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DROUGHT STUDY OF CHHINDWARA DISTRICT USING DRY SPELL ANALYSIS

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PREFACE

Drought is defined as a water shortage caused by the imbalance between water supply and demand. Drought is generally viewed as a sustained and regionally extensive occurrence of appreciably below average natural water availability, either in the form of precipitation, surface water runoff or groundwater. An area can be considered as affected by drought, if it receives total seasonal rainfall less than 75% of the normal value. The occurrence of drought on a continuous basis leads to reduce availability of fodder, decline in agricultural production, livestock wealth and badly affect the people inhabiting these areas.

The present study is aimed to study hydrological and agricultural aspects of drought in Chhindwara district as the recurrence of drought in this region in recent years caused unprecedented economic losses and great suffering to the affected areas. The study based on the analysis of rainfall includes departure analysis, frequency analysis and dry spell analysis. An occurrence of dry spells may cause partial to total crop failure. The low stream flows and reduced reservoir storages are indicative of drought situations hence stream flow analysis has been carried out using flow duration curves technique. Drought condition in the district has also been studied based on the analysis of evapotranspiration, crop and its critical stages. The study is further aimed at planning of life saving supplementary irrigation requirement for rain fed crops to reduce water stress during critical dry spells.

This report titled "Drought study of Chhindwara district using dry spell analysis" has been carried out by Sh. Ravi Galkate, Scientist-C, Sh. T. Thomas, Scientist-B and Dr.. R. P. Pandey, Scientist-E1, under the guidance of Dr. A.K. Bhar, Scientist-F, Head & Coordinator, NIH, Regional Centre, Sagar.

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ABSTRACT

The occurrence of drought leads to reduction in stream-flow, and consequent reduction in reservoir and tank levels and depletion of soil moisture and groundwater. There is a need to develop suitable criteria for planning supplemental irrigation to crops for increasing and stabilizing crop yields during non-drought conditions, and minimizing crop damages during drought. The present study is aimed to study hydrological and agricultural aspects of drought in Chhindwara district as the recurrence of drought in these parts of the country in recent years have caused unprecedented economic losses and great suffering to the affected areas. The study is based on the analysis of rainfall and stream flow.

In Chhindwara district the deficiency of annual rainfall is observed up to 65%. In the district approximately one out of every three to four year is drought year. The year 2000 and 2001 was most severely affected as most of the blocks of the district were under drought and major area of the district is found as drought prone. The mean date of onset of effective monsoon (*EMO*) in Chhindwara district varies from 13th June to 21st June and the date of withdrawal of *EMO* varies from 19th September to 1st October. On an average two critical dry spells (*CDS*) was observed during the monsoon season with duration of 12 to 17 and 13 to 27 days. The maximum crop water requirement is observed for rice and sugarcane during two *CDS*. The maximum 75% dependable flow is observed in August whereas the minimum 75% dependable flow is observed in May. The runoff deficit years are 1991 and 1997 at Hirnakheri, 1990 and 1997 at Chand and 1991 at Ramakona.

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1.0 INTRODUCTION

Drought is generally defined as water shortage caused by the imbalance between water supply and demand. Drought is generally viewed as a sustained and regionally extensive occurrence of appreciably below average natural water availability, either in the form of precipitation, surface water run off or ground water (Gbeckor-Kove, 1995). Drought has different meanings to different disciplines. What is drought for an agriculturist need not to be so to a hydrologist or meteorologist. There is no universal definition applicable to all disciplines. It is temporary feature caused by climatic fluctuations and is an extremely complicated phenomenon. The formation and intensity of drought are gradual and cumulative process, which occur so slowly that they are not easily discerned. Factors, which may induce drought, are very complex. In addition to many factors in natural environmental conditions like precipitation, evaporation temperature, wind, humidity, etc. the hydrological conditions such as surface water and ground water etc.; the agricultural condition such as soil behaviour, cropping pattern, crop varieties and growing period etc.; and the geographic condition like topography etc. also contribute to drought.

