certain amount of rainfall does not indicate that the crop will utilise all amounts. The slopes of the land and soil coverage decide the run off and infiltration components while texture and depth of soil decides soil moisture storage and drainage component and finally atmospheric demand decides water used by the crop. It is, therefore required to account for not only assured rainfall but also atmospheric demand of a place and type and depth of soil for any agroclimatic classification and to know crop potential of a place. Moisture Availability Index (MAI) defined as the ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET) (Subramanyam *et al.*, 1963) has been widely used to determine the moisture status at a place. MAI and its distribution are used as the prime factors for crop planning. MAI values are worked out on the basis of average rainfall (Raman and Murthy, 1971), however in such system the monthly MAI values are not truly representative as month is a longer period for planning any cultural operations. Moreover, if there are dry spells inbetween, causing crop failure, the monthly MAI not represent it. Hence, there is a need to use weekly MAI for agricultural planning for planning majority of the seasonal crops.

Bihar State has an area 5.3% of the total area of the Indian union and contributes about 8% of the total food grain production. In Bihar State very few studies have been made on the above aspect of climatic characterisation based on regional water balance and drought analysis and occurrence of dry and wet spells. The supreme economic importance of agriculture in the state may be realised from the fact that about 80% of the population draws sustenance from it. The gross irrigated area in the state is 3.6 mha, which is about 34% of the gross crop area under cultivation (10.63mha). Agriculture in Bihar is largely dependent on rainfall and prevailing weather condition. The *Kharif* crops raised during the South-West monsoon period are exposed to moderate to severe water stress as well as to severe floods due to the erratic behaviour of the monsoon. The *Rabi* crops are generally grown without irrigation and depend on the soil moisture accumulated during the preceding monsoon season since the winter rainfall is meagre and unreliable. The occurrence of droughts due to large year to year fluctuation of total annual rainfall and deficient rainfall spells within the crop-growing season is a major determining factor of agriculture in Bihar. During drought period, prevalence of high temperature, high wind and evaporation worsen the situation by causing faster depletion of meagre available soil moisture leading to crop damage and low yields. In view of the above factors, knowledge of the inter relationship of crop growth and productivity with various meteorological factors specially the availability of the moisture for crop growth, period of water deficiency and its severity is extremely important. Hence the present investigation has been under taken to study the impact of these factors on growth and productivity of rice and wheat in the selected region with the following objectives.

1. To study the agroclimatic characteristics of rice–wheat growing region of Bihar.
2. To determine the severity and probability of drought occurrence in the growing season with special reference to crop phenology.
3. To determine the effect of drought on crop production.
4. To determine the distribution of moisture availability index (MAI) for crop planning.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Considerable scientific efforts had been directed towards the ways of agroclimatic characterisation among the voluminous literature of the subject through out India and abroad, a brief review is made here in consonance with objective of the present investigation. The review is confined to the agroclimatic characterisation using climatological data under the following major heads.

1. Rainfall, drought and Aridity index.
2. Occurrence of dry and wet spells and their probabilities
3. Moisture availability period and their distribution.

2.1 RAINFALL

The earlier attempts to characterise climate centred on the identification of average annual, seasonal, monthly rainfall and/or temperature regimes. The first rainfall that is considered sufficient for specific agricultural operation determines the beginning of the cropping seasons. The amount of rainfall needed to permit land preparation practices depends upon the moisture retention, characteristic of the soil and the depth of the soil that must be moistened.

In this connection studies on variability of seasonal rainfall, probabilities of rainfall of occurrence of rainfall week by week will provide useful information for evaluating climatic potential for agricultural development and for evolving suitable cropping patterns. Sarker *et al.* (1982) analysed the rainfall data of dry farming tract in India where the rainfall varies from 400 to 1000 mm. Weekly rainfalls was subjected to statistical analysis by Incomplete Gamma Distribution and minimum assured rainfall was worked out at different probability levels from 10 to 90%. The entire tract was divided broadly into seven homogeneous rainfall pattern zones. The duration of crop period in each zone was indicated based on assured rainfall alone.

Kulandaivelu (1984) computed weekly totals by fitting Incomplete Gamma Distribution model by using the daily precipitation data of Coimbatore centre for a period of 70 years the assured weekly rainfall amounts with different probability levels and the probability of receiving a given amount of rainfall were worked out and presented. The data indicate the likely commencement of rains, period of drought, length of growing season and end of growing seasons. Based on the assured rainfall at 50% probability level, suitable cropping systems were suggested for Coimbatore. Biswas *et al.* (1989) has computed assured weekly rainfall at different probability levels of 10 to 90% for 103 stations of Tamilnadu by fitting Incomplete Gamma Distribution model. This assured rainfall has been used to demarcate the dry farming tract of Tamilnadu in to various homogenous rainfall zones. The analysis has brought out four homogeneous rainfall pattern zones. Important features noticed in assured rainfall distribution at different probability levels were discussed.

2.2 DROUGHT

Drought is generally understood as a period of dryness due to lack of rain and moisture in the soil. Depending on the purpose of study and basic criteria chosen, drought situation may be categorised as precipitation drought, atmospheric drought, agricultural drought, and hydrological drought. The study of drought spread, drought spell and drought severity in particular is of great practical importance in agricultural planning. In the early part of the century, a drought was considered to be just the lack of rainfall over a certain period. Thus only rainfall data were taken into consideration in analysing drought. Ramdas (1953) defined drought, as an occasion when the weekly rainfall is half of the normal or less, provided the normal rainfall itself is 5 mm or more. In USSR, drought was defined as a period of 10 days with a total rainfall not exceeding 5 mm. Van Rooy (1965) developed a drought anomaly index based on the rainfall departure and mean of the lowest ten values of rainfall in series. The index is given by

$$I = 3 \frac{p-\bar{p}}{\bar{m}-\bar{p}}$$

Where I is the anomaly index, p is actual precipitation, $\bar{p}$ is the normal precipitation, and $\bar{m}$ is the mean of the ten lowest values of the p on record.

Drought is, however evaluated in a more meaningful manner by water balance computation taking into account the rainfall pattern, evapotranspiration, moisture characteristic of soil, rooting depth and stage of crop growth etc. Van Bavel (1953) found that the amount of moisture deficit was quite sensitive to change in moisture storage capacity of the soil. According to his study the average number of drought days decreased from 45 to 10 as the moisture storage capacity increased from 25 to 100 mm.

2.3 ARIDITY INDEX

Aridity has a meaning distinct from drought in the sense that it is pseudo-permanent feature of low rainfall in an area of high average temperature. (Choudhary and Hussain, 1983). There are a large number of indices for expressing aridity and drought conditions. Full account of important drought and aridity indices was described by WMO (1975). The aridity index as defined by de Martonne (1926) is given as. Annual aridity index: I =P/T+12, Monthly Aridity index: I =12p/t+10, where P and p are the average annual a monthly rainfall in mm; T and t are the mean annual and monthly temperature in degree Celsius. If the index is less than 20, an annual or monthly aridity condition is said to exist. Thornthwaite (1948) defined the aridity index as the ratio between water deficit (PET-AET) and water needs (PET). It can be calculated for any time scale, but generally for agricultural purposes, weekly periods are considered adequate.

Aridity index was worked out in respect of all the stations in Rajasthan state by Krishnan (1968, 1969), to delineate the region into areas of different grades of aridity to help in planning of water resources development. He found that the aridity index exceeded a value of 80 in Bikaner, Ganganagar, Jaisalmer and Barmer districts, while in case of East Rajasthan, it decreased from 58 in Alwar district to 28 in Jhalwar district reflecting decreasing drought intensity. Working on the aspects of drought climatology of the dry sub humid zones of South India, Subrahmanyam and Sastri (1968) computed the aridity index by using the book keeping procedure of Thornthwaite and Mather (1955). They observed that Hassan Station, situated in interior of the peninsula got the lowest median value of aridity index and the highest standard deviation (SD.value); Nagapattinam on the Coromandel Coast, got the largest median value of aridity index and the lowest value of S.D.

2.4 SEVERITY OF DROUGHT

The aridity index had been found to be a useful parameter for classification of drought intensities (Subrahmanaym and Subramaniam, 1964). The severity of a drought situation is determined by the departure of aridity index from 'normal'. Subrahmanyam and Subramaniam (1964, 1965) classified droughts using the standard deviation (SD) as a unit and assuming various arbitrary limits following a scheme suggested and employed. However, Subrahmanyam and Sastri (1969) later modified the scheme slightly and used the 'median' rather than the normal (mean) as the base of reference. This is because of the view that in the statistical analysis of climatic data, the median is a better and more realistic average than the simple 'arithmetic mean'. Since nearly 80-85 percent of annual rainfall occurs during the south west monsoon and rainfed agriculture is the main practice in *Kharif* season, the aridity index during this season is considered more important in characterising the drought than that for the whole year.

Krishnan and Thanvi (1971) used the aridity index values for *Kharif* season (July to October) to classify various drought intensities in Rajasthan as per following criteria.

Aridity index in Kharif seasons	**Drought Intensity**
50- 60	Slight
60-70	Moderate
70-80	Severe
>80	Disastrous

They observed a marked difference in the magnitudes of aridity index for *Kharif* season between arid and semiarid zones.

Selected levels of evapotranspiration (ET) in relation to rainfall amount were used by Cocheme and Franquin (1967) to determine the nature of water availability periods during the crop growing season. These are as follows :-

P>ET : Humid Period P = ET/4toET/10: Dry period

P>ET/2 : Moist period P < ET/10 : Very dry period

P = ET/2 to ET/4 : Moderately dry period

Hargreaves (1971) defined a moisture availability index (MAI) as the ratio of the rainfall value expected with 75 % probability to the estimated PET. He determined the aridity of a region as follows:

Value of the ratio	**Period**	**Climatic type of the region**
0 to 0.33	all months	very arid
> 0.34	1 or 2 months	arid
> 0.34	consecutive 3 or 4 months	semi arid

He also gave the moisture deficit classification using moisture availability index.

MAI	**CLASS**
0.00-0.33	Very deficient
0.34-0.67	Moderately deficient
0.68-1.0	Some what deficient
1.00-1.33	Adequate moisture
> 1.33	Excessive moisture

By working out the weekly water balance, Krishnan and Thanvi (1977) estimated the probability of occurrence of moderate and severe drought conditions for crop growth season in Rajasthan State. The severity of drought in the crop growing season under rainfed farming had been categorized by them based on the relationship between AET (this takes into account both the rainfall and the stored soil moisture) and the PET values as follows :-

$AE \geq PE/2$: No drought,

$PE/2 > AE > PE/4$: Moderate drought

$AE < PE/4$: Severe drought

2.5 AGRICULTURAL DROUGHT

In dry land agriculture, a crop drought may be expected to occur whenever the root zone soil moisture storage, resulting from rainfall becomes insufficient to meet the potential needs of a crop for transpiration and for normal growth. The degree of severity of a crop drought is influenced by weather, crop and soil factors (Sastry, 1970 and Venkataraman, 1979). The concept of Transpiration index (K), the ratio of actual amount of water transpired (AT) to potential transpiration (PT) was used as a measure of crop water stress by Venkataraman (1979) to assess the crop drought. He suggested the following criteria to study the severity of moisture stress:

K	Degree of Moisture Stress
0.95 or Above	No stress
0.85 to0.94	Slight
0.75 to 0.84	Moderate
0.65 to 0.74	Severe
0.50 to 0.64	Very severe
< 0.5	Death

The requirement of K values during different crop growth stages were also stipulated as

Sowing requirement: 0.2, Vegetative phase: >0.66
Establishment : 0.8. Maturity period; 0.5 TO 0.6.

From the inter-seasonal pattern of K values Venkataraman (1979) assessed the severity of crop drought at Deesa (Gujarat) and categorized the years (from 1901 to 1970) into seven classes of drought. From the frequency of occurrence of the drought classes, he found that the occurrence of 'light' to 'no drought ' was same as compared to the frequency of severe droughts. However, it was suggested that greater occurrence of moderately severe droughts than the moderate ones calls from use of shorter duration varieties.

In a critical study of drought year of 1979, Sastri (1984) estimated the weekly aridity index for the Delhi region and the weekly drought severity was assessed by following the aridity anomaly as: (1) 1-25%: mild, (2) 26-50% : moderate and (3) more than 50% : severe. In a similar study for the drought year of 1987, Rajendra Prasad and Datar (1984) also used the same anomaly method to study the intensification and persistence of *Kharif* agricultural drought during the south-west monsoon season of 1987 in 33 meteorological sub-divisions of India. The commencement and cessation of different intensities of meteorological droughts during 1934-77 at 23 locations of the state of Maharashtra were identified by using the Palmer's approach by Sambasiva Rao and Subramaniam (1986). Adopting the following moisture index for analysing different severity of drought, they found that, compared to the dry sub-humid regions, drought conditions prevailed for longer periods in semi arid regions

INDEX	DROUGHT
- 1.00 to -1.99	Mild
-2.00 to -2.99	Moderate
-3.00 to -3.99	Severe
< -4.00	Extreme

Further they observed that the pattern of drought areas of *Kharif* was similar to that of *Rabi* season. Shekh (1989) worked out climatic water balance for six stations viz., Surat, Anand, Anej, Junagadh, Vijapur and Viramgam in Gujarat State using Keig and McAlpine (1974) water balance method. The weekly available soil moisture was estimated by using Hargreaves-Samani (1982) method for those stations and he found that the moisture availability pattern at Surat in south Gujarat was similar to that of Anand but the soil was never full to its capacity at Anand because of erratic rainfall pattern.

2.6 DROUGHT OCCURRENCE AND CROP PHENOPHASES

A first order Markov Chain model had been fitted to daily data of monsoon rainfall by Victor and Sastry (1979) and cumulative probability of dry spells with special reference to developmental stages of pearl millet crop in the Delhi region was computed. While assessing the occurrence of atmospheric drought during monsoon cropping season in the Delhi region, Sastry and Chakravarty (1984) classified the drought severity on the basis of dominance of dry weeks in phenophases of *Kharif* crops in the region as: drought in,

Four phases -Disastrous

Three phases-severe

Two phases-moderate

One phase-light and

None of the phases-unaffected.

Victor and Sastry (1984) studied agricultural drought (the ratio of AET to PET) in the Delhi region in relation to soil moisture index (SMI, the ratio of available water to available water capacity in the soil root zone) with respect to phenophases of five *Kharif* crops viz. pearlimillet, sorghum, corn, upland rice and peanut. On the basis of probability of occurrence of agricultural droughts at the flowering stage, the lowest probability was found to be in respect of pearlmillet crop followed by sorghum, peanut, corn and upland rice in increasing order.

By employing water balance approach Patel et al. (1986) studied the influence of agricultural droughts (AE/PE) in different growth phases on the yield of some *Kharif* crops at Raipur, Madhya Pradesh. They observed that rice crop under upland conditions experienced drought during most of the growing period. In case of groundnut, with slightly higher water requirement, drought occurred during beginning of vegetative and reproductive stages

2.7 WATER REQUIREMENT SATISFACTION INDEX (WRSI)

Yearly fluctuation in yield is a recurrent phenomenon under rainfed farming. Statistical models were developed for relating weather parameters with crop yield prediction (Baier, 1973) . In Sahelian zone for 1978 season, the length and starting dates of the growing season and water requirements were studied at 5 selected locations by Frere and Popov, (1978) . They observed that the water requirements were much higher in a drier environment. By using the data for a period of 32 years (1932-64) at Senegal for ground nut crop, they observed no correlation between total seasonal rainfall and yields. Minimum yields occurred in both the driest and the wettest years. However,they obtained a good correlation between the WRSI and the yield of groundnut. For rainfed agriculture system Frere and Popov (1979) suggested a technique based on crop water balance using climatic data. Their methodology for agro-meteorological crop monitoring and forecasting was first developed for the Sahelian zone.

In a study for rainfed rice crop (July to November) in Bangladesh, where rainfall amount is not a shortage for plant growth, Frere and Popov estimated the water balance, taking a water storage capacity of 60 mm (as in dry zones) and observed that it did not show any water stress for the crop, but a water storage capacity of 30 mm showed water deficit problems in the central zone of Bangladesh. Working with sorghum crop of 160 days duration in Ethiopia, Frere and Popov (1978), observed that in countries where the rainfall is adequate for growth of a crop, the variation of the cumulative water balance indicating temporary water stress is more indicative of the yield fluctuations of the crop. Studies on the relationship between the WRSI and the relative yields of sorghum crop for the Botswana region over year 1978-79 to 1982-83 (FAO, 1986), showed that index value of 50% resulted in negligible yields. This study demonstrated that linear relationship between relative yield and WRSI does not represent a feasible solution for quantitative yield estimates. For Botswana, they suggested a quantitative relation between relative yield (y) and WRSI (I) of the form :

$$Y = 0.05\ (I-48)^{1.925}$$

The work carried out using the WRSI concept in Bangladesh for rice crop, in Africa for upland rice, in Turkey and Italy for wheat, in Zambia for maize and other cereals for the purpose of development of early forecasts of expect yields, was reviewed by FAO (1986) . In view of its simplicity in use and reported real value in terms of derived information, this method is presently in use in several countries of the tropical and subtropical world including India.

An illustrative study in case of sorghum crop of 130 days duration at Hyderabad was reported by Stern and Coe (1982) to assess the use of the simulated data in crop models. They worked out water balance model developed by Keig and McAlpine (1974) and computed WRSI following Frere and Popov (1979) . The probability distribution of the index was evaluated to assess the probability of crop failure in the region. Further examination of the data by them showed that some of the variability of the WRSI at the end of the season could be due to variability in the date signifying the start of the rains. Their result also indicated that late planting results in a low value of the index which is predictive of lower yields.

To quantify the crop yields under rainfed conditions for pearl millet crop of 13 weeks duration at Jodhpur station, Victor et al. (1988) studied the relationship between WRSI and yield indicating the exponential behaviour of the yield as affected by the water availability to the crop. The simulation results further showed good correlation between the observed and expected yields, and the commencement of rainy season from 25^{th} to 28^{th} weeks to be most suited for millet production at Jodhpur.

By utilizing the concept of Frere and Popov's index, Srivastava et al (1989) determined the risk of low productivity of groundnut crop in Rajkot district of Gujarat state. They observed that the productivity was less than average during the years with WRSI below 81 percent and the risk of below-average production increased with delay in commencement of growing season beyond 2^{nd} July.

2.8 OCCURRENCE OF DRY AND WET SPELLS -

In rainfed agriculture it is a pre-requisite in contingent crop planning that selection of varieties within a crop should be based upon probabilities of rainfall. In addition, due to random nature of occurrence of dry spells and its frequent nature, it is necessary to adjust the crop planning to maximise the crop output. Probabilities of wet and dry spells can give the broad idea and help the agricultural planners in solving various problems.

The success or failure of crops particularly under rainfed conditions is closely linked with the rainfall pattern. Simple criteria related to sequential phenomenon like dry and wet spells could be used for analysing rainfall data to obtain specific information needed for crop planning and for carrying out agricultural operation (Sastry 1976). A method to evaluate frequencies of continuousday with rainfall above or below any chosen threshold value has been reported earlier. Synoptic systems including rainfall or dry spells have been found to persist for a few days over region. It is useful to ascertain the probability of sequential events like a wet day following a wet or dry day during the crop-growing season. Markov Chain probability model has been found suitable to describe the long term frequency behaviour of wet or dry weather spells (Gabriel and Neuman 1962). Choudhary (1978) studied the occurrence of wet and dry spells in Bihar and revealed that (1) the probability of a dry day far exceeds that of a wet day even in the rainiest months of July and August. Only

3 to 4 rainy days can be expected in any 10-day periods in these months. (ii) Strong persistence in rainfall is observed contributing to frequent floods but severe droughts appear to be improbable over Bihar. (iii) High probability of a dry day is observed particularly in early June and October, irrespective of the conditions of previous two days, correspondingly, the probability of a third day being wet is generally small. Choudhary *et al.* (1979) examined dry spells over Maharashtra and concluded that the core of the drought area is situated over Ahmednager district.

A first order Markov chain probability model has been applied by victor and Sastry (1978) to evaluate conditional probabilities for monsoon months and duration of dry spells at different cumulative probability levels during the growth, stages of *Bajra* crop in the Delhi region. The probabilities of occurrence of dry and wet spells has been analysed using the concept of Markov chain modeling in two extreme farming situations of Bastar district in central India, (Choudhary 1978) observed that the probability of getting a wet week was higher in the low land *gabhar* situation as compared to the up land *marhan* situation. This is due to higher water requirement of the rice crop in the upland *marhan* situation. It was also concluded that the low land *gabhar* situation was favourable for sowing of rice crop and the cultivation of long duration rice varieties. In the upland *marhan* situation, the cultivation of short duration varieties was found to be suitable. In addition, the favourable crop growth duration was also recommended by him for the two farming situations.

2.9 MOISTURE AVAILABILITY INDEX:

Optimum crop production can be expected when the periods and levels of water availability match the water needs of the crop. The moisture adequacy index is defined as the ratio of actual evapotranspiration (AE) to potential evapotransportation (PE) by Subrahmanyam *et at.* (1963) to indicate the moisture status of a place. It was reported that there was a close relationship between I_{ma} value and the type of crop and its distribution in the India region. Yao (1969) coined I_{ma} as R-index and pointed out that the behaviour of R-index distribution frequency follows that of beta distribution frequency

Bishnoi (1980) observed that the moisture adequacy indices (the ratio of actual evapotranspiration to potential evapotranspiration) have been found to follow closely the beta distribution. The goodness of fit of the beta distribution was tested using the Kolmogorov-Smirnov test for 144 stations and 36 seasonal curves out of which. 25 moisture indices failed the Kolmogorov-Smirnov tests. The probability distribution of moisture adequacy indices has been further used to assess irrigation requirement, optimum evapotranspiration, water management, land use pattern and crop planning aspects for optimum utilisation of available natural resources in the region.

Sarkar and Biswas (1980) suggested improvements in Hargreave's moisture availability index. They suggested:

1. MAI be calculated on weekly basis;

2. Dependable rainfall be considered at 50% probability level;

3. Different value of MAI may be used as appropriate to various crop phases. However, MAI of 0.7 be considered as optimum.

Biswas and Sarker (1978) and Biswas (1982b) analyzed the rainfall data of dry farming tract of Gujarat. The tract was divided into four agro-climatic zones, i.e. D, E, F and G on the basis of MAI at 50% probability level. The classification was as cited below:

Classification	No.Of weeks where MAI at 50% levels is	
	0.3	0.7
D	≤10	≤1
E	10-11	1-4
F	11-14	4-7
G	≥14	≥7

Zone D has low potential for crop production and could be identified as drought prone area. Zone E is an area of fairly good crop potential. The MAI is normally more than 0.3 for 10 to 11 weeks and more than 0.7 for one to four weeks. A short duration crop may be raised.

Zone F has good crop potential. A medium duration crop (3 to 3.5 months) may be successfully raised once in two years. Zone G has the highest crop potential. MAI is normally more than 0.3 for 14 to 19 weeks and more than 0.7 for 7 to 13 weeks. A crop of 13 to 18 weeks duration may be raised in this zone under rained condition once in two years.

Patel and Mistry (1981) analysed the daily meteorological data of a 15-year period using Thornthwaite and Mather (1955) technique at Rajkot, Keshod, Mahuwa, Bhavnagar and Jamnagar. The results indicated that the yield of groundnut (*Arachis hypogaea* L.) was linearly related to the percentage of moisture available days ($R>0.59$). On an average 60% reduction in yield was observed to be due to lack of adequate soil moisture. The crop suffered for want of soil moisture in a majority of years. The short duration bunch variety was found to be more suited than the spreading type.

Victor *et al.* (1982) computed the monthly values of moisture adequacy index for groundnut (*Arachis hypogaea* L.) for July-October period during 1941-72. The frequency of this index closely followed beta distributions as revealed by Kolmogorov-Smirnov test. The probabilities at threshold values of moisture adequacy index $AE/PE \leq 0.50$ and $\geq .90$ were evaluated. For 44% of the time, the top soil (0-15 cm) would remain dry consecutively for more than fortnightly period. They found that on an average, severe dry weather might damage groundnut in Delhi region once in four years.

Suryanarayana et al. (1984) divided the state of Karnataka into four climatic zones, based on the moisture adequacy index during the cropping season. The suitable period for cropping in each zone was worked out by considering the rainfall and actual evapotranspiration (AET). Keeping in view the soil moisture availability in relation to the evaporative demand of the climate during the crop growing season, the optimum dates of the sowing for *kharif* and *rabi* crops were suggested. The possibility of modifying the cropping pattern has been discussed in relation to the computed safe cropping period for each zone.

Moisture Index (%)	Agroclimatic zone
More than 20	Humid (Include per humid)
20 to 0	Moist sub-humid
0 to -20	Dry sub-humid
Less then –20	Dry

Virmani and Singh (1986) observed the MAI values exceeded the lower threshold value of 0.33 in all rainy months at the various probability levels studied except October and November (at 80 % probability in such cases). In this groundnut growing areas, soil fertility and its physical limitations are likely to be more important constraints to increase groundnut production compared to the soil moisture adequacy of crop growth

Patil *et al.* (1989) worked out soil water availability periods on the basis of weekly Moisture Adequacy Index for four different soils of 25, 50, 100 and 200mm available soil water. In his analysis, water availability period of shallow soil was found to be much longer than water availability period for deeper soils, indicating anomalous situation that any crop could be raised on shallow soil of 25 mm AWC.

Subramaniam and Kesava Rao (1984) calculated climatic water balance elements and moisture adequacy for all the available meteorological stations in the Karnataka state following the method of Thorthwaite and Mather (1955). The general distribution of crops and the result of the analysis of moisture adequacy for certain important crops like paddy, sorghum, pearl millet, ragi, sugarcane, groundnut, cotton and coffee. In *kharif* seasons, sorghum yields were generally found to be recording high production in areas of 70% moisture adequacy.

Mondal (1991) studied the rainfall patterns for states of Punjab and Haryana, which belong to part of arid and semi-arid regions of India. MAI was worked to demarcate them in to different agro-climatic zones. The four zones identified were Very Low Potential (V.L.P.), Low Potential (L.P.), Moderate Potential (M.P.) and High Potential (H.P.) zones.

The above review shows that the rainfall, Aridity index, MAI and dry and wet spells have been used to identify and classify drought severity. While several investigations were directed towards study of seasonal drought, its occurrence during the individual growth phases of crop appears to have received relatively less attention. Since the effect of drought the final yields is known to depend on the particular growth stage affected by drought, it is considered necessary to derive probabilities of occurrence of drought in different phenophases of crops.

MATERIALS AND METHODS

MATERIALS AND METHODS

To achieve the objective of the study envisaged the procedures and methods that have been adopted for this investigation are given below under different heads.

3.1 AGROCLIMATIC ZONES AND SOIL CHARACTERISTICS OF STUDY AREA

Bihar, a corrupt form of the name "Vihar" which means Budduhist Monastry is situated in the north region of the Indian union and lies between 21.97^0 and 27.52^0 N latitude and 83.33^0 and 88.29^0 E longitude. Bihar is the second largest state in India by population and ranks fifth in area (17.3 mha).

Bihar is situated in monsoon subtropical zone. The summer (March-June) is characterized by gradual rise in temperature, occasional thundershowers coupled with hailstorms at places and high winds in the north and south Bihar causing dust storms. The maximum temperature occurs is between later part of May and first fortnight of June. The monsoon season is characterized by cloudy weather, high humidity, frequent rains and variable surface winds. A maximum average rainfall of 330 mm is received during the month of July-August. The post monsoon (October to November) season is characterized by fair weather with a gradual fall in temperature. Winter season (December to February) is characterized by low temperature with occasional frost at some places.

Bihar State is divided into six (NARP) zones. Six selected stations representing different agroclimatic zones of the state (Fig 1.), differing in rainfall pattern have been utilised in this study. The cropping system in Bihar shows predominance of cereal, mainly rice based. Major crops of the state are rice, wheat, maize, sugarcane, pulses and jute.

Some physical characteristics of the soil at the stations under different agroclimatic zones of Bihar State are presented in Table 1

Table 1
Agroclimatic Zones and Soil Physical Characteristic

Station	Soil type	Agroclimatic Zones	F.C %	PWP %	B.D g/cc	AWHC mm/m
Patna	clay	III	37	13	1.35	250
Gaya	clay loam	III	30	12	1.4	200
Bhagalpur	clay	III	35	12.5	1.3	250
Dumka	sandy loam	IV	20	10	1.4	150
Ranchi	sandy loam	IV	22	9.0	1.5	150
Hazaribagh	sandy loam	IV	23	8.0	1.4	150

3.2 CROP

The study is confined to rice and wheat. Normal sowing week and crop growth duration utilized for the study is presented in Table 2.

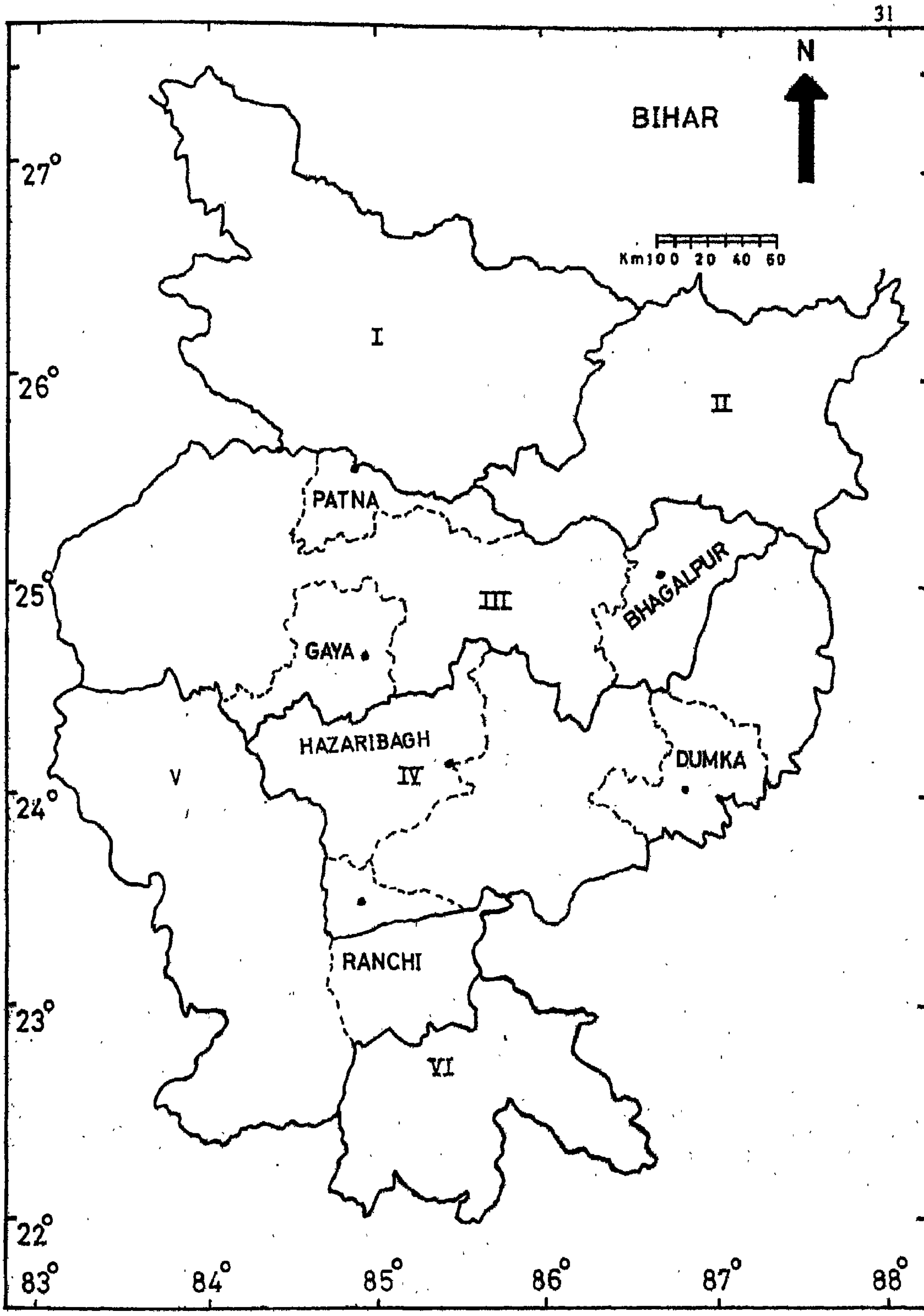


Fig. 1 : Location Map of Bihar State

Table 2

Crop Growth Duration for Rice Crop at Different Stations in Bihar

Stations	Initial seedling stage	vegetative stage (max. vigour)	Reproductive stage	Maturity stage
Patna	24^{th}-26^{th} week	27^{th}-35^{th} week	36^{th} -39^{th} week	40^{th}-42^{nd} week
Gaya	24^{th}-26^{th} week	27^{th}-35^{th} week	36^{th}-39^{th} week	40^{th}-42^{nd} week
Bhagalpur	23^{rd}-25^{th} week	26^{th}-34^{th} week	35^{th}-38^{th} week	39^{th}-41th week
Dumka	23^{rd}-25^{th} week	26^{th}-34^{th} week	35^{th}-38^{th} week	39^{th}-41th week
Ranchi	23^{rd}-25^{th} week	26^{th}-34^{th} week	35^{th}-38^{th} week	39^{th}-41th week
Hazaribagh	23^{rd}-25^{th} week	26^{th}-34^{th} week	35^{th}-38^{th} week	39^{th}-41th week

Crop Growth Duration for Wheat Crop at Different Stations in Bihar

Normal sowing week for wheat is 46^{th} standard week (middle of November) for all the stations. Wheat is normally harvested in the middle of March.

3.3 COLLECTION OF METEOROLOGICAL DATA

As already mentioned, a month is too long period compared to the entire crop life and hence daily meteorological data recorded at agrometeorological observatories in respect of six main research stations have been utilised in this study.

The daily values of different weather parameters were used to compute weekly values for standard weeks (Appendix I) and these were employed to derive further estimates as needed for investigation. The formation of the database for different stations is shown in Table 3.

Table 3

Meteorological database for different stations

Station	Rainfall	Max. Temp	Min. Temp
Patna	1969-1993	1969-1993	1969-1993
Gaya	1969-1993	1969-1993	1969-1993
Bhagalpur	1969-1991	1969-1991	1969-1991
Dumka	1969-1991	1969-1991	1969-1991
Ranchi	1969-1985	1969-1985	1969-1985
Hazaribagh	1969-1985	1969-1985	1969-1985

3.4 POTENTIAL EVAPOTRANSPIRATION (PET)

The original method of Thornthwaite (1948) was adopted here to estimate potential evapotranspiration using tables and nomogram published by Thornthwaite and Mather (1957).

3.5 CLIMATIC WATER BALANCE

Climatic water balance on weekly basis for individual years was calculated using the procedure developed by Thornthwaite and Mather (1957). Weekly potential evapotranspiration (PET), actual evatranspiration (AET), and water deficit (WD) derived form this method were used to calculate water requirements and weekly aridity indices , corresponding to the crop growth stages.

3.6 CROP WATER BALANCE

Crop water balance is the difference between precipitation received by the crop and the water lost by the crop and the soil. The correlative crop water balance proposed by Frere and Popov (1979) was adopted to estimate reference crop ET, water requirement and Water Requirement Satisfaction Index for the crop at the stations under study. Due consideration was given for the water available capacity of the soil in the crop root zone and thus soil moisture recharge, excess (more than field capacity) or deficit (less than zero) are computed with reference to water holding capacity of the soil.

3.6.1 CROP COEFFICIENT (kc) AND PHENOLOGY

Crop coefficient accounts for the effect of the crop characteristics on crop water requirements .The water requirement at different growth stage of crop were obtained by multiplying reference crop ET by the crop coefficient. The coefficients at different growth stages of rice and wheat are shown in Table 4. Based on the crop data and personal discussions with the scientists the growing period and duration of the growth stages of rice and wheat crops were identified and used in the study.

Table 4

Crop coefficients and growth stages

Crop	Growth stage	Phasename	Duration (weeks)	Crop Coefficient
Rice	I	Vegetative	10:4	0.90
			:6	1.10
	II	Reproductive	2	1.05
	III	Grainfilling and Maturity	5	0.95
Wheat	I	CRI	3	0.30
	II	Vegetative	8	0.5-1.0
	III	Flowering	3	0.90
	IV	Maturity	3	0.60-0.30

3.6.2 WATER REQUIREMENT SATISFACTION INDEX (WRSI)

The water requirement satisfaction index was calculated for successive weeks of crop growth period from sowing to harvest by using the crop water balance method proposed by Frere and Popov (1979). This method is intended mainly for use in localities where rainfed agriculture is practised. The method is based on a cumulative water balance established over the whole growing seasons for the given crop and computed over successive weekly periods.

The water requirement satisfaction index was calculated as follows. The index has to be 100 at the time of sowing. The index continues to remain at 100 for the successive weeks until the occurrence of water stress. The calculation was carried out at the end of the growing seasons.

3.7 CROP WATER DEFICIT INDEX (CWDI)

Stress condition of the crop as suggested by Hiller and Clark (1971) was computed by the relation (1-AET/PET) X 100, where the AET and PET values were derived by the Thornthwaite and Mather (1957) water balance technique. The weekly values of the Aridity index were summed over each growth stage and also the growing seasons of the crop to provide an accumulated Aridity Index for the crop seasons. Since this index reflects climatic water deficit in the seasons or in the different growth stages of crops, henceforth it is being referred to as " crop water deficit index".

3.7.1 CLASSIFICATION OF DROUGHT YEARS

Drought years were segregated on the basis of their severity following the procedure adopted by Subrahmanyam and Sastri (1969). The levels of classification are given below:

Departure of Crop Water Deficit Index Value from the Median	Drought Intensity
0-<1/2 σ	Mild
1/2σ-σ	Moderate
σ-2σ	Severe
>2σ	Disastrous

Where σ 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.

3.7.2 PROBABILITY OF CROP WATER DEFICIT INDEX

Cumulative probability of occurrence of CWDI of different magnitudes was calculated by using the methods given by Thom (1966). Similar computations were performed for the phenophasic duration of the crops.

3.8 DRY AND WET SPELLS

Robertson (1976) gave many possibilities for using theory of Markov Chain. In the Markov Chain, the probability of an event that would occur on any week depends only on the conditions during the proceeding weeks and is independent of the events of further weeks. The Markov Chain probability model has been formed to describe the long-term frequency behaviour of dry and wet spells. The shortest period that can be considered for crop yield modelling is a day. However, the measurable growth of a plant is almost negligible on the daily basis. The soil water holding capacity can be used in crop weather models. Markov chain probability modelling is also solving many application-oriented objectives as well and this modeling has been found suitable to describe the long-term frequency behaviour of dry and wet spells. With this initial and conditional probabilities of occurrence of dry and wet spells can be calculated. Initial probabilities of occurrence of dry weeks during the different stages of crop growth and conditional probabilities (taking into account the sequential events) provide the basic information on rainfall distribution characteristics necessary for agricultural operations such as irrigation scheduling, time of transporting and fertilisers.

The daily rainfall data have been collected for 6 stations and utilised in the study of the dry and wet spells. For effective growth of rice crop, a minimum weekly rainfall amount of 50-mm is considered. A week receiving more than 50-mm rainfall is taken as wet week and less than 50-mm rainfall is taken as dry week. Similarly in case of wheat this limit is taken as 10-mm.

Based on the historical data of weekly rainfall, initial probabilities were worked out for each station as mentioned below:

$$P(W) = F(W)/n \text{ and } P(D) = F(D)/n$$

Where,

P (D) - probability of occurrence of a dry week
P (W) - probability of occurrence of wet week
F (D) - frequency of occurrence of dry week
F (W) - frequency of occurrence of wet week in n years

Similarly, the conditional probabilities are calculated by formulae

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

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

$$P(D/W) = \frac{F(D/W)}{F(W)} = 1 - P(W/W)$$

$2D = PD_{w1}.\ PDD_{w2}$

$3D = PD_{w1}.\ PDD_{w2}.\ PDD_{w3}$

$2W = PW_{w1}.\ PWW_{w2}$

$3W = PW_{w1}.\ PWW_{w2}.\ PWW_{w3}$

Where,

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

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

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

2D, 3D - Probability of 2 and 3 consecutive dry weeks respectively starting with the week

2W, 3W - probability of 2 and 3 consecutive wet weeks respectively starting with the week

w_1, w_2, w_3 - indicate three consecutive weeks.

The first letter in the conditional probability is indicating the present week and the second letter is indicating the past week.

3.9 COMPUTATION OF 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, the weekly MAI and probability of exceedance of weekly moisture availability were calculated.

$$MAI = \frac{AE}{PE}$$

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+Δ S

Where, P = precipitation

ΔS = change in soil moisture

The crop growth period was considered as the period during which the MAI was more than 0.5 at the time of sowing and active vegetative growth period and more than 0.3 at the time of maturity. All periods during active vegetative growth for which MAI was less than 0.5 were considered as stress period. Cessation of rainy season does not mean the end of crop season. Crop can thrive on stored soil moisture and it is therefore, necessary to examine and find out the amount of moisture stored in the soil at the end of the season. However, the cumulative seasonal evapotranspiration for dry land crop like sorghum etc., even under relatively favourable moisture conditions may be only 65 % of PE (Jenson, 1968). Replay (1966) observed that in many farm crops seasonal water use might range to 55-75 % of PE.

The probably earliest date of sowing of *Kharif* crop was assumed to be the day when rainfall along with the stored soil moisture met half the PET during the moist period following the sub humid period and the probable date of sowing of *Rabi* crop was assumed to be the day when the soil moisture stored was sufficient to meet the full evaporation demand of the climate. Based on the assumptions the moisture availability periods (number of days in the moist period and following sub-humid period) were worked out for planning the cropping pattern for each region.

For deciding the length of growing period and to determine the probability of moisture availability to meet crop water demand at different stations, following two assumptions were made

1.Period during which MAI≥0.5 was considered as the length of growing period.

2.To determine the probability of moisture availability to meet crop water demand for rice and wheat at different stages, MAI values used are as follows:

For rice: ≥0.75 at the time of seedling, 1 for vegetative and reproductive stage and ≥0.5 for maturity stage.

For wheat: ≥0.3 at CRI stage, ≥0.5 at tillering and jointing stage, ≥0.75 at flowering stage and ≥0.3 at maturity stage.

These assumptions were similar to that of Mondal (1991). The crop growth period and probability of moisture availability to meet crop water demand of rice and wheat crops were worked out for different stations by considering the above assumptions.