The recurrence of drought over many parts of the country in recent years caused unprecedented economic losses and great suffering to the affected areas. They not only reduced the agricultural production but also threatened country with famine. Drought causes innumerable problems immediately or with the time lag as the economy gradually experiences the adverse shock of the phenomenon. According to Indian Meteorological Department (IMD), a meteorological subdivision (part of India) is considered to be affected by drought if it receives total seasonal rainfall less than 75% of the normal value.

The occurrence of drought leads to reduction in stream-flow, and consequent reduction in reservoir and tank levels and depletion of soil moisture and groundwater. This on a continuous basis leads to reduce availability of fodder, decline in agricultural production and livestock wealth, besides causing misery to people inhabiting these areas. The drought characteristics and associated problems vary from area to area, depending upon the amount of variability of available water supplies and the demand of water for specified users.

Severe and prolonged water stress due to deficit of rainfall over the prolonged periods with reference to normal rainfall expectation is apt to describe a meteorological drought in general term. According to the National Commission on Agriculture (1976), agricultural drought refers to the inadequate soil moisture during crop growing period and the hydrological drought refers to marked depletion of surface water storage in lakes, reservoirs, rivers and streams etc. in fact the meteorological drought precedes the agricultural and hydrological drought. The agricultural and hydrological drought needs not to occur simultaneously but occur subsequent to a meteorological drought (Sastry, 1986).

In literature, no criterion is available for planning a supplemental irrigation to crop based on critical dry spells and critical crop growth stages. The Critical dry spells are those dry spells, which exceed certain limiting duration identified to be critical to the crop. Of late, more emphasis is being given to store excess runoff in tanks for supplemental irrigation to crops. However, excess runoff collection and storage of water on dug out ponds or tanks is more expensive than the national resource (Verma and Sarma, 1989). Thus, there is a need to develop suitable criteria for planning supplemental irrigation to crops for increasing and stabilizing crop yields during non-drought conditions, and minimizing crop damages during drought.

The present study is aimed to study hydrological and agricultural aspects of drought in Chhindwara district as the recurrence of drought in this part of the Madhya Pradesh in recent years caused unprecedented economic losses and great suffering to the affected areas. The study based on the analysis of rainfall includes seasonal and annual rainfall departure analysis, frequency analysis of seasonal and annual rainfall and dry spell analysis of monsoon season. The analysis of dry spells within monsoon season is very important especially for rainfed agriculture in the country. The occurrence of dry spells may result in drought occurrence even if the total amount of rainfall during monsoon season is about 75% of the normal rainfall in the period. Occurrence of dry spells may cause partial to total crop failure. If a long dry spell occurs during active growing period of crops, especially during fruiting and flowering stages it will be disastrous for crops.

Stream flow is one of the important hydrological parameter as it represents the runoff from a basin or catchment and determines the quantity of water available in various surface water resources. The rainfall deficiency is reflected in the resulted stream flow. The low stream flows and reduced reservoir storages are indicative of drought situations. In the present study, stream flow analysis has been carried out using flow duration curves technique. Also drought has been studied based on the analysis of evapotranspiration, soil characteristics, crop and its critical stages. The study is further aimed at planning of life saving supplementary irrigation requirement for rain fed crops to reduce water stress during critical dry spells.

2.0 REVIEW OF LITERATURE

WMO (1975) Meteorological drought is characterised by the water shortage induced by the imbalance between precipitation and evaporation, in particular, water shortage based solely on precipitation e.g. rainless situation. Meteorological drought over an area is defined as a situation when seasonal rainfall over the area is less than 75% of its long term normal. It is further classified as "moderate drought" if the rainfall deficit is between 26 and 50% and "severe drought" when it exceeds 50%.

Banerjee and Raman (1976) suggested a simple approach to delineate good or bad monsoon years have been suggested by. They considered a year to be a bed monsoon year if in more than two-third number of meteorological stations the seasonal rainfall is deficient.

Martin and Cunnae (1976) concluded that hydrological drought occurs when actual water supply is less than the required for the hydrological operation. The hydrological droughts are often characterised by low stream flow, low precipitation, and fall in the levels of lakes; well and reservoirs, depletion of soil moisture, lowering of groundwater tables, changes in runoff. Changes in parameters together with several other hydrological factors have been used to quantify the severity of hydrological droughts.