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The present investigation is based on meteorological and crop data for 17-25 years in respect of six stations representing different agro-climatic conditions in Bihar state. The results pertaining to information on agro-climatic characterization of rice and wheat growing regions of the state and phenophasic and seasonal drought occurrence are discussed here. Results obtained through computation of weekly rainfall probability, aridity index, occurrence of dry and wet spells their probabilities and moisture availability index in relation to phenophases of crops have been examined, analyzed, tested statistically and discussed under the following major head: -

1. Rainfall characteristics & weekly rainfall probabilities during cropping seasons
2. Climatic water balance
3. Aridity index and crop water deficit index
4. Water requirement satisfaction index
5. Occurrence of dry and wet spells
6. Moisture availability index

4.1 Rainfall characteristics

4.1.1 Rainfall during the cropping season.

From daily rainfall data the total amount of precipitation received during the growing seasons of rice and wheat crops at all the six stations were worked out separately. These were averaged over the years for which data were collected at each station and are presented in Table 5. While working out the total rainfall received during the total growing season of crops, the normal sowing week was taken into consideration. The total rainfall corresponding to the lifecycle of rice and wheat crop starting from sowing week was cumulated for each year and then averaged for the entire period. The mean and coefficient of variation (cv%) were calculated and presented in Table 5.

Table 5: Seasonal rainfall (mm) for rice and wheat crop growing duration: -

Station	Rice	Wheat
Patna	1033(25)	52(97)
Gaya	965(17)	68(82)
Bhagalpur	948(25)	43(92)
Dumka	1088(32)	38(80)
Ranchi	1220(16)	83(50)
Hazaribagh	1025(24)	68(45)

Coefficient of variation (cv%) is shown in parenthesis.

It is seen from the table that the average rainfall for rice growing season ranges from 948 mm at Bhagalpur to 1220 mm at Ranchi. For wheat, seasonal rainfall ranges from 38 mm at Dumka to 83 mm at Ranchi. This reflects a wide variation in seasonal rainfall at different stations.

In general, the station Dumka recorded higher coefficient of variation (32%) in rice seasonal rainfall whereas it was lowest for Ranchi (16%). In case of wheat, seasonal rainfall coefficient of variation was higher for the station Patna followed by Bhagalpur and lowest for the station Hazaribagh 45%. Low coefficient of variation shows relatively low variation in seasonal rainfall and higher reliability. This is also associated with stations with high rainfall while stations with low rainfall are associated with high coefficient of variation.

4.1.2 Weekly rainfall probabilities during cropping season: -

Weekly rainfall probabilities were computed by fitting gamma distribution following Thom (1966) using daily rainfall data for several years in respect of the selected stations. The weekly-assured rainfall values at different probability levels (10%, 25%, 50%, 75%, and 90%), using the gamma distribution are presented in Table 6a and 6b.

Discussion on assured rainfall distribution has been limited to important weeks for the sake of brevity.

24^{th} week (11 – 17 June): - The monsoon is normally established over the whole state by this week. Rainfall has generally increased in all areas under the influence of the monsoon. The region of highest rainfall area shifts to Hazaribagh where it is more than 76 mm at 25% probability level. It reduced to 36 mm and 14 mm at 50% and 75% levels respectively. The zone of low rainfall is observed in Gaya where it is 35 mm at 25% levels. In this area assured rainfall is in the order of 14 mm and 3 mm at 50% and 75% levels respectively. One can expect rainfall of 14 mm in Gaya in 5 out of 10 years.

28th week (9-15 July): - Considerable increase of rainfall is noticed after 24th week in all station. The main rainfall belt has shifted towards south where it is the highest for Ranchi i.e. 67 mm and 47 mm at 50% and 75% probability level respectively. At 50%, 75% and 90% probability the magnitude of assured rainfall is very high for Ranchi and Hazaribagh. One can expect 33 mm rainfall in Ranchi in 9 out of 10 years.

32nd week (6-12 August): - Assured rainfall is high in Ranchi which is 105 mm at 25% level and 78 mm and 55 mm at 50% and 75% level respectively. Low rainfall was noticed in Bhagalpur and Patna at 50% and 75% level.

36th week (3-9 September): - Assured rainfall is again high in Ranchi at all probability level and it is lowest for Gaya and Bhagalpur where it is only 33-39 mm, 23-26 mm and 7.1 to 7.9 mm at 50%, 75% and 90% probability level respectively. One can expect only 7.1 mm rainfall in Bhagalpur in 9 out of 10 years.

40th week (1-7 October): - Assured rainfall has decreased in south Bihar and increased in north and eastern region. This is clearly seen at 50% level. The main rainfall belt has shifted towards Dumka where it is 38 mm and 13 mm at 50% and 75% probability level respectively.

Table 6a

Assured weekly precipitation (mm) at 10% probability level

Station	Weeks 22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Patna	29	47	100	83	127	171	215	221	174	157	151	119	199	99	145	148	89	112	128	59	48
Gaya	10	63	67	71	149	188	165	160	143	142	136	130	140	162	111	159	75	110	79	24	34
Bhagalpur	57	111	119	93	149	166	163	150	164	185	103	107	146	87	93	141	98	101	98	78	51
Dumka	54	98	125	121	135	154	180	166	142	122	139	150	114	159	121	127	123	207	158	68	45
Ranchi	62	119	83	134	184	160	119	173	167	136	135	152	121	179	168	179	116	135	87	61	60
Hazaribagh	35	131	130	91	161	88	119	119	166	206	182	120	127	97	120	194	100	131	60	63	8.8

Assured weekly precipitation (mm) at 25% probability level

Station	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Patna	16	25	49	49	71	102	123	136	111	100	88	68	126	61	95	93	53	61	63	29	21
Gaya	6.2	32	35	43	89	114	108	104	98	93	92	87	89	92	71	98	40	65	40	13	16
Bhagalpur	31	56	67	61	87	97	102	103	103	110	65	63	89	58	60	91	56	64	51	39	24
Dumka	31	56	67	76	77	105	109	110	103	79	98	102	77	97	77	88	69	116	88	37	22
Ranchi	32	69	54	83	126	106	92	127	111	105	106	108	79	125	119	108	68	73	45	30	29
Hazaribagh	18	72	76	53	112	65	83	86	89	130	118	76	82	64	76	111	58	72	33	32	5.4

Assured weekly precipitation (mm) at 50% probability level

Station	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Patna	6.4	10	17	24	31	50	56	70	60	55	41	32	68	32	54	50	27	26	22	10	5.9
Gaya	3.1	12	14	21	44	57	62	59	60	53	55	52	49	41	39	51	16	31	14	5.3	5.7
Bhagalpur	13	20	30	35	41	46	54	63	55	54	34	30	45	34	33	51	25	35	20	14	7.6
Dumka	14	25	28	40	35	65	55	63	68	44	63	61	47	49	42	55	30	52	38	15	7
Ranchi	12	33	32	43	77	62	67	86	64	76	78	69	46	79	77	54	32	30	18	11	10
Hazaribagh	7.1	31	36	26	70	45	52	57	37	70	66	41	46	38	42	51	27	31	14	11	2.8

Assured weekly precipitation (mm) at 75% probability level

	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Patna	1.9	3	3.9	9.5	11	20	20	30	29	27	16	12	32	14	27	23	11	8.2	5.1	2.4	0.9
Gaya	1.3	3	3.8	8.8	18	24	32	29	33	27	30	28	24	14	18	23	4.7	12	3.5	1.6	1.3
Bhagalpur	4.2	4.9	11	18	16	18	24	36	25	22	16	12	19	18	16	26	8.8	17	5.3	3.4	1.5
Dumka	5.2	9	8.4	18	13	36	23	33	42	22	38	34	25	21	20	32	10	18	13	4.4	1.4
Ranchi	3.3	12	16	19	42	32	47	55	33	53	56	42	23	46	46	22	12	8.8	4.8	2.4	2.2
Hazaribagh	2	10	14	9.9	41	30	30	35	11	32	32	19	23	20	20	19	9.9	9.8	4.4	2.7	1.2

Assured weekly precipitation (mm) at 90% probability level

	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Patna	0.4	0.7	0.6	3.3	2.9	7.3	6.1	12	12	12	5	3.6	14	5.6	13	9.6	4	2.1	0.8	0.4	0.1
Gaya	0.5	0.6	0.8	3.2	6.6	9	15	13	18	13	15	14	11	4.2	7.9	9	1.1	3.8	0.6	0.4	0.2
Bhagalpur	1.1	0.9	3.1	8.3	5.1	5.8	9.9	19	10	7.6	6.4	4.1	7.4	8.8	7.1	12	2.6	7.5	1.1	0.6	0.2
Dumka	1.6	2.7	2	7.7	3.7	19	8.7	16	26	10	22	18	13	7.9	8.5	18	2.8	5	3.4	1	0.2
Ranchi	0.7	4	7.8	7.7	23	16	33	35	16	37	40	24	11	26	27	8.1	4	2.1	1	0.4	0.3
Hazaribagh	0.4	2.7	4.7	3.3	23	20	16	22	2.7	14	15	8.3	11	9.8	8.7	5.7	3.1	2.5	1.1	0.5	0.5

Table 6b

Assured weekly precipitation (mm) at 10% probability level

Station	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10
Patna	2.7	1.6	8.1	0	13	4	9.6	7	4.5	35	13	12	8.8	16	23	10	12
Gaya	2	1.6	13	1.6	2.3	2.1	7.8	13	6.9	19	42	13	8.7	20	17	17	6.8
Bhagalpur	4.1	1.6	5.1	1.3	7.3	4.2	9.3	3	11	7.8	29	11	10	15	10	13	6.2
Dumka	2	1.6	13	1.6	2.3	2.1	7.8	13	6.9	19	42	13	8.7	20	17	17	6.8
Ranchi	5.9	9.1	19	3.4	4.3	1.4	10	10	9.2	17	29	26	31	23	12	25	17
Hazaribagh	12	18	6.6	1.6	3.2	1.6	13	8	1.6	15	27	13	13	19	15	29	15

Assured weekly precipitation (mm) at 25% probability level

Station	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10
Patna	1.9	1.3	4.5	0	6.2	2.6	5.7	4	3	16	7.7	7.2	6.2	11	15	5.8	6.9
Gaya	1.6	1.3	6.8	1.3	1.7	1.6	4.6	7	4.3	9.7	19	7.5	6.2	14	12	8.9	4.1
Bhagalpur	2.6	1.3	3.2	1.2	4.2	2.7	5.3	2	6.4	4.5	14	6.1	7.2	9.9	7.1	7	3.9
Dumka	1.6	1.3	6.8	1.3	1.7	1.6	4.6	7	4.3	9.7	19	7.5	6.2	14	12	8.9	4.1
Ranchi	3.5	5	9.4	2.4	2.7	1.2	5.7	6	5.4	9.3	15	14	23	16	8.2	13	9.3
Hazaribagh	5.9	9.2	4	1.3	2.2	1.3	6.9	5	1.3	8.8	15	8	9.7	13	10	15	8.5

Assured weekly precipitation (mm) at 50% probability level

Station	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10
Patna	1.2	0.9	2	0	2.1	1.4	2.8	2	1.8	4.7	3.6	3.5	2.3	4.5	4.8	2.6	3
Gaya	1.2	0.9	2.7	0.9	1.2	1.2	2.3	3	2.3	3.6	6	3.5	2.3	4.9	4.3	3.6	2.1
Bhagalpur	1.5	0.9	1.7	1	1.9	1.5	2.4	1	3	2.1	4.4	2.8	2.8	3.8	2.6	3.1	2.1
Dumka	1.2	0.9	2.7	0.9	1.2	1.2	2.3	3	2.3	3.6	6	3.5	2.3	4.9	4.3	3.6	2.1
Ranchi	1.7	2.1	3.4	1.5	1.4	1.1	2.5	3	2.6	4.2	5.4	6.1	12	7.3	3.2	4.9	3.8
Hazaribagh	2.2	3.3	2	0.9	1.4	0.9	2.8	3	0.9	4.2	6.3	4.2	4.6	6.4	4.3	6	3.9

Assured weekly precipitation (mm) at 75% probability level

	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10
Patna	0.7	0.7	0.7	0	0.5	0.7	1.1	1	0.9	0.8	1.3	1.4	0.4	0	0	0.9	1
Gaya	0.8	0.7	0.7	0.7	0.7	0.8	0.9	1	1.1	0.9	1.1	1.3	0.5	0	0	1.1	0.9
Bhagalpur	0.7	0.7	0.8	0.9	0.7	0.8	0.9	1	1.1	0.8	0.9	1	0.5	0	0	1	1
Dumka	0.8	0.7	0.7	0.7	0.7	0.8	0.9	1	1.1	0.9	1.1	1.3	0.5	0	0	1.1	0.9
Ranchi	0.7	0.7	0.8	0.8	0.7	0.9	0.8	1	1	1.5	1.4	1.9	3.4	0.8	0.2	1.3	1.2
Hazaribagh	0.6	0.8	0.8	0.7	0.8	0.7	0.9	1	0.7	1.6	2	1.9	1.5	1.5	0.4	1.7	1.4

Assured weekly precipitation (mm) at 90% probability level

	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10
Patna	0.4	0.5	0.2	0	0.1	0.3	0.4	0	0.5	0.1	0.4	0.5	0	0	0	0.3	0.3
Gaya	0.6	0.5	0.2	0.5	0.5	0.6	0.3	0	0.4	0.2	0.1	0.4	0	0	0	0.3	0.4
Bhagalpur	0.3	0.5	0.3	0.8	0.2	0.3	0.3	1	0.3	0.3	0.1	0.3	0	0	0	0.3	0.4
Dumka	0.6	0.5	0.2	0.5	0.5	0.6	0.3	0	0.4	0.2	0.1	0.4	0	0	0	0.3	0.4
Ranchi	0.2	0.2	0.2	0.5	0.3	0.8	0.2	0	0.3	0.4	0.3	0.5	0	0	0	0.2	0.3
Hazaribagh	0.1	0.1	0.3	0.5	0.4	0.5	0.2	1	0.5	0.5	0.5	0.8	0	0	0	0.4	0.4

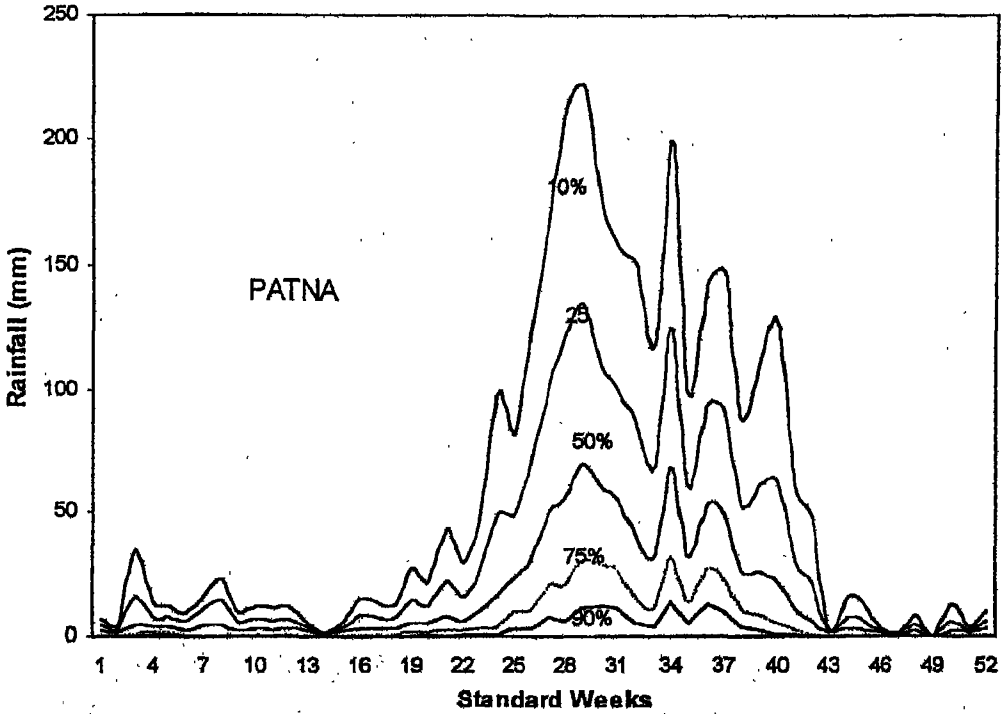
A critical examination was made of the spatial and temporal assured rainfall (A.R) distribution to find out the homogeneous rainfall zones. The A.R values for all the probability levels have been plotted against the standard weeks for all the stations (fig 2a-2c). These have been examined to find out, if there is any, typical pattern and if so, how far this pattern is distributed. Shapes of the curves especially the time of peaks and valleys and their duration have been used to identify this pattern and classify them and then they have been used to demarcate the area with respect to their spatial distribution.

Patna: The major peak observed during 29th standard week when A.R is 70 mm at 50% probability level. A secondary peak is observed during 34th week when A.R is 68 mm. A minor peak is observed during 36th week after which the A.R generally decreases upto 42nd week.

Gaya: Fig 2a shows assured rainfall pattern of Gaya. At this station rainfall duration was short varying from 10 to 14 weeks. A peak of A.R is observed at 28th week. Second peak is observed during 37th week at 50% level. *Rabi* crop does not suit normally in this area. One may cultivate short duration crops. A *Kharif* crop of 11-14 week duration appears suitable in this area.

Bhagalpur, Dumka, Ranchi and Hazaribagh: Similar pattern of A.R is observed for these four stations. More than 20 mm A.R is observed during the 23rd standard week at 50% probability level, this indicates the early onset of monsoon.

In general, there is a high rainfall belt in the southern part of Bihar i.e Ranchi, Hazaribagh and Dumka. The *Kharif* crop prospects in this area are good. These stations are suitable for rainfed crop cultivation. Rice can grow with supplementary irrigation at Patna, Bhagalpur and Gaya.