Appa Rao (1986) stated that India Meteorological Department (IMD) defined seasonal drought as the period with the seasonal rainfall deficiency more than 25% from its normal value

Carpenter (1987) has discussed on different aspects of the conjunctive use of surface and ground water for irrigation in two sub-basins within the Sevier River system.

Soni and Sarvasri (1988) studied the gravity of the drought situation in selected districts in states of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra and Rajasthan. Study included rainfall analysis, soil moisture analysis, ground water data analysis and stream flow data analysis to study the hydrological aspects of drought in that states. The study indicated the areas selected for study were drought affected areas and year 1985-86 recorded seasonal rainfall deficit of more than 20% of normal and flow condition experienced drought that year.

Choudhary et al. (1989) has made an attempt to quantify drought for the country as a whole and to identify drought years by developing drought index. He concluded that India could sometime even experience spells of three successive years of drought of varying intensity and extent.

Delleur, et al. (1989) developed a statistical model for simulation of sequences of dry and wet days, based on discrete autoregressive moving average for forecasting of droughts and floods.

Chang (1990) studied the effect of drought on stream flow characteristics using daily stream flow series and different truncation levels of the recorded daily flow to define drought. He studied the changes in flow ratios of 17 selected sub-basins with increasing truncation levels and developed a drought intensity function to investigate drought severity in the basin.

Wijayratne and Golub (1990) conducted a study on modeling of multiyear droughts by using synthetically generated annual flow series for development of a methodology to model annual flow based on an analysis of the harmonic and stochastic properties of observed flow. He also worked on selection of a truncation level to distinguish low flows from high flows.

Agrawal (1992) stated that the studies on hydrological aspects of droughts are less attempted as compared to the meteorological and agricultural aspects of droughts in India. He suggested that in drought studies, it is not sufficient to go by analysing the variability of total rainfall amount alone but also to analyse water, soil moisture and groundwater as well as demand patterns to understand drought in better prospective. In this connection the hydrological drought indices are to be developed. A suitable water distribution policy for different water uses linked with anticipated or current deficiencies in water supplies both surface and ground water has to be evolved for drought prone areas. He also suggested that the need for water conservation is important in delineating the effect of drought. The water conservation is need at all possible sources and places of utilization such as surface water, groundwater and uses such as domestic, agricultural, industrial and other uses. The conservation by water harvesting, lining of canals, irrigation methods interlinking the basins by long transfer of water can be few practices to conserve the water to meet the need of drought.

Sahoo, (1993) concluded that the pre-monsoon showers of high intensity cannot be considered as the effective monsoon, particularly, because they are normally followed by long dry spells, which may affect the germination of seeds resulting in crops failure if the showing is undertaken immediately after these showers

Pandey (1999) have studied the hydrological and agricultural aspect of drought in Kalahandi district of Orissa. The rainfall data has been analysed to portend the drought frequency, duration, dates of onset and withdrawal of monsoon and critical dry spells. He concluded that the average frequency of drought in the district has been 4-5 years and on an average monsoon period in the area observed 2-3 intervening critical dry spells per year. He also suggested the plan for supplemental irrigation during the critical dry spells in the area and emphasized on need of supplementary irrigation to the Kharif crop and assured water supply for at least one irrigation to rabbi crop.

3.0 STUDYAREA

3.1 Location and Extent

Chhindwara district of Madhya Pradesh is named after its headquarters town Chhindwara. It is located on a section of the Satpura plateau it extends between the parallels of latitude 21 28 to 22 49 N and the longitude 78 20 to 79 24 E. The district falls under the Jabalpur division of Madhya Pradesh. The districts of Hoshangabad and Narsinmhapur make the northern boundary of Chhindwara district, the former lying in the northwest. Nagpur District in Maharashtra State marks the southern boundary. Two districts of Satpura plateau, Seoni and Betul flank on the east and west respectively. A small section of district boundary is contagious with Amraoti district of Maharashtra. The geographical area of Chhindwara district is 11815 sq. km constituting 2.66% of the total area of state. The District is divided into *9 Tahsils, namely,* Chhindwara, Parasia, Junnardeo, Tamia, Amarwara, Chourai, Bicchua, Sausar and Pandhurna. The district has 11 Development Blocks namely, Chhindwara, Parasia, Junnardeo, Tamia, Amarwara, Chourai, Bicchua, Harrai, Mohkher, Sausar and Pandhurna (Directorate of Rajbhasha Evam Sanskriti, Chhindwara District Gazetteer 1985). Chhindwara district is one of the chronically drought prone district of Madhya Pradesh. All of its 11 blocks are affected by the drought. Index map of Chhindwara district is shown in Figure 3.1.