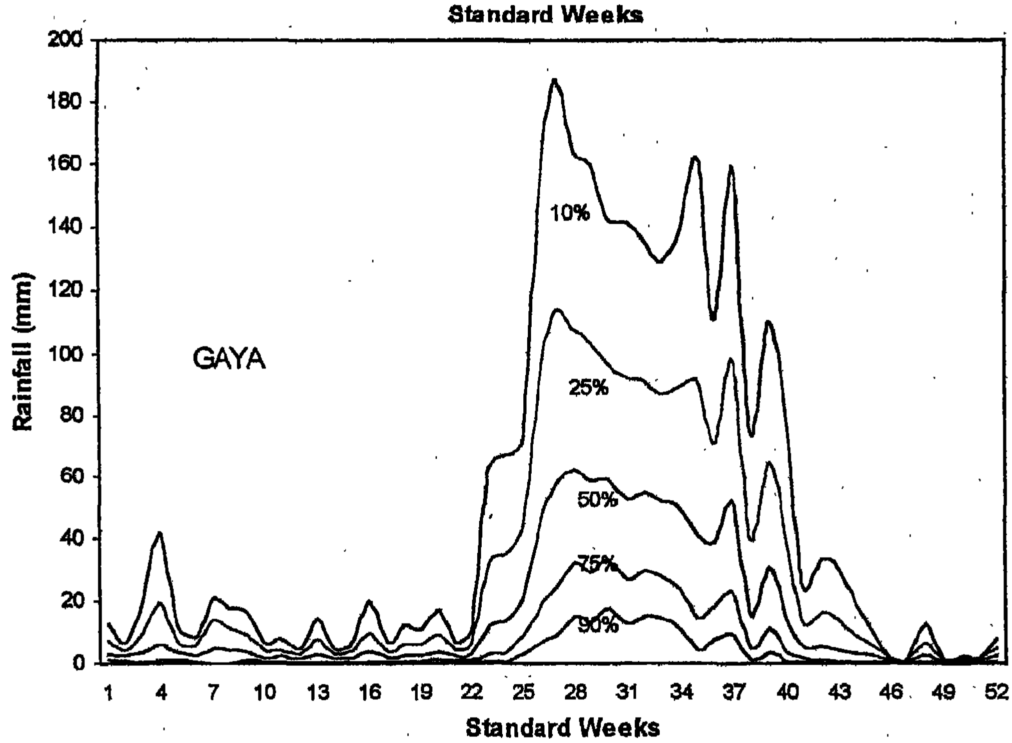


Fig. 2a : Assured weekly rainfall at different probability level

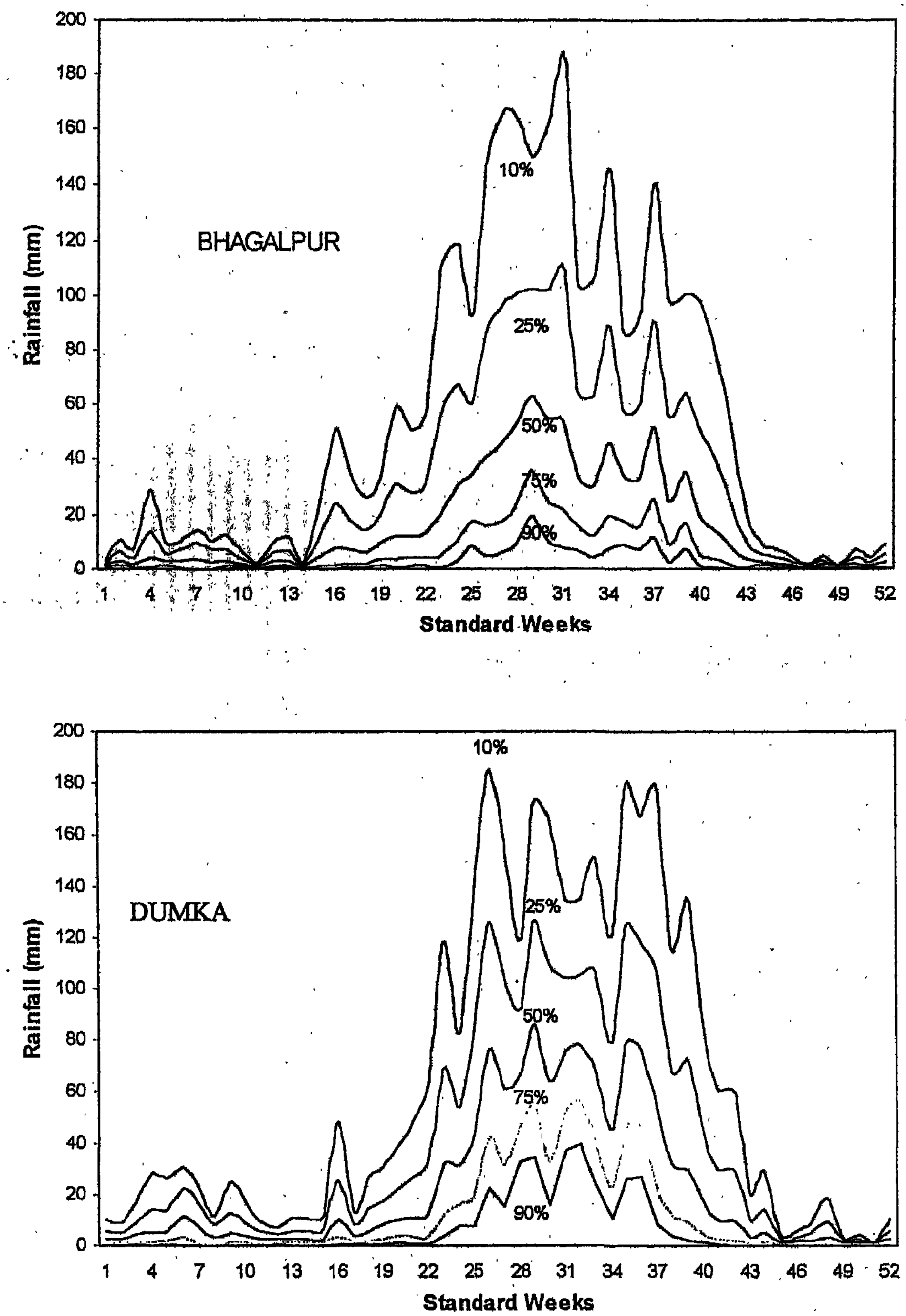
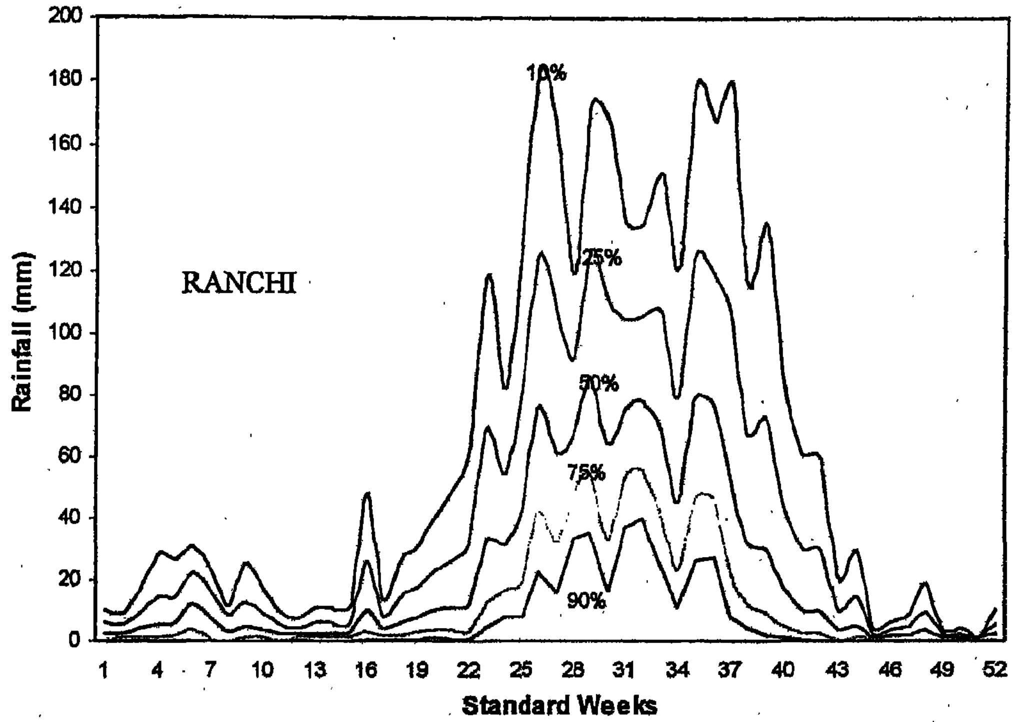


Fig. 2b : Assured weekly rainfall at different probability level



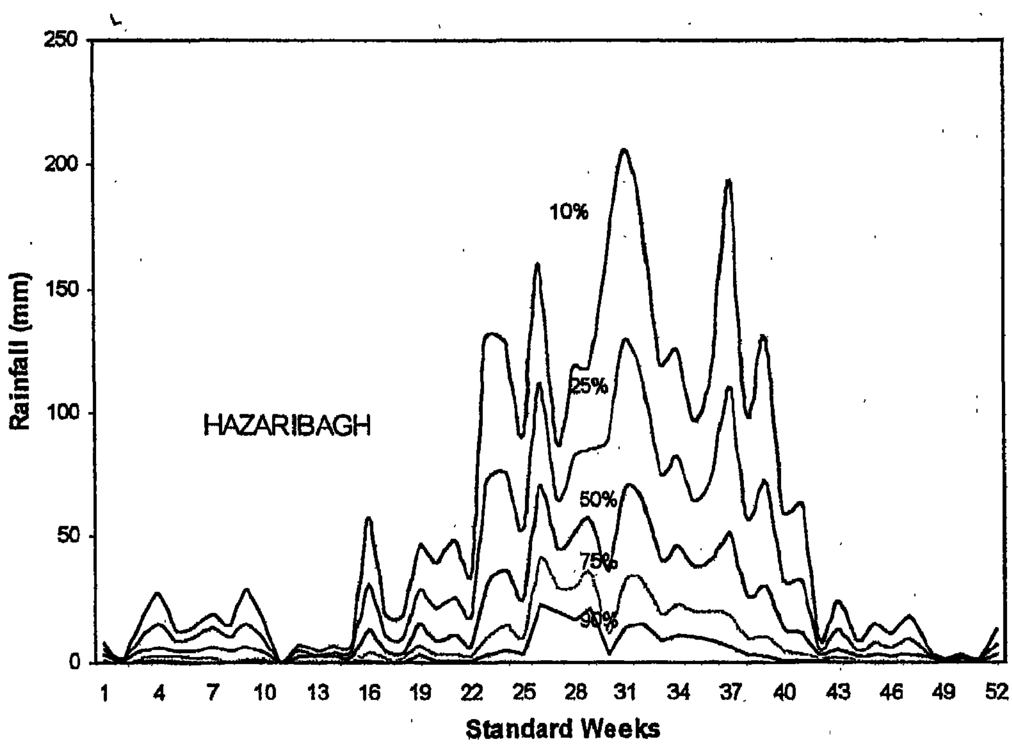


Fig. 2c : Assured weekly rainfall at different probability level

For wheat crop assured rainfall during the different probability level is presented in Table 6b. It is clear from this table that in the *Rabi* season expected assured rainfall is meagre to sustain the wheat crop thereby preventing the farmers to go for *Rabi* crops under rainfed conditions. The farmers have taken care for wheat crop only if irrigation facilities are available.

4.2 Climatic water balance

Climatic water balance provides an estimate of water availability to crops in relation to potential evapotranspiration (PET) and rainfall. For the evaluation of water balance of a station the average precipitation was compared with PET making allowance for the storage of water in the soil and its utilization for evapotranspiration (AET) purposes. Thus, the soil moisture status and the water surplus or water deficiency in any week during the crop seasons are determined. Results on average weekly water balance for rice and wheat growing seasons were computed following Thornthwaite and Mather (1957) method for each station and are presented in fig.3a to 3f in the form of climograms.

Patna, situated in agroclimatic zone III has an annual rainfall of 1212 mm with annual PET of 1991 mm. For rice crop it is clear from the fig. 3a that there is 12 weeks of soil moisture recharge period with practically no moisture deficit. A mild deficit is noticed after 40th week and evapotranspirational demand is met from rainfall and soil moisture storage to some extent for the remaining part of the growing year during which wheat crop is grown.

Gaya, situated in relatively low rainfall region, has an annual rainfall of 1113 mm with annual PET of 2018 mm. The climatic water balance diagram (fig. 3b) shows that soil moisture recharge starts in the 25th week and continues till 37th week. Rice crop is not affected by water shortage. After 38th week deficit starts and prevails till the end of *Rabi* season. Due to soil moisture utilization during this period the deficit was not high and *Rabi* crops can be taken up. However, there is no surplus in any of the weeks in the year.

Bhagalpur, also situated in the III zone has an annual rainfall of 1213 mm and total PET for this station is 2115 mm comparable with that of Patna. With the help of climatic water balance the annual actual evapotranspiration (AET) has been calculated as 1199 mm and annual deficit is found to be 880 mm. It has a recharge period of 5 weeks (from 27th to 31st week) during which no water deficit occurs. Starting from 39th week moisture deficit occurs during the entire wheat crop season (fig. 3c).

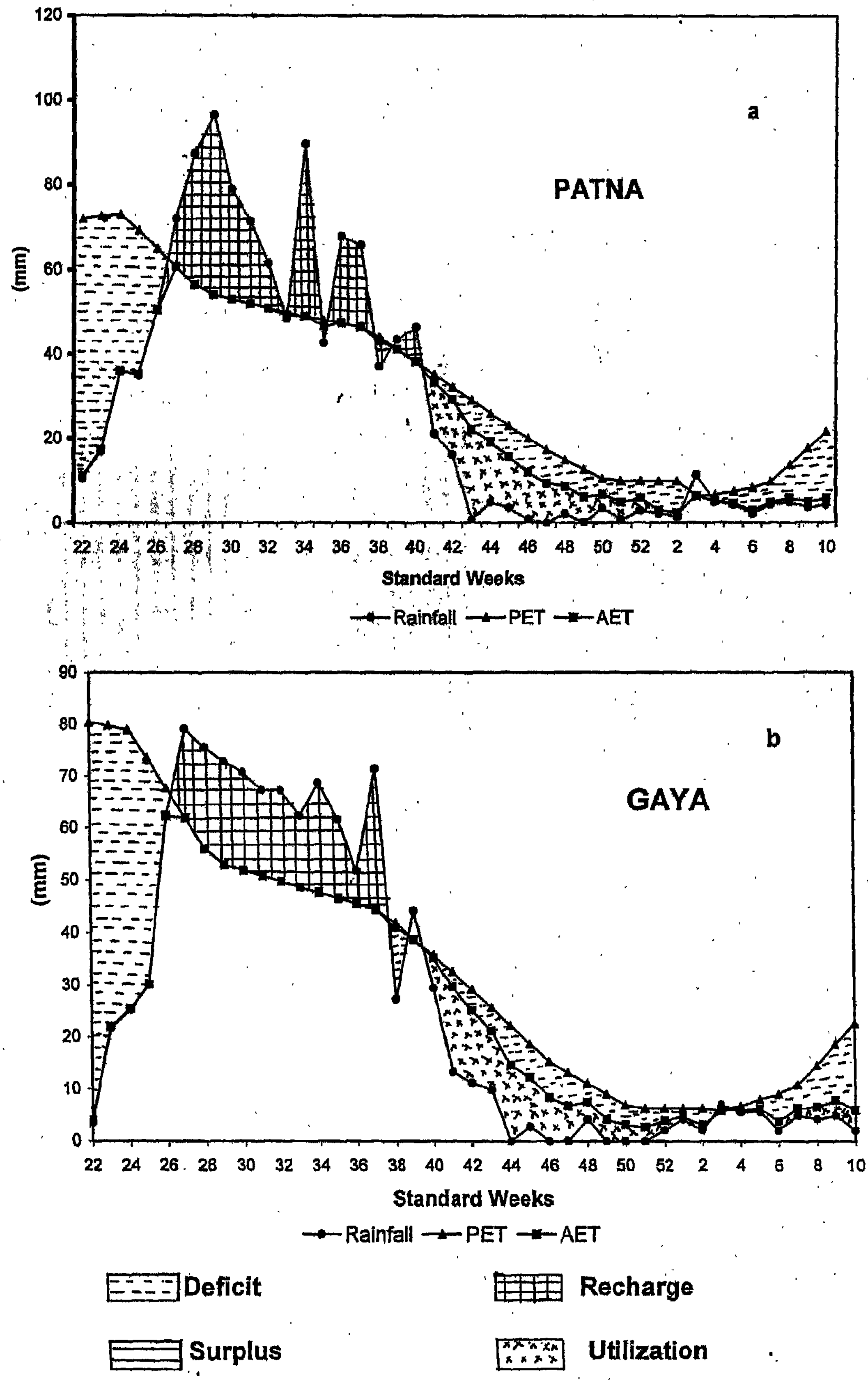
At station Dumka in the eastern part of Bihar with slightly higher annual rainfall of 1393 mm and less annual PET of 1886 mm (Fig 3d), water surplus occurs during *Kharif* from 32nd to 40th week. A deficit from 22nd standard week reduced to zero by the 26th week. A second period of deficiency occurs from the 41st standard week. Thereafter crop growth could be supported only by the stored moisture till the end of the season. This reveals that rice crop normally does not suffer from water deficit if sowing operations are carried out around the 26th week. Deficit during *Rabi* season is also marginal (166 mm).

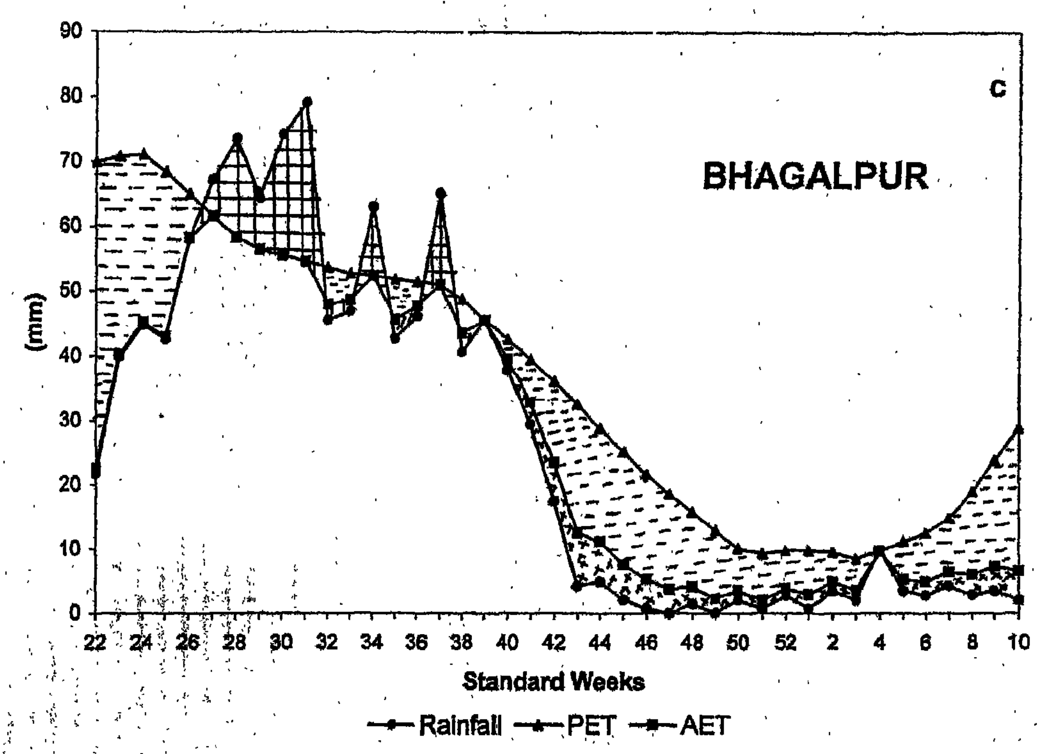
At Ranchi, which has an annual rainfall of 1534 mm with annual PET of 1428 mm, soil moisture recharge starts in the 25th week with practically no deficit till the 42nd week which corresponds to the harvest period for the rice (Fig. 3e). A large surplus of 528 mm is noticed after 28th week till the 40th week. Due to high surplus during this period the deficit is very less which is observed after 42nd week. The soil moisture storage is sufficient to take any rainfed crop during *rabi*.

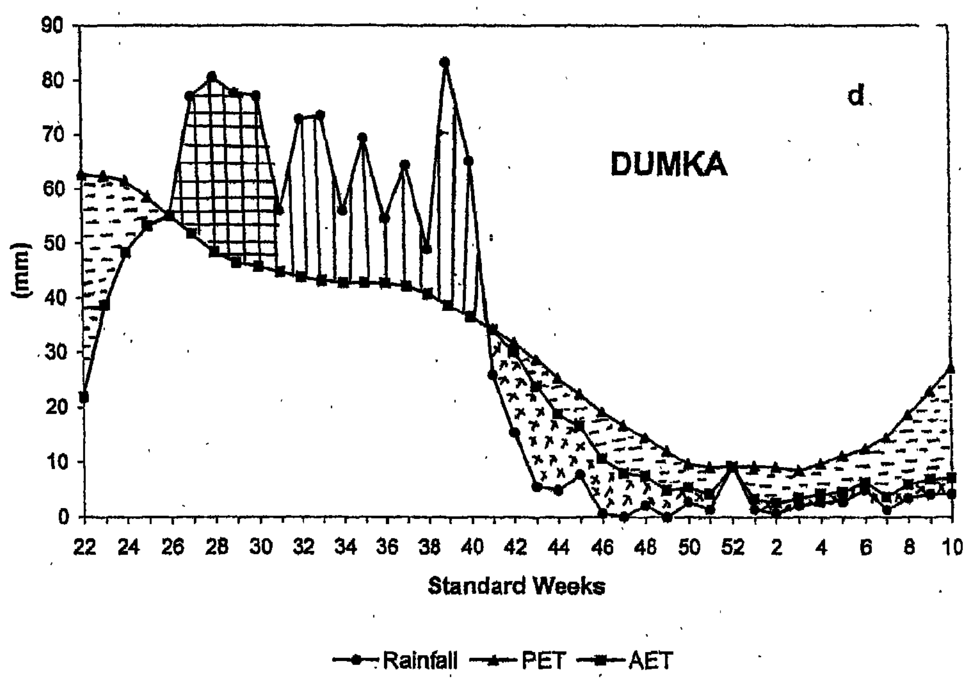
Hazaribagh shows (fig. 3f) a similar pattern as that of Ranchi and Dumka having annual rainfall and PET as 1266 mm and 1415 mm respectively. Soil moisture recharge starts in the 23rd week with no deficit till the 41st week and moderate deficit continues till 22nd week of next season. An annual deficit and surplus are found to be 490 mm and 286 mm respectively. A large surplus is noticed after 29th week till the end of rice growing season.

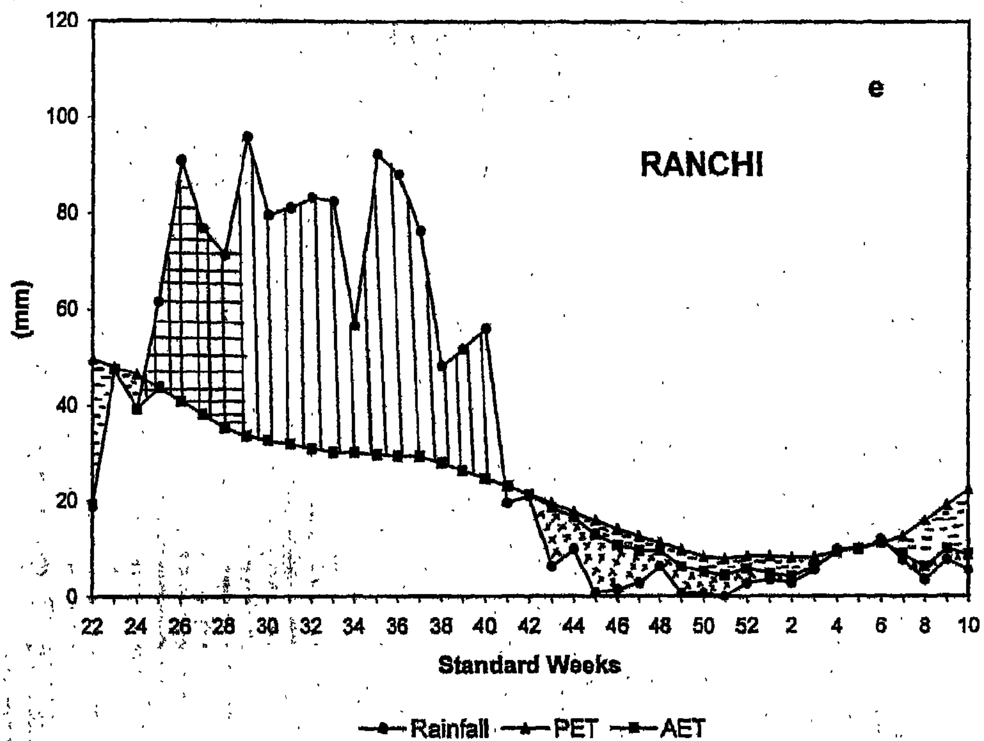
In general, this analysis shows that the station Ranchi, Hazaribagh, Dumka have large surplus and there is no need of supplementary irrigation for rice crop. Rainfed crop can be taken without any adverse effect. The stations Patna, Gaya and Bhagalpur show mid seasonal moisture deficit with no water surplus in any week during the growing season. Without supplementary irrigation *rabi* crop can not be grown. Of all the stations considered, with respect to rainfed crops, Gaya is relatively drier with large deficit in the post anthesis period.

Fig. 3 Climatic Water Balance




c
BHAGALPUR
(mm)
0
10
20
30
40
50
60
70
80
90
22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 2 4 6 8 10
Standard Weeks
Rainfall PET AET


d
DUMKA
(mm)
0
10
20
30
40
50
60
70
80
90
22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 2 4 6 8 10
Standard Weeks
Rainfall PET AET


e
RANCHI
(mm)
120
100
80
60
40
20
0
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
2
4
6
8
10
Standard Weeks
Rainfall
PET
AET

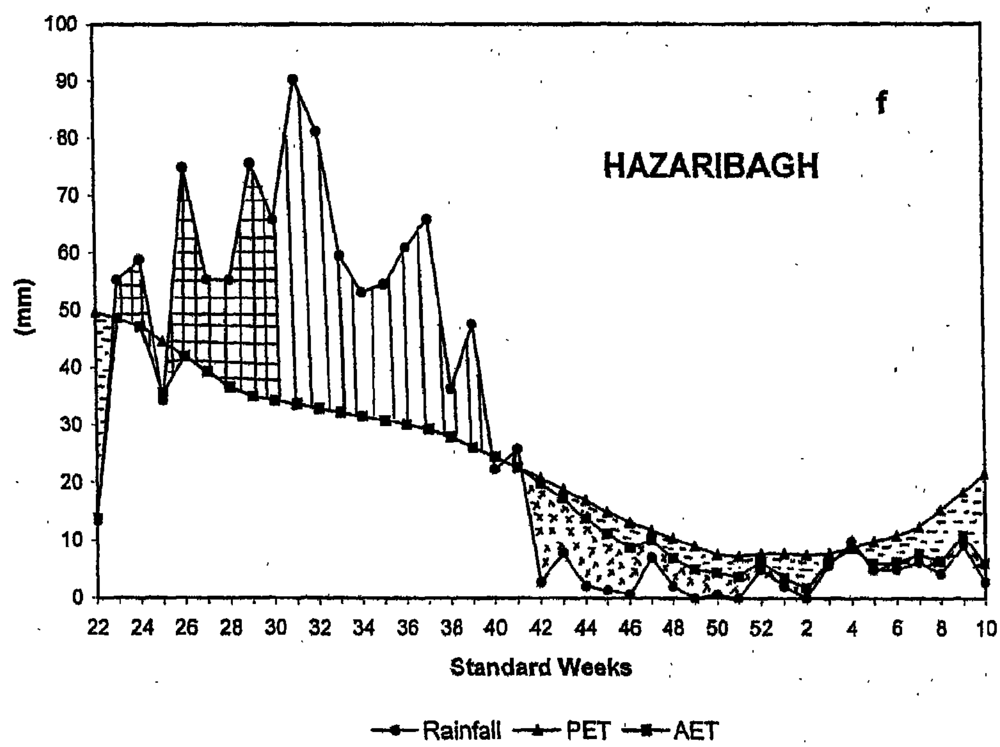

f
HAZARIBAGH
(mm)
100
90
80
70
60
50
40
30
20
10
0
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
2
4
6
8
10
Standard Weeks
Rainfall
PET
AET

Table 7: - Pattern of water availability and duration

Stations

	Patna	Gaya	Bhagalpur	Dumka	Ranchi	Hazari-bagh
Water surplus (mm)	Nil	Nil	Nil	196	528	286
Duration (weeks)	Nil	Nil	Nil	32nd-40th (9 weeks)	29th-40th (12 weeks)	30th-41st (12weeks)
Water deficit (mm)	860	968	880	726	486	490
Duration (weeks)	1st- 26th & 41st-52nd (38 Week)	1st-26th & 38th-52nd (41 week)	1st- 25th & 38th-52nd (40 week)	1st -25th & 41st-52nd (37 week)	1st-24th & 43rd-52nd (34 week)	1st-22nd & 42nd-52nd (33 week)

4.3 Aridity Index

The yearly aridity index for each station was computed by the method given by Thornthwaite and Mather (1957) using the values of AET and PET from the climatic water balance. Classification of drought for six stations under study is given in Table 8.

From the table the drought years are 7 out of 17 years for Ranchi and Hazaribagh with different intensities. Number of drought years is more for Patna and Gaya, while 12 years of drought out of 25 years. For Bhagalpur and Dumka 11 years are found as drought years out of 23 years. At Patna, Bhagalpur and Dumka one year of disastrous drought is observed but there is no disastrous drought occurring at stations Gaya, Ranchi and Hazaribagh out of the years under study for drought intensity.

Table – 8

YEARLY CLASSIFICATION OF DROUGHT ON THE BASIS OF ARIDITY INDEX (AI)

No Drought	Mild	Moderate	Severe	Disastrous	Total no. of drought year
Patna					
1969	1973	1975	1972	1982	
1970	1974	1987	1979		
1971	1989	1992	1983		
1976		1993	1991		
1977					
1978					
1980					
1981					
1984					
1985					
1986					
1988					
1990					
Total- 13	3	4	4	1	12
Gaya					
1969	1975	1970	1979		
1971	1976	1972	1987		
1973	1981	1974	1989		
1977		1982			
1978		1986			
1980		1993			
1983					
1984					
1985					
1988					
1990					
1991					
1992					
Total- 13	3	6	3		12
Bhagalpur					
1969	1982	1970	1976	1972	
1971	1986	1977	1979		
1973		1978	1983		
1974		1980	1990		
1975					
1981					
1984					
1985					
1987					
1988					
1989					
1991					
Total- 12	2	4	4	1	11

	No Drought	Mild	Moderate	Severe	Disastrous	Total no. of drought year
Dumka						
	1969	1970	1974	1972	1987	
	1971	1975	1976	1982		
	1973	1983	1979	1985		
	1977			1986		
	1978					
	1980					
	1981					
	1984					
	1988					
	1989					
	1990					
	1991					
Total-	12	3	3	4	1	11
Ranchi						
	1969	1973	1976	1972		
	1970	1984	1979			
	1971		1982			
	1974		1985			
	1975					
	1977					
	1978					
	1980					
	1981					
	1983					
Total-	10	2	4	1	-	7
Hazaribagh						
	1973	1970	1969	1971		
	1974	1976		1972		
	1975	1981		1975		
	1977					
	1978					
	1979					
	1980					
	1982					
	1983					
	1984					
Total-	10	3	1	3	-	7

Station Ranchi is least affected by drought and the intensity is also very less as compared to other stations. Only one severe drought year was observed out of 17 years, whereas at rest of the stations severe drought years was observed 3-4 times. Station Gaya is affected by more moderate droughts.

By taking the total drought year in percentage the drought year was 41% of total 17 years for Ranchi and Hazaribagh and 48% of 25 years for Patna and Gaya and same percentage of 23 years for Bhagalpur and Dumka. It reveals that the frequency of occurrence of drought years is more for Patna, Gaya, Bhagalpur and Dumka as compared to Ranchi and Hazaribagh.

4.4 Crop Water Deficit Index (CWDI)

The weekly aridity index for rice and wheat crop was computed by the method given by Thornthwaite and Mather (1957), using the values of AET and PET obtained from the weekly water balance. The weekly values were then accumulated for the growth period of each crop separately to provide a seasonal index. Since this index reflects climatic water deficit in the season with reference to the crop growth phases and duration, henceforth it is referred as crop water deficit index (CWDI). The values of CWDI thus derived for the six stations under study are given in Table 9.

It is observed from the table that the crop water deficit index range from 124 to 857 in case of rice and 609 to 1351 for wheat at Patna. Values of similar magnitudes are observed at other stations also. A lower value of this index signifies "no drought" condition and the higher the value of this index, the higher the crop water deficit during crop growth period at any given station.

4.4.1 Classification of rice, wheat cropping seasons in relation to crop water deficit index

Standard deviation (S.D.) and median of the seasonal index values for both crops at each of the stations for the data period used in this analysis were worked out. The amplitude of the departure of CWDI from the median was utilized to categorize of drought years by the method described on Page 36.

The limits of crop water deficit index so obtained in respect of rice and wheat crops are given in Table 10a. Years categorized under different degree of drought intensity are shown in Table 10b.

Comparison between yearly drought intensity (Table 8) and intensity of drought derived by CWDI (Table 10 b) show interesting results that yearly drought intensity is not wholly reflected in the seasonal droughts. Since the annual aridity Index derived from annual water deficiency which is due to the deficiency either in the *kharif* or *rabi*, the yearly droughts are reflected as seasonal droughts either in *kharif* or *rabi* and some times in both but with a varying degree of intensity. In certain occasions,there is a slight time lag between the time of occurrence of water deficiency and droughts. However the present analysis aims to classify the seasonal droughts and derived its impact on the yields of the corresponding crops grown in the season in the area.

4.4.2 Probability of seasonal drought in crops

The cumulative probability of occurrence of seasonal drought of different intensities was calculated by the method following Thom (1966) and the results are depicted in the form of bar diagrams and are discussed in the following sections:

Table 9: - Seasonal Crop Water Deficit Index for Rice and Wheat Crops.

Patna

Year	Rice (CWDI)	Year	Wheat (CWDI)
1969	329	1969-70	850
1970	306	1970-71	1140
1971	162	1971-72	862
1972	673	1972-73	997
1973	457	1973-74	1129
1974	221	1974-75	1059
1975	365	1975-76	1108
1976	330	1976-77	1210
1977	162	1977-78	801
1978	238	1978-79	798
1979	532	1979-80	1087
1980	287	1980-81	609
1981	338	1981-82	1038
1982	857	1982-83	1358
1983	654	1983-84	1076
1984	199	1984-85	1299
1985	185	1985-86	989
1986	250	1986-87	965
1987	343	1987-88	867
1988	124	1988-89	1351
1989	308	1989-90	982
1990	198	1990-91	1067
1991	484	1991-92	1264
1992	344	1992-93	1186
1993	461		

Gaya

Year	Rice (CWDI)	Year	Wheat (CWDI)
1969	334	1969-70	941
1970	546	1970-71	1238
1971	166	1971-72	983
1972	394	1972-73	543
1973	406	1973-74	1351
1974	360	1974-75	957
1975	957	1975-76	1186
1976	324	1976-77	1191
1977	222	1977-78	877
1978	877	1978-79	767
1979	461	1979-80	1081
1980	239	1980-81	514
1981	387	1981-82	1081
1982	666	1982-83	1033
1983	221	1983-84	728
1984	728	1984-85	1311
1985	386	1985-86	1054
1986	506	1986-87	1475
1987	367	1987-88	1201
1988	382	1988-89	1183
1989	562	1989-90	1250
1990	121	1990-91	977
1991	139	1991-92	797
1992	167	1992-93	859
1993	603		

Bhagalpur

Year	Rice (CWDI)	Year	Wheat (CWDI)
1969	205	1969-70	1189
1970	427	1970-71	1242
1971	158	1971-72	990
1972	784	1972-73	1096
1973	430	1973-74	1197
1974	194	1974-75	1017
1975	176	1975-76	1335
1976	515	1976-77	1352
1977	482	1977-78	1132
1978	506	1978-79	889
1979	536	1979-80	1249
1980	360	1980-81	1001
1981	423	1981-82	1156
1982	224	1982-83	1281
1983	664	1983-84	1124
1984	176	1984-85	1407
1985	366	1985-86	1017
1986	493	1986-87	1165
1987	461	1987-88	1324
1988	271	1988-89	1203
1989	329	1989-90	985
1990	544	1990-91	1311
1991	304		

Dumka

Year	Rice (CWDI)	Year	Wheat (CWDI)
1969	153	1969-70	986
1970	146	1970-71	1124
1971	128	1971-72	1121
1972	455	1972-73	1285
1973	58	1973-74	1225
1974	350	1974-75	1268
1975	320	1975-76	1315
1976	336	1976-77	1232
1977	82	1977-78	1003
1978	91	1978-79	920
1979	392	1979-80	1032
1980	67	1980-81	1014
1981	268	1981-82	1095
1982	528	1982-83	1376
1983	192	1983-84	1117
1984	68	1984-85	1217
1985	521	1985-86	1329
1986	681	1986-87	1261
1987	586	1987-88	1309
1988	197	1988-89	1290
1989	155	1989-90	1217
1990	76	1990-91	1273
1991	58		

Ranchi

Year	Rice (CWDI)	Year	Wheat (CWDI)
1969	92	1969-70	857
1970	60	1970-71	965
1971	31	1971-72	904
1972	352	1972-73	634
1973	218	1973-74	717
1974	90	1974-75	750
1975	70	1975-76	900
1976	82	1976-77	1028
1977	88	1977-78	764
1978	97	1978-79	581
1979	224	1979-80	901
1980	139	1980-81	733
1981	42	1981-82	840
1982	137	1982-83	1204
1983	157	1983-84	911
1984	49	1984-85	902
1985	178		

Hazaribagh

Year	Rice (CWDI)	Year	Wheat (CWDI)
1969	670	1969-70	934
1970	293	1970-71	858
1971	528	1971-72	1130
1972	336	1972-73	1061
1973	142	1973-74	584
1974	20	1974-75	887
1975	155	1975-76	903
1976	193	1976-77	1077
1977	1.3	1977-78	603
1978	133	1978-79	690
1979	20	1979-80	813
1980	110	1980-81	870
1981	167	1981-82	988
1982	330	1982-83	1147
1983	166	1983-84	585
1984	4.5	1984-85	1072
1985	279		

Table 10a

Limits of crop water deficit index for drought categorization

	RICE	WHEAT
	PATNA	
NO DROUGHT	<330	<1067
MILD	331-420	1068-1161
MODERATE	421-509	1162-1255
SEVERE	>510	>1255
	GAYA	
NO DROUGHT	<367	<1045
MILD	368-448	1046-1167
MODERATE	449-528	1168-1289
SEVERE	>528	>1290
	BHAGALPUR	
NO DROUGHT	<366	<1177
MILD	367-454	1178-1247
MODERATE	455-542	1248-1317
SEVERE	>543	>1318
	DUMKA	
NO DROUGHT	<192	<1221
MILD	193-288	1222-1286
MODERATE	289-374	1257-1351
SEVERE	>374	>1352
	RANCHI	
NO DROUGHT	<97	<901
MILD	98-146	902-981
MODERATE	147-195	982-1061
SEVERE	>195	>1062
	HAZARIBAGH	
NO DROUGHT	<167	<928
MILD	168-263	929-1035
MODERATE	264-359	1036-1132
SEVERE	>390	>1133

TABLE 10b

Classification of drought years on the basis of crop water deficit index

PATNA

RICE					WHEAT				
No Drought	Mild	Moderate	Severe	Disastrous	No Drought	Mild	Moderate	Severe	Disastrous
1969	1975	1973	1972	1982	1969-70	1970-71	1976-77	1982-83	1988-89
1970	1981	1991	1979		1971-72	1973-74	1992-93	1984-85	
1971	1987	1993	1983		1972-73	1975-76		1991-92	
1974	1992				1974-75	1979-80			
1976					1977-78	1983-84			
1977					1978-79				
1978					1980-81				
1980					1981-82				
1984					1985-86				
1985					1986-87				
1986					1987-88				
1988	Median:		330		1989-90	Median:		1067	
1989	S.D:		178		1990-91	S.D:		188	
1990									

GAYA

RICE					WHEAT				
No Drought	Mild	Moderate	Severe	Disastrous	No Drought	Mild	Moderate	Severe	Disastrous
1969	1972	1979	1970	1975	1969-70	1979-80	1970-71	1973-74	1986-87
1971	1973	1986	1989	1978	1971-72	1981-82	1975-76	1984-85	
1974	1981		1993	1982	1972-73	1985-86	1976-77		
1976	1985				1974-75		1987-88		
1977	1988				1977-78		1988-89		
1980					1978-79		1989-90		
1983					1980-81				
1984					1982-83				
1987					1983-84				
1990	Median:		367		1990-91	Median:		1045	
1991	S.D:		161		1991-92	S.D:		244	
1992					1992-93				

BHAGALPUR

RICE					WHEAT				
No Drought	Mild	Moderate	Severe	Disastrous	No Drought	Mild	Moderate	Severe	Disastrous
1960	1970	1971	1976	1972	1971-72	1969-70	1979-80	1975-76	1984-85
1971	1973	1978	1979	1983 /	1972-73	1970-71	1982-83	1976-77	
1974	1981	1986	1990		1974-75	1973-74		1987-88	
1975					1977-78	1988-89			
1980					1978-79				
1982					1979-80				
1984					1980-81				
1985					1981-82				
1987					1983-84				
1988	Median:		366		1985-86	Median:		1177	
1989	S.D:		176		1986-87	S.D:		140	
1991					1989-90				

DUMKA

RICE

No Drought	Mild	Moderate	Severe	Disastrous
1969	1981	1974	1972	1982
1970	1988	1975	1979	1985
1971		1976		1986
1973				1987
1977				
1978				
1980				
1983				
1984				
1989				
1990				
1991				

Median: 192
S.D: 191

WHEAT

No Drought	Mild	Moderate	Severe	Disastrous
1969-70	1972-73	1975-76	1982-83	
1970-71	1973-74	1985-86		
1971-72	1974-75	1987-88		
1977-78	1976-77	1988-89		
1978-79	1986-87			
1979-80	1990-91			
1980-81				
1981-82				
1983-84				
1984-85				
1989-90				

Median: 1221
S.D: 129

RANCHI

RICE

No Drought	Mild	Moderate	Severe	Disastrous
1969	1980	1983	1973	1972
1970	1982	1985	1979	
1971				
1974				
1975				
1976				
1977				
1978				
1981				
1984				

Median: 97
S.D: 86

WHEAT

No Drought	Mild	Moderate	Severe	Disastrous
1969-70	1970-71	1976-77		1982-83
1972-1973	1971-72			
1977-78	1983-84			
1978-79	1984-85			
1979-80				
1980-81				
1981-82				

Median: 901
S.D: 159

HAZARIBAGH

RICE

No Drought	Mild	Moderate	Severe	Disastrous
1970	1976	1972		1969
1973		1982		1971
1974		1985		
1977				
1978				
1979				
1981				
1983				
1984				

Median: 167
S.D: 193

WHEAT

No Drought	Mild	Moderate	Severe	Disastrous
1970-71	1969-70	1971-72	1972-73	
1973-74	1981-82	1976-77	1982-83	
1977-78		1984-85		
1978-79				
1983-84				

Median: 928
S.D: 194

4.4.2.1 Probability of occurrence of moderate seasonal drought

Among the six stations considered, the probability of moderate drought occurrence for rice crop growing season on a seasonal basis is the lowest at Patna (13%) and highest at Hazaribagh (21%). At Ranchi wheat has the lowest (7%) probability of moderate drought occurrence and it is highest for Gaya (27%). In general, probability of occurrence of moderate drought ranges from 13-21% for rice crop and 7-27% for wheat crop among the stations under study (fig. 4a).

4.4.2.2 Probability of severe seasonal drought conditions

Unlike in the case of moderate drought conditions, Bhagalpur has the highest probability (13%) of occurrence of severe seasonal drought conditions for both rice and wheat crops. No severe drought occurrence is noticed at Hazaribag and Ranchi in case of rice and wheat crops respectively (fig. 4b). Probability of occurrence of severe drought ranges from 0-13% for both rice and wheat crops among the stations under study.

In general, moderate seasonal drought has higher probability at all the stations than that of severe drought occurrence.

4.4.2.3 Probability of drought occurrence in Phenophases

With a view to understand the drought probability in more detail, the probability of crop water deficit index for flowering and grain filling stage for rice and wheat was computed and results are shown in (Fig. 5 and 6). Probability of occurrence of moderate and severe drought at these two stages was worked out.

(a) Flowering Stage: -

Among the six stations studied, the station Hazaribagh shows no moderate and severe drought occurrence at the flowering stage in case of rice. Station Dumka shows the highest probability of occurrence (30%) for the moderate drought for wheat crop. Station Gaya shows the highest probability of occurrence (20%) for severe drought for wheat crop. In case of rice crop the highest probability of occurrence of moderate drought is at Patna (12%) and that of severe drought is at Dumka (8%).

(b) Grainfilling stage for rice and milking stage for wheat: -

As seen in case of flowering stage, station Patna shows the highest probability of occurrence for moderate drought (28%) intensity at the grainfilling stage for rice crop. At Hazaribagh and Ranchi no moderate drought occurs but probability of occurrence of severe drought is highest (13%) for rice crop.

Among the stations Gaya has highest probability of occurrence of moderate drought (36%) and Patna has highest probability of occurrence of severe drought (28%) at milking stage in case of wheat crop.