3.2 Physiography and Relief

Chhindwara district from geographical point of view can be divided into three main regions, the southern region of plains, the central Satpura mountain region and northern region comprising of hilly terrain. The district has fairly extensive network of rivers, most of them are rain fed. There are *five major rivers,* which flow through the district namely Kanhan, Pench, Jam, Kulbehra, Shakkar and Doodh. Kanhan flows in the Southern direction through the western parts of Chhindwara tahsil and drains in to Wainganga, a tributary of Godawari. Kulbehra starts at Umreth and flows through Chhindwara and Mohkher and joins with Pench river. Jam flows mostly through the Sausar region and joins with the Kanhan. Pench flows in the border areas of Chhindwara and Seoni Districts and mixes with the Kanhan in Nagpur District.

3.3 Climate

The average annual rainfall in the district is 1324 mm. The climate of the district is milder but not uniform because of its topographic and physiographic conditions. The southwest monsoon happens to be the larger contributor of monsoon rains contributing about 85% of annual rainfall, July being the rainiest month in the region. May is the hottest month with the mean daily maximum temperature at 39.4^{0}C and temperature on individual day may reach up to 43^{0}C. January is generally the coldest month with the mean daily minimum temperature at 10.6^{0}C and on some occasions the region is sometime affected by cold waves, the minimum temperature may drop down to about 3^{0}C.