Fig.4a Probability of occurrence of moderate seasonal drought in Bihar state

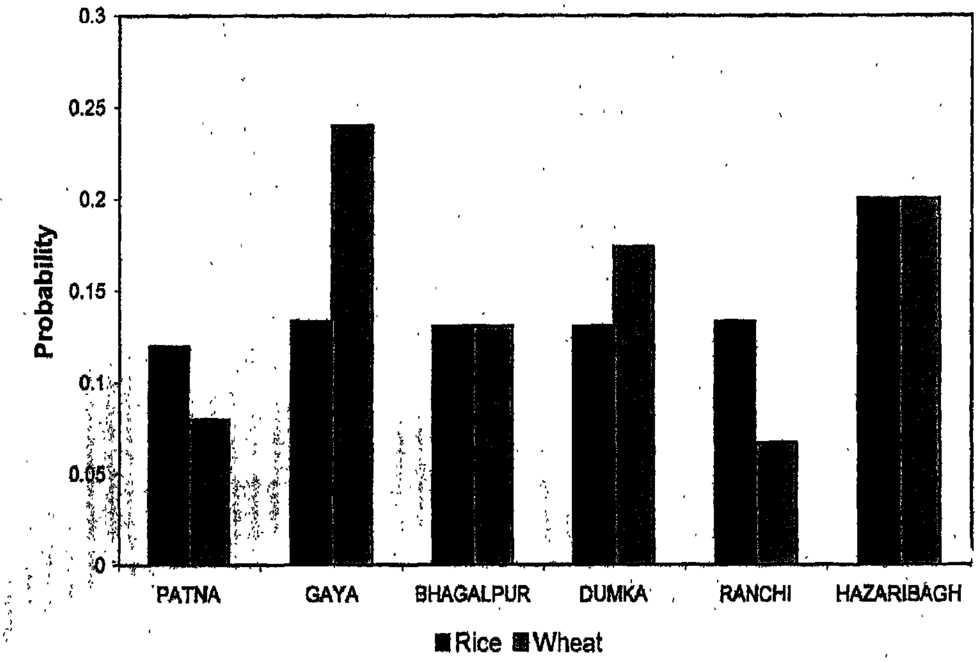


Fig.4b probability of occurrence of severe seasonal drought in Bihar state

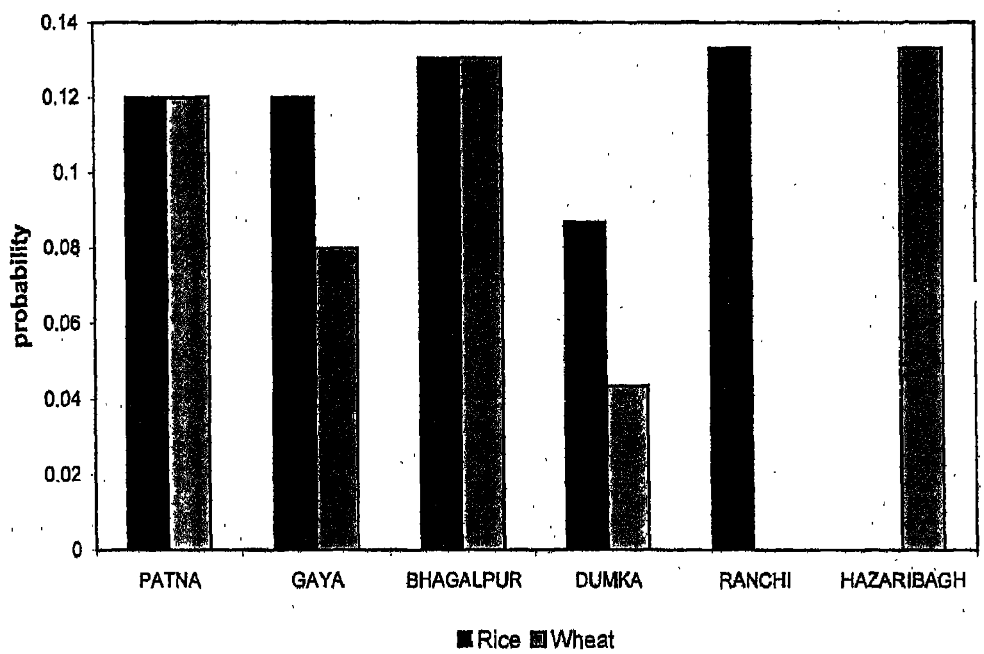


Fig.5a Probability of occurrence of moderate drought at flowering stage

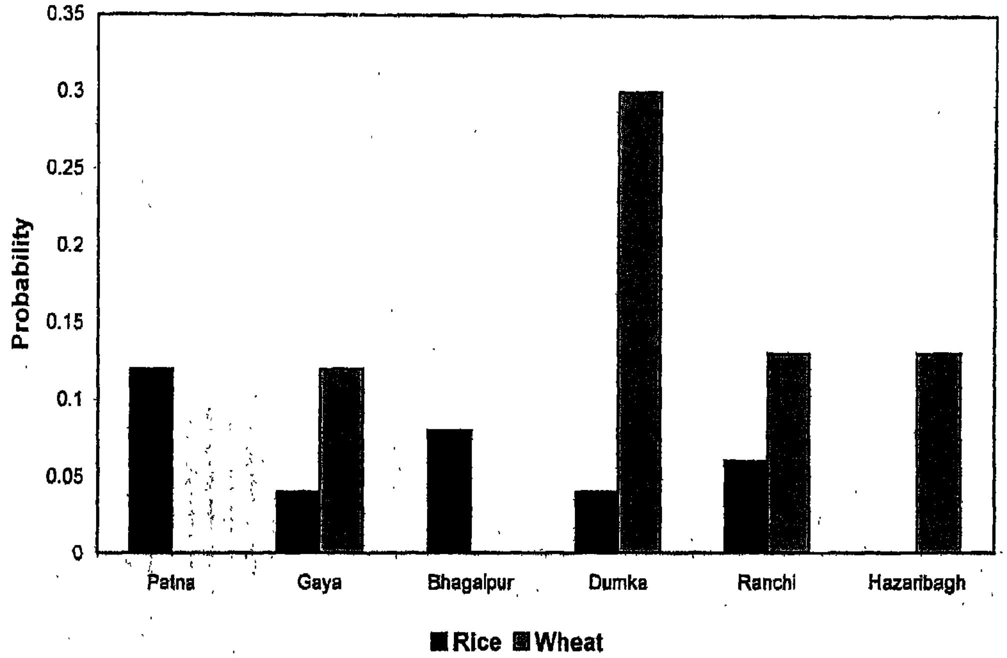


Fig.5b Probability of occurrence of severe drought at flowering stage

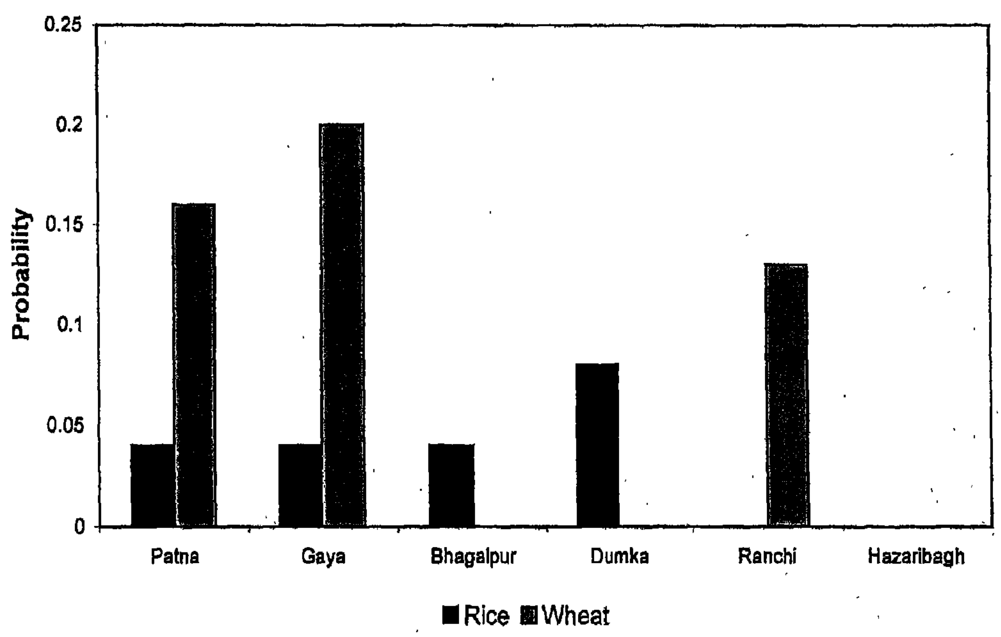


Fig.6a Probability of occurrence of moderate drought

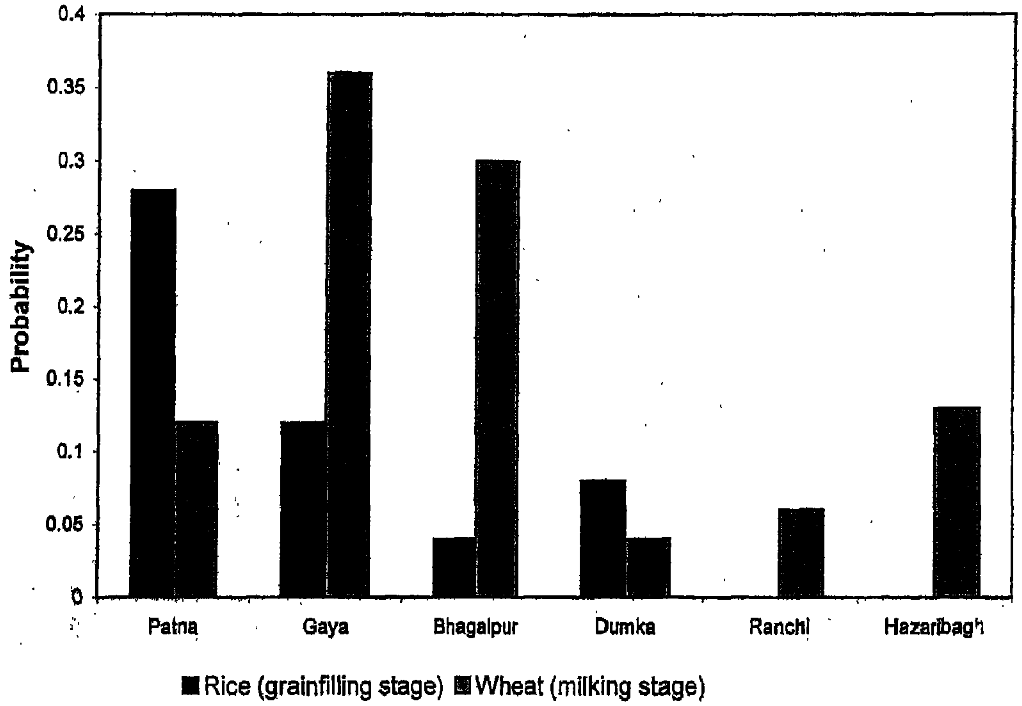


Fig. 6b Probability of occurrence of severe drought

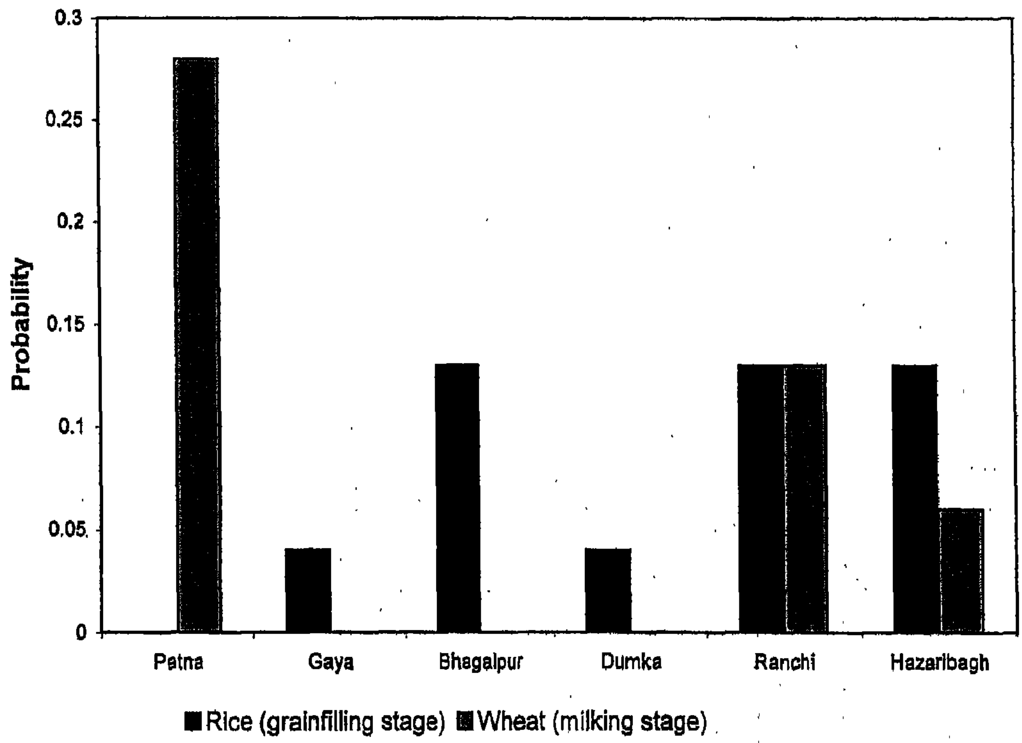


Table 11: WRSI at the end of the season for rice and wheat crops

PATNA				GAYA			
RICE		WHEAT		RICE		WHEAT	
YEAR	WRSI	YEAR	WRSI	YEAR	WRSI	YEAR	WRSI
1969	82	1969-70	81	1969	82	1969-70	100
1970	84	1970-71	85	1970	60	1970-71	93
1971	94	1971-72	91	1971	90	1971-72	91
1972	63	1972-73	81	1972	79	1972-73	100
1973	74	1973-74	78	1973	76	1973-74	50
1974	94	1974-75	72	1974	78	1974-75	70
1975	82	1975-76	59	1975	77	1975-76	55
1976	80	1976-77	54	1976	74	1976-77	65
1977	94	1977-78	97	1977	90	1977-78	100
1978	97	1978-79	100	1978	100	1978-79	100
1979	71	1979-80	91	1979	76	1979-80	100
1980	89	1980-81	100	1980	88	1980-81	100
1981	90	1981-82	71	1981	76	1981-82	100
1982	46	1982-83	62	1982	59	1982-83	61
1983	59	1983-84	100	1983	88	1983-84	100
1984	98	1984-85	58	1984	94	1984-85	56
1985	91	1985-86	65	1985	80	1985-86	60
1986	87	1986-87	100	1986	68	1986-87	52
1987	89	1987-88	100	1987	84	1987-88	78
1988	97	1988-89	51	1988	78	1988-89	54
1989	89	1989-90	86	1989	67	1989-90	79
1990	93	1990-91	74	1990	96	1990-91	90
1991	69	1991-92	66	1991	92	1991-92	91
1992	87	1992-93	70	1992	90	1992-93	100
1993	76			1993	67		

BHAGALPUR				DUMKA			
RICE		WHEAT		RICE		WHEAT	
YEAR	WRSI	YEAR	WRSI	YEAR	WRSI	YEAR	WRSI
1969	89	1969-70	63	1969	88	1969-70	52
1970	70	1970-71	80	1970	92	1970-71	61
1971	92	1971-72	77	1971	87	1971-72	48
1972	57	1972-73	76	1972	73	1972-73	38
1973	81	1973-74	51	1973	97	1973-74	32
1974	89	1974-75	73	1974	78	1974-75	38
1975	80	1975-76	55	1975	83	1975-76	32
1976	62	1976-77	44	1976	85	1976-77	44
1977	71	1977-78	79	1977	91	1977-78	87
1978	69	1978-79	85	1978	96	1978-79	77

1979	69	1979-80	60	1979	79	1979-80	69
1980	75	1980-81	96	1980	91	1980-81	66
1981	72	1981-82	87	1981	85	1981-82	80
1982	86	1982-83	50	1982	64	1982-83	29
1983	59	1983-84	69	1983	93	1983-84	52
1984	80	1984-85	48	1984	95	1984-85	38
1985	79	1985-86	66	1985	63	1985-86	25
1986	68	1986-87	53	1986	57	1986-87	31
1987	93	1987-88	49	1987	70	1987-88	53
1988	85	1988-89	65	1988	97	1988-89	43
1989	82	1989-90	69	1989	85	1989-90	59
1990	63	1990-91	69	1990	93	1990-91	30
1991	90			1991	97		

RANCHI				HAZARIBAGH			
	RICE		WHEAT		RICE		WHEAT
YEAR	WRSI	YEAR	WRSI	YEAR	WRSI	YEAR	WRSI
1969	93	1969-70	87	1969	84	1969-70	72
1970	96	1970-71	83	1970	80	1970-71	88
1971	98	1971-72	66	1971	61	1971-72	72
1972	81	1972-73	89	1972	79	1972-73	67
1973	86	1973-74	63	1973	99	1973-74	100
1976	89	1976-77	78	1974	99	1974-75	60
1977	98	1977-78	100	1976	86	1976-77	58
1978	94	1978-79	100	1977	94	1977-78	100
1979	94	1979-80	100	1978	94	1978-79	85
1980	91	1980-81	99	1979	99	1979-80	90
1981	97	1981-82	84	1981	93	1981-82	66
1982	99	1982-83	59	1982	79	1982-83	39
1983	93	1983-84	77	1983	97	1983-84	100
1984	94	1984-85	64	1984	96	1984-85	42
1985	90			1985	87		

4.5 Water Requirement Satisfaction Index (WRSI)

Water requirement satisfaction index (WRSI) at the end of the season in respect of a crop is an indicator of the effect of the moisture deficit on yield (Frere and Popov 1979). This index computed for both rice and wheat season for the data period is shown in Table 11.

At Patna, the lowest value of the index for rice crop is 46 and for wheat crop 51. At Gaya it is 59 for rice and 50 for wheat. For Ranchi where the rainfall is higher the lowest value of index for rice is 81 and for wheat 59.

It may be mentioned that the highest value does not exceed 100 at any time according to the method proposed by Frere and Popov (1979). This corresponds to the average of three best yields at any location for any crop. Any decreases below this value, indicates incidence of drought conditions and further decreases leads to severe or disastrous drought. Frere and Popov (1986) suggested that an index value between 50 and 59 would result in poor yield (10-20% of best yield) of cereal crops and a value below 50 would result in complete failure of the crop. The lowest WRSI value at the different stations mentioned above correspond to the severe or disastrous years at the station. In the present investigation at relatively low rainfall station like Patna during disastrous year the WRSI value was below 50. The threshold value as suggested by Frere and Popov. However, in Ranchi and Hazaribagh where the seasonal rainfall is more, the WRSI in moderate and severe drought years attained a value between 55 and 85 for the both crops.

Thus, for each location for specific crops the threshold value of WRSI would be different in relation to the severity of drought occurrence. As seen in the above case, at the end of cropping season, the WRSI value exhibits a large difference in magnitude for the same drought class. Purpose of WRSI vs. yield fluctuation could not be solved because data is insufficient to derive it.

4.6 Crop Yield and Drought Index

The area and production of the crop in the different stations under study were collected from the Bihar through figure, Department of Statistics & Evaluation for the period from 1969-70 to 1992-93, the average yield and the mean and coefficient of variation were calculated for rice and wheat crops for all the stations under study. The mean productivity (Kg/ha) and coefficient of variation (%) are presented in Table 12.

Table12: - Mean productivity (kg/ha) of rice and wheat crops in six stations of Bihar.

Stations	Rice	Wheat
PATNA	1318(27)	1727(25)
GAYA	993(31)	1220(25)
BHAGALPUR	1124(23)	1232(30)
DUMKA	1016(18)	1333(27)
HAZARIBAGH	708(31)	796(55)
RANCHI	688(27)	969(40)

Figures in bracket indicate cv. percentage.

The result indicates that in general, the productivity ranges between 688 to 1318 Kg/ha for rice and 1727 to796 Kg/ha for wheat crops at the different stations. In order to assess the relative adaptability of the crops at the different stations they have been ranked according to productivity and its variability. The rankings are shown in Table 13.