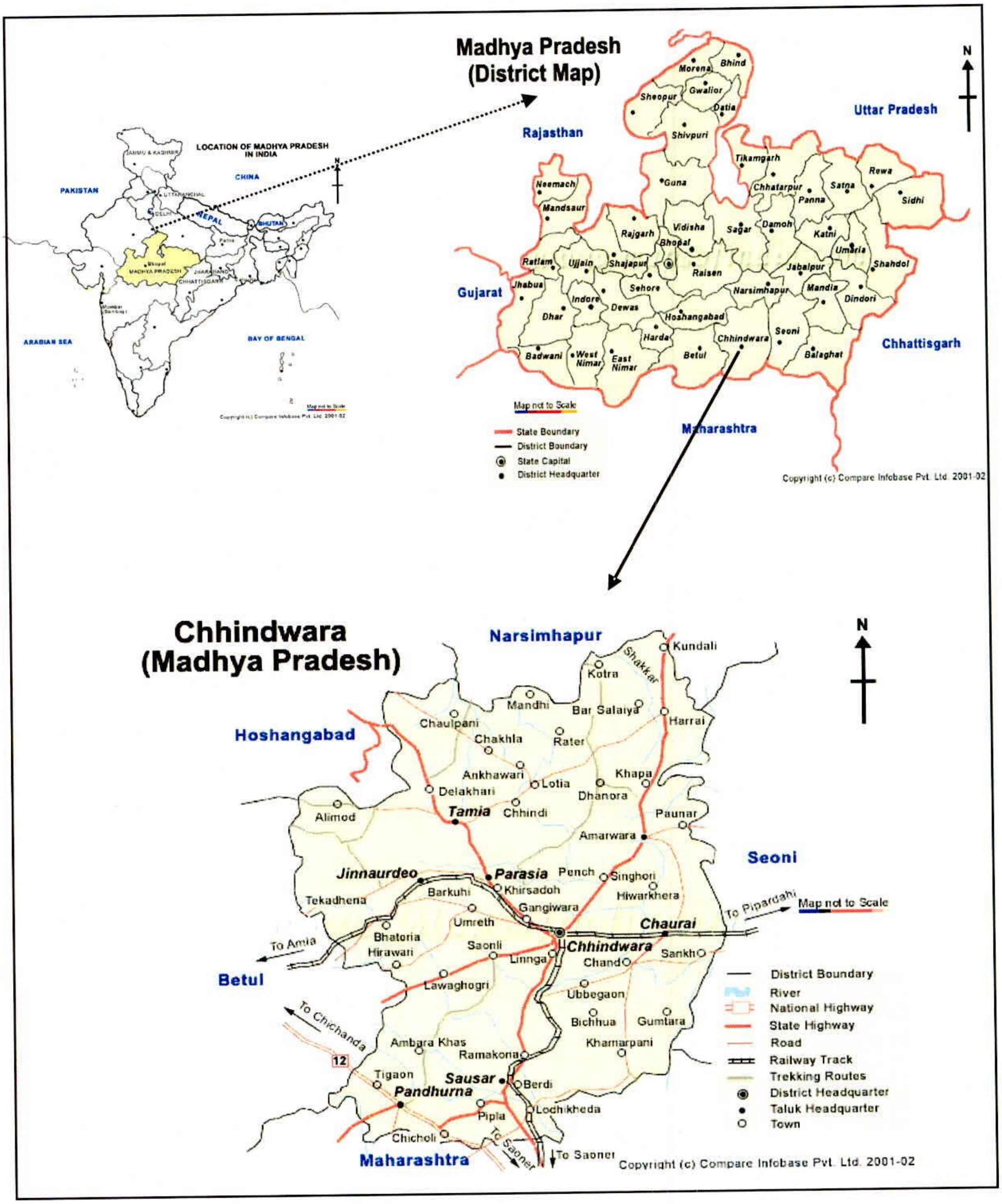

Fig. 3.1: Index Map of Chhindwara district

3.4 Geology

The oldest formations occurring in this district comprise of Archean rocks. The rocks exposed in the area are granite, pegmatite, gneiss, schist, amphibolite, quartzite, crystalline limestone, marble, silicate rocks etc. The Deccan trap flows are resting over the older lithologies. Deccan traps are of varying thickness, of basaltic and dolomitic rocks.

3.5 Soils

Five types of soils are present in the district. Alluvial soil is commonly associated with rivers and streams. Silty soil is occurring on the bank of river Kanhan near Sausar town. Lateritic soil is occurring in the eastern and southwestern part of the district. Sandy soil is associated with Pench and Kanhan rivers. Black cotton soil is occurring in the central, northern and southern parts of the district. Soil of recent origin is developed in low-lying valleys.

3.6 Agriculture

Soyabean, Wheat, Sorghum, Groundnut and Cotton are the major crops cultivated in the district. Pulses, gram and cotton are other crops grown in the district. The Nagpur plain and Pench river alluvium areas are the areas of high intensity, cropping and irrigation. Other important crops are Pulses Paddy, Ragi and Sesamum. Nagpur Plains is the orange, wheat and cotton-growing tract in the district. Out of total geographical area around 18429 ha area is available for agriculture purpose (Directorate of Rajbhasha Evam Sanskriti, Chhindwara District Gazetteer 1985).

4.0 ASSESSMENT OF DROUGHT YEARS

Drought can be defined as a temporary harmful and widespread lack of available water with respect to specific need. It implies a deficiency of rainfall of sufficient magnitude over a prolonged duration so as to interfere with some phases of regional economic activities. According to the India Meteorological department (IMD) an area / region is considered to be drought if it receives seasonal total rainfall less than 75% of its normal value. The rainfall records for all the eleven blocks of the Chhindwara district were obtained from the Department of Water Resources, Chhindwara and analysed to study the magnitude and frequency of drought in terms of rainfall deficiency. The Block wise rainfall distribution in Chhindwara district is shown in Table 4.1. Rainfall data has been subjected to various kind of analysis including seasonal & annual rainfall departures, probability distribution and dry spell analysis etc. The stream flow data for three gauge sites on river Pench in Chhindwara district were obtained from Water Resources Department, Government of Madhya Pradesh and analysed to develop flow duration curves, deficit volume and its severity. The locations of raingauges and river network and flow gauging sites are shown in Figure 4.1