Table 13: Rankings of stations according to productivity and variability

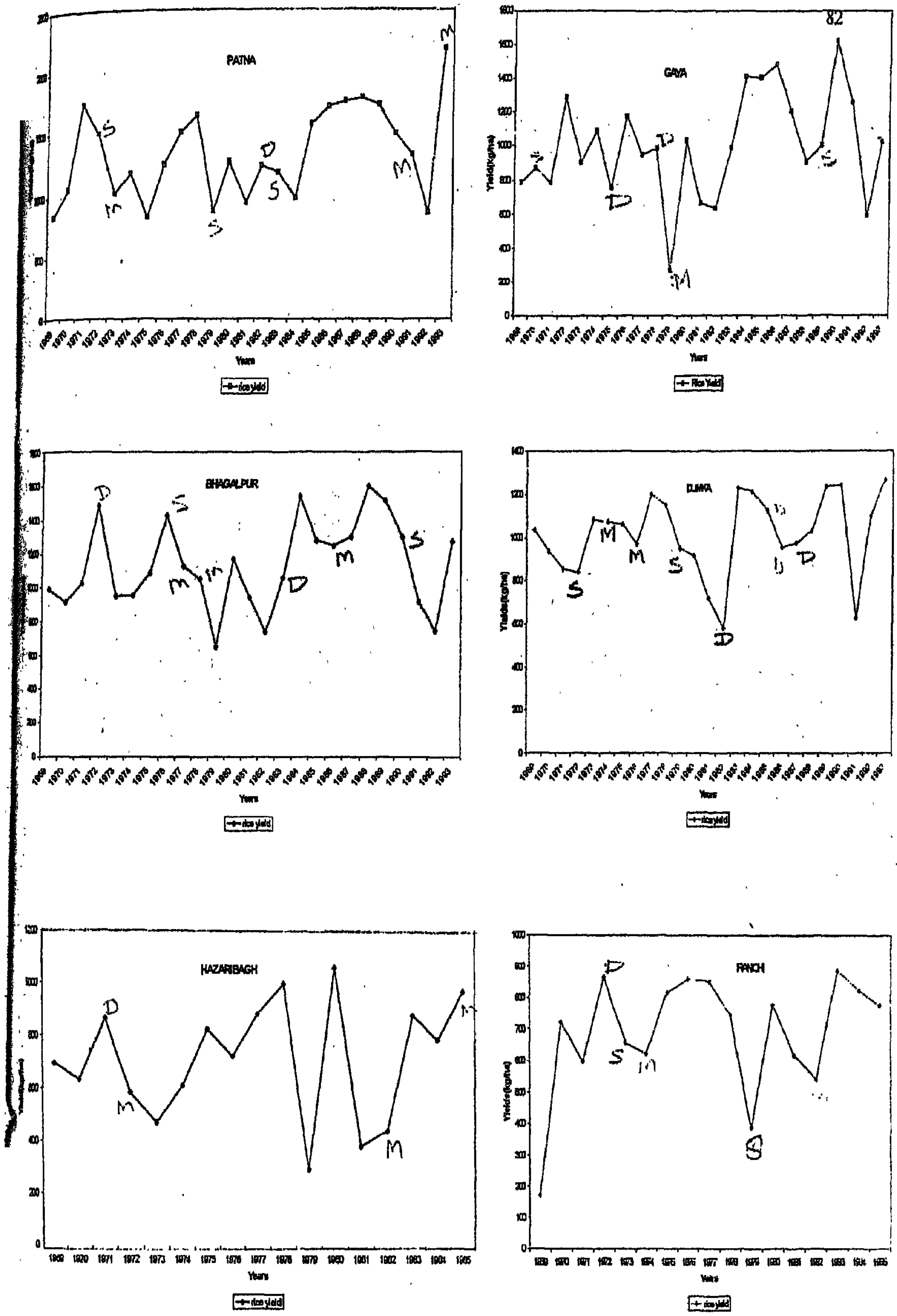
CROPS	PRODUCTIVITY (Highest → Lowest)
Rice	Patna,Bhagalpur,Dumka,Gaya,Hazaribagh,Ranchi
Wheat	Patna,Dumka,Bhagalpur,Gaya,Ranchi,Hazaribagh

CROPS	VARIABILITY (Lowest → Highest)
Rice	Dumka,Bhagalpur,Ranchi,Patna,Hazaribagh,Gaya
Wheat	Patna,Gaya,Dumka,Bhagalpur,Ranchi,Hazaribagh

From the results it is seen that Patna has the highest mean productivity for both rice (1318 kg/ha) and wheat (1727 kg/ha) crops. The lowest mean productivity for rice is observed at Ranchi (688 kg/ha) and for wheat it is lowest at Hazaribagh (796 kg/ha), although, the rainfall is high for these two stations. Among the six stations, the coefficient of variation in rice productivity was lower (18-31%) as compared to that of wheat (25-55%). Variability in wheat productivity is the highest for station Hazaribagh and lowest for Patna. Variability in crop productivity for rice is highest at Gaya while Dumka has lowest variability.

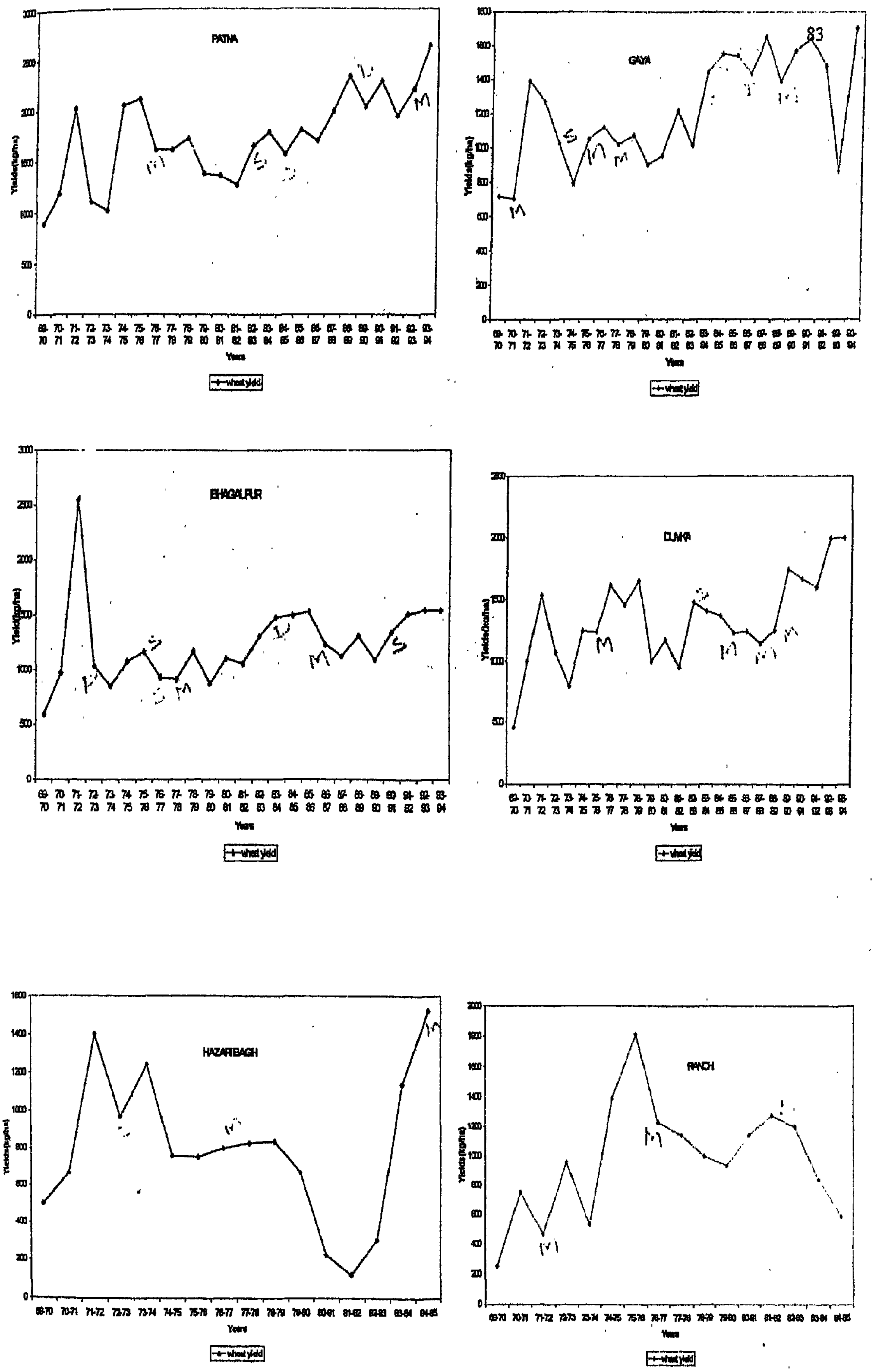
For examining the fluctuations of rainfall and CWDI on crop yields, an analysis of the rice and wheat yields from 1969 to 1993 is done. The intensity of agricultural drought is categorised as Moderate (M), Severe (S) and Disastrous (D).

It is interesting to note from the fig. 7a and 7b that for all the six stations, drought intensity and yield is not corresponding to each other. Some times the decrease in yield due to drought is reflected in yield reduction but the decrease in yield is not uniform in all the years. In general, there is an increasing trend in yield of rice and wheat crops and no direct relationship between drought intensity and yields could be established because crop yields are not solely determined by weather. Other factors like soil type of a particular station, variety of crop, agronomic practices followed in that region, incidence of diseases and pests, also affect the yields of crops. Similar drought situation did not follow similar reduction in yields at these stations. This is due to the fact that there is a general increase in the yields over the years which is mainly due to technological changes like increase in fertiliser application / pesticides / improved seeds etc. For example, station Ranchi receives highest amount of rainfall among the stations under study but due to sandy loam soil type and topographical features, productivity of rice and wheat is very less. Hence an integrated approach for yield prediction is necessary. One should also take into account the soil type, time of sowing and harvesting, agronomic practices, fertiliser application and other technological changes, in addition to meteorological/water balance parameters.



D-Disastrous, S-Severe, M-Moderate

Fig. 7a : Rice Yields since 1969 at different stations and drought occurrence



D-Disastrous, S-Severe, M-Moderate

Fig. 7b : Wheat Yields since 1969 at different stations and drought occurrence

4.7 Occurrence of dry and wet spells

Farmer's cropping strategies are undoubtedly influenced by the variability experienced in the onset and end of rainy season. Generally they plant or dry seed their crop when a certain amount of rainfall has sufficiently moistened the topsoil. Further, in rainfed agriculture many agricultural operations revolve around the probability of receiving given amounts of rainfall. Hence, a comprehensive idea regarding the probability of rainfall received is essential in view of the economic implications of certain weather-sensitive operations.

The first rainfall that is sufficient for specific agricultural operations determines the beginning of a cropping season. The amount of early rain needed to permit land preparation practices such as ploughing would depend on the moisture retention characteristics of the soil and the depth of the soil that must be moistened. Hence, the length of the growing season for rainfed crops in any region will be determined by the time between the first useful rainfall and the end of the useful rainfall, although droughts can occur during the middle of this period. However, the probability of late rainfall is important because later rains can severely damage mature crops that have not been harvested.

It is observed that there is a random nature of occurrence of dry and wet spells. The initial and conditional probability of getting wet and dry week at each stations in Bihar with a minimum amount of 50 mm and 10 mm for rice and wheat crop respectively are shown in Table 14 and Table 15.

In regions where rainfall is highly erratic and short, dry period can be expected within the wet season. It is important to know to what extent, the probability is representing a consecutive dry period of two or three weeks. If such period coincides with a sensitive phonological stage, this can affect the crop development but dry periods at the ripening stage of the rice crop are some time beneficial.

It can be very well observed from Table 14 that during rice growing season the probability occurrence of dry week is higher in the first four weeks of Patna (72-92%) and in the first three weeks at Gaya (76-88%) and Bhagalpur (74-78%). The conditional probability of dry week preceded by a dry week and probability occurrence of two or three consecutive dry weeks is also high for these three stations.

The probability occurrence of a dry week is moderate to high in the first four weeks at Dumka (52-70%) and in first three weeks at Ranchi (53-73%) and Hazaribagh (47-67%). The conditional probability of dry week preceded by a dry week is high but the probability occurrence of two or three consecutive dry weeks is moderate to high. But it rapidly falls in subsequent weeks.

In any period the larger the values of conditional probability P(W/W) and P(D/D) the greater will be the probability of a long continuous wet and dry spells. These probabilities also have been shown in fig. 8a to 8c. As expected, the largest spells of wet days should occur either in July or in early August, because during this period the monsoon activity is at its peek. This is also clear from the figure that the probability occurrence of wet week is higher at Ranchi, Hazaribagh and Dumka as compared to Patna, Gaya and Bhagalpur. Monsoon withdraws from Bihar around second week of October consequently, it is also noticed that probability occurrence of dry spell followed by dry spell become considerably high after 41st standard week at almost every station.

In some years, only a few weeks are having the wet period causing persistent drought condition in this region. The failure of the monsoon showers during the different months results in the adverse condition and therefore the need arises to go for suitable crops by changing the cropping pattern or to go for suitable selection. Persistent dry weeks during the rainy season may cause moisture stress at critical crop growth periods and have deleterious effects on the yields. Stress during the flowering and reproductive stage of rice crop is visually most critical causing a reduction in grain formation.

As the pattern of dry weeks and wet weeks show a considerable variation from year to year. It became necessary that the cropping strategies and crop planning should be based upon these probabilities. It can also be very well observed that rainfall distribution is highly erratic and unpredictable in these stations. As the P (D/D) became considerably high at different location from 41st standard week therefore it becomes necessary that the reproductive stage of rice crop must be avoided from water stress during this period. This stage is very crucial to water stress and stress at this stage will have harmful effect on the crop yield.

As one wet week during the crop growth is beneficial, similarly two consecutive weeks are also beneficial for the crop of one specific phenophase but in the same way, intense rains may also cause adverse effect on crop yield at another phenophase. It can be very well observed that Ranchi, Hazaribag and Dumka stations earlier sowing of the rice crop by broadcasting seeds around the 23rd to 24th standard week are favourable. The peak growth vegetative stage and reproductive stage can be completed around 38th to 39th standard weeks. It can be very well seen that all these stations can support the cultivation of a rice variety, which is having the duration of 16 to 17 weeks. While in the Patna, Gaya and Bhagalpur, the results lead to the conclusion that these stations can not support the cultivation of varieties whose duration is more than 15 to 16 weeks. Therefore short duration variety are suitable for rice cultivation in these stations. The entire agriculture being based upon rainfall cultivation, it is further recommended for these stations to reduce the risk factor by cultivation of those varieties, which are not having the duration greater than 13 or 14 weeks. However, there are locational differences as well and crop planning can be done station wise according to farming situation.

For wheat probability of occurrence of dry week as well as conditional probability of dry week preceded by dry week is very high (67- 100%) for each stations during entire growing period of wheat. Similarly, two or three consecutive dry weeks is also very high for the stations selected under study.

Table 14: Markov Chain probability % of dry, wet weeks for rice growing season

WEEK	P(D)	P(D/D)	2D	3D	P(W)	P(W/W)	2W	3W	P(D)	P(D/D)	2D	3D	P(W)	P(W/W)	2W	3W
	BHAGALPUR								DUMKA							
23	78	80	57	43	22	33	4	1	70	76	43	26	30	100	9	5
24	74	72	57	20	26	20	9	1	65	63	39	33	35	29	22	12
25	74	76	26	12	26	33	4	3	52	60	43	14	48	63	26	16
26	48	35	22	11	52	17	30	19	65	83	22	14	35	55	22	16
27	43	45	22	11	57	58	35	27	35	33	22	10	65	63	48	27
28	43	50	22	5	57	62	43	17	39	63	17	5	61	73	35	21
29	35	50	9	6	65	77	26	17	43	44	13	8	57	57	35	21
30	48	25	35	20	52	40	35	6	35	30	22	12	65	62	39	20
31	52	73	30	25	48	67	9	4	48	63	26	9	52	60	26	19
32	70	58	57	20	30	18	13	7	52	55	17	5	48	50	35	15
33	74	81	26	20	26	43	13	3	30	33	9	4	70	73	30	15
34	39	35	30	15	61	50	13	0	48	29	22	12	52	44	26	13
35	78	78	39	14	22	21	0	0	48	45	26	4	52	50	26	9
36	61	50	22	22	39	0	26	10	52	55	9	3	48	50	17	5
37	35	36	35	27	65	67	26	17	39	17	13	6	61	36	17	10
38	74	100	57	38	26	40	17	2	57	33	26	21	43	29	26	14
39	65	76	43	38	35	67	4	1	43	46	35	30	57	60	30	10
40	74	67	65	65	26	13	9	2	61	80	52	49	39	54	13	0
41	83	88	83	79	17	33	4	0	78	86	74	74	22	33	0	0
42	96	100	91	91	4	25	0	0	96	94	96	96	4	0	0	0
43	96	95	96	96	4	0	0	0	100	100	100	91	0	0	0	0
44	100	100	100	100	0	0	0	0	100	100	91	91	0	0	0	0
	GAYA								HAZARIBAGH							
23	88	88	68	61	12	0	4	2	47	50	33	22	53	100	27	9
24	76	77	68	44	24	33	12	10	60	71	40	16	40	50	13	13
25	80	89	52	26	20	50	16	12	67	67	27	20	33	33	33	24
26	56	65	28	11	44	80	32	17	27	40	20	7	73	100	53	30
27	40	50	16	9	60	73	32	23	40	75	13	4	60	73	33	19
28	44	40	24	7	56	53	40	27	40	33	13	4	60	56	33	19
29	40	55	12	8	60	71	40	26	40	33	13	7	60	56	33	30
30	32	30	20	13	68	67	44	35	40	33	20	5	60	56	53	34
31	44	63	28	17	56	65	44	23	27	50	7	3	73	89	47	28
32	40	64	24	9	60	79	32	11	33	25	13	7	67	64	40	22
33	52	60	20	12	48	53	16	8	40	40	20	14	60	60	33	21
34	52	38	32	21	48	33	24	13	47	50	33	25	53	56	33	24
35	56	62	36	18	44	50	24	17	53	71	40	20	47	63	33	24
36	56	64	28	25	44	55	32	9	53	75	27	18	47	71	33	4
37	40	50	36	20	60	73	16	3	40	50	27	16	60	71	7	2
38	80	90	44	38	20	27	4	2	80	67	47	47	20	11	7	2
39	60	65	52	49	40	20	16	0	60	58	60	55	40	33	13	0
40	76	87	72	69	24	40	0	0	87	100	80	80	13	33	0	0
41	96	95	92	84	4	0	0	0	93	92	93	93	7	0	0	0
42	96	96	88	80	4	0	0	0	100	100	100	100	0	0	0	0
43	92	92	84	84	8	0	0	0	100	100	100	93	0	0	0	0
44	92	91	92	92	8	0	0	0	100	100	93	93	0	0	0	0
	PATNA								RANCHI							
23	92	96	72	61	8	100	0	0	67	69	47	25	33	50	7	3
24	80	78	68	46	20	0	0	0	73	70	40	5	27	20	13	8
25	88	85	60	26	12	0	0	0	53	55	7	2	47	50	27	12
26	72	68	32	17	28	0	16	10	27	13	7	3	73	57	33	29
27	44	44	24	13	56	57	36	28	47	25	20	0	53	45	47	34
28	44	55	21	10	56	64	44	30	27	43	0	0	73	88	53	36
29	36	55	16	3	64	79	44	22	20	0	0	0	80	73	53	48
30	36	44	8	4	64	69	32	13	27	0	7	3	73	67	67	51
31	40	22	20	20	60	50	24	15	13	25	7	2	87	91	67	42
32	56	50	56	18	44	40	28	12	27	50	7	4	73	77	47	28
33	72	100	24	12	28	84	12	4	33	25	20	6	67	64	40	35
34	40	33	20	9	60	43	20	12	47	60	13	4	53	60	47	39
35	60	50	28	7	40	33	24	9	20	29	7	2	80	88	67	33
36	44	47	12	9	56	60	20	8	20	33	7	5	80	83	40	10
37	48	27	36	29	52	36	20	8	47	33	33	18	53	50	13	7
38	68	75	56	38	32	38	12	0	73	71	40	40	27	25	13	4
39	76	82	62	46	24	38	0	0	53	56	53	49	47	50	13	0
40	76	68	68	58	24	0	4	0	87	100	80	69	13	29	0	0
41	88	89	76	76	12	17	0	0	93	92	80	74	7	0	0	0
42	88	86	88	84	12	0	0	0	87	86	80	74	13	0	0	0
43	100	100	96	92	0	0	0	0	93	92	87	87	7	0	0	0
44	96	96	92	92	4	0	0	0	93	93	93	93	7	0	0	0

Table 15. Markov chain probability % of dry, wet weeks for wheat growing season

BHAGALPUR

Week	P(D)	P(D/D)	P(2D)	P(3D)	P(W)	P(W/W)	P(2W)	P(3W)
46	96	95	96	91	4	0	0	0
47	100	100	96	96	0	0	0	0
48	96	96	96	91	4	0	0	0
49	100	100	96	91	0	0	0	0
50	96	96	91	83	4	0	0	0
51	96	95	87	0	4	0	0	0
52	91	91	0	0	9	0	0	0
1	100	100	87	83	0	0	0	0
2	87	87	83	75	13	0	0	0
3	96	95	87	70	4	0	0	0
4	91	91	74	70	9	0	0	0
5	83	81	78	67	17	0	4	0
6	91	95	78	70	9	25	0	0
7	87	86	78	63	13	0	4	0
8	87	90	70	66	13	33	0	0
9	83	80	78	78	17	0	4	0
10	91	95	91	83	9	25	0	0

DUMKA

Week	P(D)	P(D/D)	P(2D)	P(3D)	P(W)	P(W/W)	P(2W)	P(3W)
46	100	100	100	91	0	0	0	0
47	100	100	91	91	0	0	0	0
48	91	91	91	87	9	0	0	0
49	100	100	96	91	0	0	0	0
50	96	96	91	79	4	0	0	0
51	96	95	83	0	4	0	4	0
52	83	86	0	0	17	100	0	0
1	95	95	95	87	5	0	0	0
2	100	100	91	83	0	0	0	0
3	91	91	83	71	9	0	0	0
4	91	90	78	74	9	0	4	3
5	83	86	78	74	17	50	13	0
6	83	95	78	71	17	75	0	0
7	96	95	87	79	4	0	0	0
8	91	91	83	78	9	0	4	1
9	87	90	83	75	13	50	4	0
10	91	95	83	75	9	33	0	0

GAYA

Week	P(D)	P(D/D)	P(2D)	P(3D)	P(W)	P(W/W)	P(2W)	P(3W)
46	100	100	100	92	0	0	0	0
47	100	100	92	92	0	0	0	0
48	92	92	92	92	8	0	0	0
49	100	100	100	100	0	0	0	0
50	100	100	100	88	0	0	0	0
51	100	100	88	0	0	0	0	0
52	88	88	0	0	12	0	0	0
1	92	90	88	76	8	0	0	0
2	92	96	80	55	8	50	4	0
3	88	87	60	53	12	0	0	0
4	72	68	64	64	28	0	0	0
5	80	89	80	73	20	43	12	5
6	92	100	84	69	8	40	8	4
7	88	91	72	62	12	50	4	0
8	84	82	72	69	16	0	0	0
9	84	86	80	73	16	25	4	1
10	92	95	84	80	8	25	4	0

RANCHI

Week	P(D)	P(D/D)	P(2D)	P(3D)	P(W)	P(W/W)	P(2W)	P(3W)
46	93	93	87	68	7	0	0	0
47	93	93	73	73	7	0	0	0
48	80	79	80	75	20	0	0	0
49	100	100	93	93	0	0	0	0
50	93	93	93	81	7	0	0	0
51	100	100	87	0	0	0	0	0
52	87	87	0	0	13	0	0	0
1	79	83	65	50	21	50	0	0
2	87	83	67	50	13	0	0	0
3	80	77	60	38	20	0	7	2
4	73	75	47	33	27	33	7	3
5	67	64	47	33	33	25	13	0
6	67	70	47	43	33	40	0	0
7	80	70	73	52	20	0	0	0
8	93	92	67	61	7	0	0	0
9	73	71	67	62	27	0	7	3
10	87	91	80	80	13	25	7	3

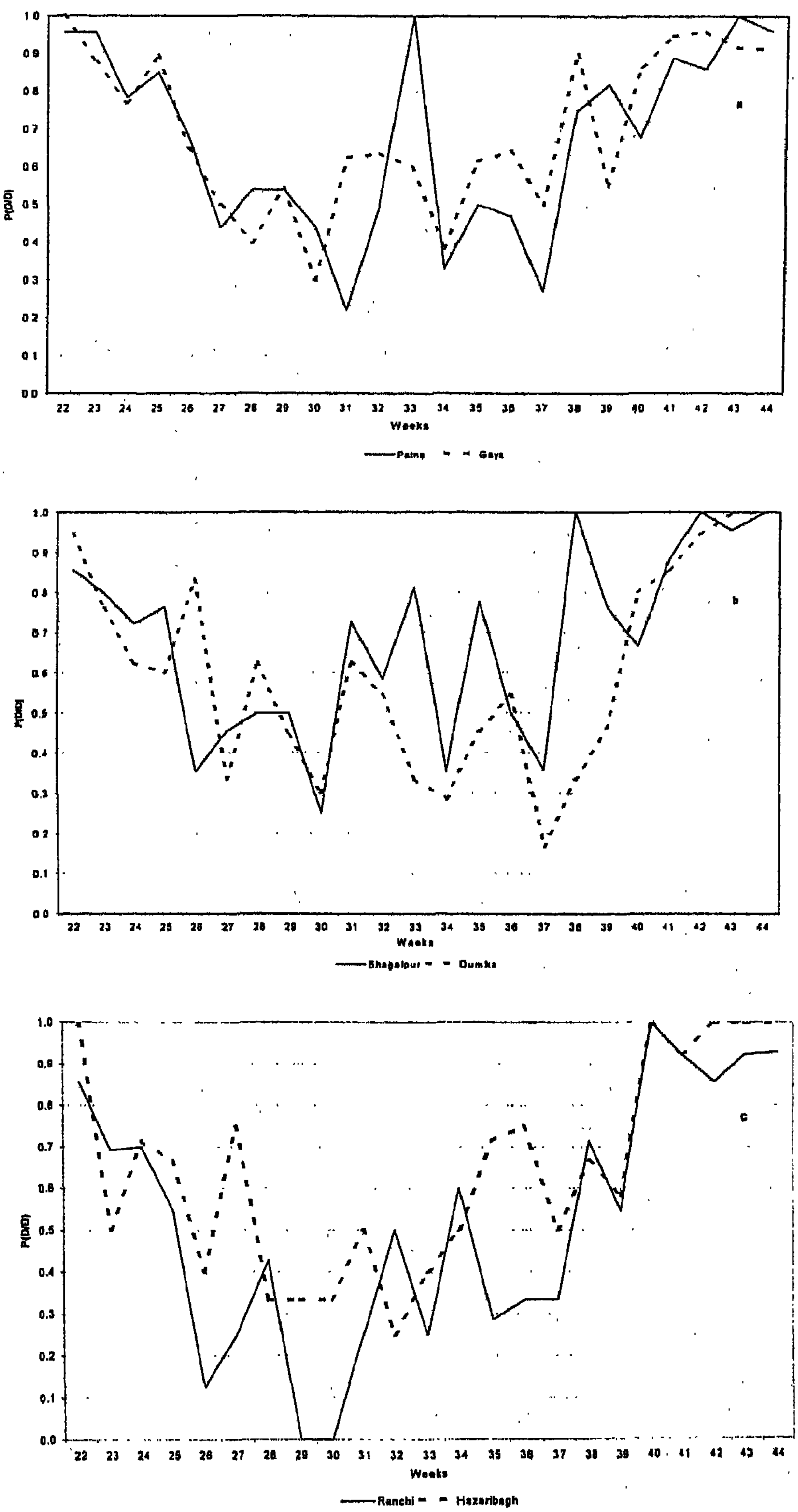
PATNA

Week	P(D)	P(D/D)	P(2D)	P(3D)	P(W)	P(W/W)	P(2W)	P(3W)
46	96	96	96	88	4	0	0	0
47	100	100	92	92	0	0	0	0
48	92	92	92	88	8	0	0	0
49	100	100	96	96	0	0	0	0
50	96	96	96	92	4	0	4	0
51	96	100	92	0	4	100	0	0
52	96	96	0	0	4	0	0	0
1	92	91	92	73	8	0	0	0
2	100	100	80	68	0	0	0	0
3	80	80	68	58	20	0	4	1
4	84	85	72	72	16	20	4	2
5	84	86	84	69	16	25	8	4
6	92	100	76	68	8	50	4	1
7	80	83	72	62	20	50	4	0
8	88	90	76	69	12	20	0	0
9	88	86	80	73	12	0	4	1
10	88	91	80	69	12	33	4	1

HAZARIBAGH

Week	P(D)	P(D/D)	P(2D)	P(3D)	P(W)	P(W/W)	P(2W)	P(3W)
46	93	100	80	74	7	50	0	0
47	87	86	80	80	13	0	0	0
48	93	92	93	93	7	0	0	0
49	100	100	100	100	0	0	0	0
50	100	100	100	87	0	0	0	0
51	100	100	87	0	0	0	0	0
52	87	87	0	0	13	0	0	0
1	100	100	100	87	0	0	0	0
2	100	100	87	73	0	0	0	0
3	87	87	73	56	13	0	0	0
4	87	85	67	56	13	0	0	0
5	80	77	67	51	20	0	0	0
6	87	83	67	61	13	0	0	0
7	80	77	73	62	20	0	7	0
8	87	92	73	66	13	33	0	0
9	87	85	80	80	13	0	13	0
10	80	92	80	75	20	100	0	0

Fig.8 Conditional probabilities of dry spells followed by dry spells



4.8 Moisture availability index (MAI)

The choice of crop and suitable varieties for a given cropping season will depend on the combined variation in precipitation and potential evapotranspiration. The safe cropping season could be worked out on the moisture availability index. The MAI = AE / PE is a valuable index of climatic water balance at a particular station. With the help of probability distribution of MAI for different weeks one can assess the length of the growing period (LGP) and also the suitability of crops of different duration at a given place. It also gives the idea about probabilities of moisture availability to meet crop water demands, at the stations under study. The length of growing period as well as the probability of MAI at 50% threshold value were determined and presented here for different probability level (10-90%) in respect of rice and wheat crops.

(a) Length of growing period: -

At 50% probability level length of growing period (MAI $\geq$ 0.5) ranges from 19 to 21 weeks for Patna, Gaya and Bhagalpur. A crop of 19 to 21 weeks' duration may be raised from this region in rainfed condition once in two years. At the same probability level, length of growing period ranges from 22 to 26 weeks for Ranchi, Hazaribagh and Dumka in which station Ranchi shows a larger length of growing period of 26 weeks (Table 16).

At 75% and 90% probability level Patna, Gaya and Bhagalpur have the potential to grow a medium and short duration crop i.e. 16-17 weeks and 10-12 weeks respectively. At Ranchi, Hazaribagh and Dumka the length of growing period ranges from 18-23 weeks and 13-18 weeks at 75% and 90% probability levels respectively. A short duration crop may, therefore, be raised at Patna, Gaya and Bhagalpur in 9 out of 10 years.

(b) Probability of moisture availability to meet crop water demand of rice and wheat: -

Normal sowing week for rice crop i.e. 24th standard week at Patna and Gaya and 23rd standard week at Bhagalpur, Dumka, Ranchi and Hazaribagh and 46th standard week for wheat crop at all the stations were taken into consideration while working out for probability of moisture availability to meet crop water demands of rice and wheat. The results are presented in the Table 17 and Table 18.

It is clear from the Table 17 that at Dumka, Ranchi and Hazaribagh the probability of moisture availability at each stage is very high as compared to Patna, Gaya and Bhagalpur. In general, the probability of moisture availability to meet crop water demand is comparatively lower at seedling stage of rice at each station.

However, the lower limits of probability at seedling stage at the stations Patna, Gaya and Bhagalpur is much less (20-22%) as compared to those of other stations (39-53%). Here it can be said that even mild and moderate drought have detrimental effects on crop at seedling stage at these stations.

For wheat crop, probability of water availability is also very low at Patna, Gaya and Bhagalpur ie 60-80% at crown root initiation stage while it is high at Ranchi, Hazaribagh and Dumka i.e. 87-100%. Probability of moisture availability to meet crop water demand of wheat is highest for Ranchi and Hazaribagh at each stage. Considering the all-critical stages of wheat probability of moisture availability is lowest at flowering stage for each stations.

In general, chances of failure of rice crop due to drought are more at seedling stage while for wheat it is at flowering stage.

Table 16

Length of the growing periods in weeks (MAI ≥0.5) at different probability levels: -

Probability (%)	Patna	Gaya	Bhagalpur	Dumka	Ranchi	Hazaribagh
10	44	42	36	32	47	45
25	26	28	27	27	42	42
50	19	21	19	22	24	26
75	17	16	16	18	21	23
90	12	10	12	13	18	14

Table-17: Probability of moisture availability to meet crop water demand of rice crop at different stations of Bihar state: -

Growth Stage	Period (weeks)	MAI	Probability(%) Patna	Gaya	Bhagalpur
1. Seedling	4	0.75	20-72	20-72	22-56
2.Vegetative	7	1.0	28-60	48-64	26-60
3.Reproductive	4	1.0	40-56	24-60	22-61
4.Maturity	2	0.5	88-96	86-96	95-100
			Dumka	Ranchi	Hazaribagh
1.Seedling	4	0.75	39-61	47-87	53-80
2.Vegetative	7	1.0	52-70	60-93	60-80
3.Reproductive	4	1.0	52-61	80-93	67-73
4.Maturity	2	0.5	95	100	93

Table-18: Probability of moisture availability to meet crop water demand of wheat crop at different stations of Bihar state: -

Growth Stage	Period (weeks)	MAI	Probability(%)		
			Patna	Gaya	Bhagalpur
1. CRI	3	0.3	82-92	72-76	60-64
2. Tillering stage	4	0.5	44-68	52-56	30-52
3. Jointing stage	4	0.5	48-64	56-64	30-52
4. Flowering	3	0.7	28-36	24-40	13-26
5. Maturity	3	0.3	64-72	60-72	30-52
			Dumka	Ranchi	Hazaribagh
1. CRI	3	0.3	87-95	100	93
2. Tillering stage	4	0.5	21-34	60-73	46-73
3. Jointing stage	4	0.5	17-34	60-86	40-73
4. Flowering	3	0.7	4-21	33-53	33-46
5. Maturity	3	0.3	26-39	86-100	66-80

SUMMARY

SUMMARY

The present investigation was undertaken at the Indian Agricultural Research Institute to study the agroclimatic characteristics of Bihar state in relation to rice and wheat crops covering two agroclimatic zones of Bihar State. Six stations were selected for the study namely Patna, Gaya, Bhagalpur, Dumka, Ranchi, and Hazaribagh. As rice and wheat are the main crops grown in the region, these were taken up for analysis in this investigation.

Weekly rainfall data were analysed and seasonal rainfall for the crop growth period (average for the data period) was worked out for rice and wheat crops separately at each of the six stations. Normal sowing week was taken into consideration for computing seasonal rainfall for the cropping period. Variability of the rainfall was also calculated.

Results showed that the station Dumka recorded higher variability of rainfall of 32 percent in rice growing season. At Ranchi, which has the highest rice seasonal rainfall, c.v was the lowest with 16 percent. Seasonal rainfall was more reliable at Ranchi, Hazaribagh and reliability was very low at Patna, Bhagalpur, Dumka and Gaya.

Weekly rainfall probabilities were computed by fitting gamma distribution following Thom (1966) using weekly data for several years in respect of the six stations. The weekly-assured rainfall values at different probability level (10%, 25%, 50%, 75%, and 90%) using the gamma distribution were presented and discussed. In general, the high rainfall belt was noticed in the southern part of the Bihar i.e. Ranchi, Hazaribagh and Dumka. Early sowing

operation could be done at these stations. Magnitude of assured rainfall at every probability level was very high for these stations. k*harif* crop prospects in this area are very good and suitable for rainfed crop cultivation also. Short duration crops are suitable for station Patna and Gaya. Rice can be grown with supplementary irrigation.

In rabi season, expected assured rainfall was meagre to sustain the wheat crop thereby preventing the farmers to go for *rabi* crops, under rainfed conditions. The farmer must have irrigation facilities for taking wheat crop.

Climatic water balance following Thornthwaite and Mather (1957) method was computed for rice and wheat crop growing season on weekly basis for estimating the water availability pattern at each station. Periods of water deficit, soil moisture use at the six stations were identified and climograms were presented. In general, the stations Ranchi, Hazaribagh and Dumka showed large surplus till the end of the rice growing season. The stations Patna, Gaya and Bhagalpur showed mild seasonal moisture deficit with no water surplus in any week during the rice growing season with respect to rainfed crops. Gaya is relatively dry with larger deficit in post anthesis period. Without supplementary irrigation, wheat crop can not be grown in all the six stations.

Yearly aridity index for the selected stations was evaluated from climatic water balance. Frequency of occurrence of drought on annual basis was found to be more for Patna, Gaya, Bhagalpur and Dumka (48%) as compared to Ranchi and Hazaribagh (41%). This indicates that there is 5 years of drought out of 10 years.

Weekly aridity index for the rice and wheat crop duration was evaluated from the result of climatic water balance. A significant feature of the present study was that while deriving seasonal aridity index, emphasis was given to the crop growth duration and the individual growth phases. This index was named as "Crop Water Deficit Index" (CWDI) since it reflects climatic water balance with reference to crop growth.

The seasonal CWDI for rice growing season at Patna ranged from 124 to 157 and for wheat, from 609 to 1351. Values of similar magnitude were obtained at other stations.

Based on seasonal crop water-deficit index, rice and wheat growing duration for the data period was categorised in to different drought classes for each crop separately. For this categorisation, standard deviation from the median of CWDI or its multiple was used as the criteria. Results showed that at Patna, Gaya, Dumka and Bhagalpur, chances of failure of rice and wheat crops were higher than those for Ranchi and Hazaribagh.

Probabilities of occurrence of (1) moderate seasonal drought, (2) severe seasonal drought, (3) moderate and severe drought at flowering stage and (4) moderate and severe drought at grainfilling and milking stage of rice and wheat crops were worked out for the six stations and depicted in the form of bar diagrams. Results showed that:

(a) Among the six stations considered, the probability of occurrence of moderate drought was the lowest at Patna and highest at Hazaribagh for rice growing season while it was lowest at Ranchi and highest at Gaya for wheat growing season.

(b) The probability of occurrence of severe seasonal drought was the highest at Bhagalpur for rice and wheat crops. No severe drought was observed at Hazaribagh and Ranchi in case of wheat and rice crops respectively.

(c) Probability of occurrence of moderate seasonal drought has higher at all the stations than that of severe drought occurrence.

(d) Results on probability of occurrence of drought in different phenophases showed that among the six stations considered, Patna showed the highest probability of occurrence of moderate drought at flowering and grainfilling stage for rice crop and highest probability of occurrence of severe drought at milking stage in case of wheat crop. Station Hazaribagh showed no moderate and severe drought occurrence at flowering stage but probability of occurrence of severe drought was highest at grainfilling stage in case of rice crop.

Information on these phenophasic probabilities, which has not been generally reported by other research workers, is considered useful for breeding varieties, tailored to the drought conditions at different stations and also for ranking crops according to the probability of their proneness to drought occurrence.

Water requirement satisfaction index developed by Frere and Popov (1979) was computed for rice and wheat crop separately for all the years under study has been used.

In the present investigation, in relatively low rainfall region of Bihar like Patna, Gaya Bhagalpur and Dumka, seasonal WRSI was found to be below 60 percent in disastrous year.

At Ranchi and Hazaribagh stations where rainfall was very high, the WRSI in moderate and severe drought years remained between 60 to 95 for rice and wheat crops. This result showed that for heavy and low rainfall stations, WRSI could have a different threshold for the same crop under drought conditions.

District crop yield data for the period 1969-70 to 1992-93 for six stations of Bihar showed that under a given intensity of drought, the productivity was fluctuating over the years. The variations in the yield over the year under the same drought intensity could be attributed to changes like increase in fertilizer application/pesticides/improved seeds. It can also be concluded that though Ranchi and Hazaribagh received high rainfall, productivity of rice and wheat were observed to be relatively low. Heavy rainfall and high wind at the time of flowering of rice crop worsen the situation and productivity decreases. Productivity of a crop depends on many factors and the most important are technological changes, sunshine duration and soil type as well as weather. Due to cloudy weather and low rainfall during grainfilling and maturity periods, the productivity of rice is restricted.

The probability of sequential events like a wet day following a wet or dry day during the crop-growing season Markov Chain probability model has been found suitable to describe the long term frequency behaviour of wet or dry weather spells. The daily rainfall data have been collected for 6 stations and utilised in the study of the dry and wet spells. For effective growth of rice crop, a minimum weekly rainfall amount of 50-mm and for wheat 10-mm is considered. A week receiving more than 50-mm rainfall is taken as wet week and less than 50-mm rainfall is taken as dry week. Similarly in case of wheat this limit is taken as 10-mm.

Based on the historical data of weekly rainfall, initial and conditional probabilities were worked out for each station was calculated.

From the dry and wet spells analysis at six stations of Bihar it can be observed that Ranchi, Hazaribagh and Dumka stations earlier sowing of rice crop by broadcasting seeds around the 23rd to 24th standard weeks are favourable. It can be very well seen that all these stations can support the cultivation of a rice variety, which is having the duration of 16 to 17 weeks. While in the Patna, Gaya and Bhagalpur it is further recommended for these stations to reduce the risk factor by cultivation of those varieties which are not having the duration greater than 13 to 14 weeks. Wheat crop can not be taken up without irrigation.

Thus, it can be concluded that the pattern of dry weeks shows the considerable locational variations and this information is highly useful for agricultural planners in determining the suitable crops or varieties for a particular location and in adopting suitable management practices. This study can be used as a tool for detecting the hazards with regard to water availability during the growth periods. This study can also be used as an extensive study. 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 pheno stages. Based upon these conditions, the alternative strategies (for fertilizer application, pesticides etc.) can be recommended to the farmers.

By using weekly AE and weekly PET, the weekly MAI and probability of exceedance of weekly moisture availability were calculated to determine

(i) Length of growing period and (ii) probability of moisture availability to meet crop water demand for rice and wheat crops separately.

Length of the growing period is defined as the period during which MAI $\geq$ 0.5.

Result showed that at 50% probability level, the length of growing period is more for Dumka, Ranchi and Hazaribagh (23-26 weeks) as compared to Patna, Bhagalpur and Gaya (20-21 weeks). It has potential to grow a long duration crop while at Patna, Gaya and Bhagalpur, short duration crop should be recommended.

Probability of moisture availability to meet crop water demand for rice and wheat crops at different stations of Bihar were calculated and found that failure of rice crop due to drought at seedling stage is more while for wheat it is at flowering stage.

This type of study if extended to other region can bring out the agroclimatic potential of the region by emphasising salient agroclimatic features of each zone. Whenever yield fluctuations are noticed they can be interpreted by using some of the indices employed in the study. From the study of the probability of dry and wet spells and MAI during different crop phenophases, the most vulnerable phases can be identified in each region. 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.

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* Original not seen.

Appendix - 1

Standard Meteorological Weeks

Met. week no.	Dates	Met. week no.	Dates
1	1-7 Jan.	27	2-8 July
2	8-14 Jan.	28	9-15 July
3	15-21 Jan.	29	16-22 July
4	22-28 Jan.	30	23-29 July
5	29 Jan.-4 Feb.	31	30 July-5 Aug.
6	5-11 Feb.	32	6-12 Aug.
7	12-18 Feb.	33	13-19 Aug.
8	19-25 Feb.	34	20-26 Aug.
9	26 Feb.-4 March	35	27 Aug.-2 Sept.
10	5-11 March	36	3-9 Sept.
11	12-18 March	37	10-16 Sept.
12	19-25 March	38	17-23 Sept.
13	26 March-1 April	39	24-30 Sept.
14	2-8 April	40	1-7 Oct.
15	9-15 April	41	8-14 Oct.
16	16-22 April	42	15-21 Oct.
17	23-29 April	43	22-28 Oct.
18	30 April-6 May	44	29-4 Nov.
19	7-13 May	45	5-11 Nov.
20	14-20 May	46	12-18 Nov.
21	21-27 May	47	19-25 Nov.
22	28 May-3 June	48	26 Nov.-2 Dec.
23	4-10 June	49	3-9 Dec.
24	11-17 June	50	10-16 Dec.
25	18-24 June	51	17-23 Dec.
26	25 June-1 July	52	24-31 Dec.