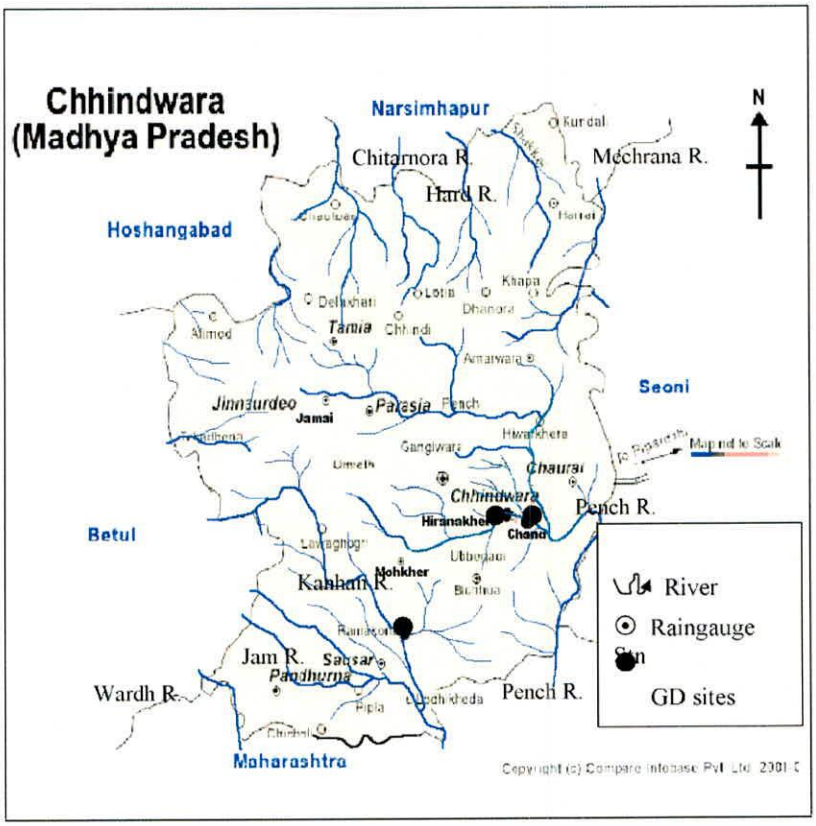

Fig. 4.1: Location of raingauges, flow gauge sites and river network

4.1 Annual Rainfall Departure

For identification of drought years and the extent of deficit of annual rainfall, the annual rainfall departure analysis has been carried out. A year is considered as drought year if the total amount of annual rainfall over an area is deficient by more than 25% of its normal value. The percentage annual rainfall departures in all blocks of Chhindwara district are given in Figure 4.2 (a-k). From the annual rainfall departure analysis, the drought years have been identified and its average frequency of drought is presented in Table 4.2.

4.2 Seasonal Rainfall Departure

About 85% of the annual rainfall in the Chhindwara district is received from southwest monsoon that occurs during June to September. The variation in the rainfall from year to year is not large. In the district the entire cultivation is governed by quantity, distribution and time of onset of effective monsoon. The dry spells which occur within the rainy season causes severe effect on agriculture and normal life pattern of the region. In order to compute the deficiency of seasonal rainfall, the seasonal rainfall analysis has been carried out. Normal rainfall of the monsoon season was calculated as the arithmetic average of rainfall during June to September, over the districts. India meteorological Department defined seasonal drought as the period with the seasonal rainfall deficiency more than 25% from its normal value. The percentage seasonal rainfall departures in all blocks of Chhindwara district are given in Figure 4.3 (a-k). From the seasonal rainfall departure analysis, the drought years have been identified and its average frequency of drought is presented in Table 4.3.

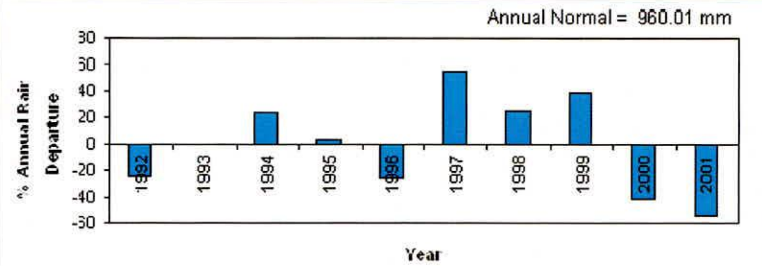

Fig. 4.2a: Chhindwara

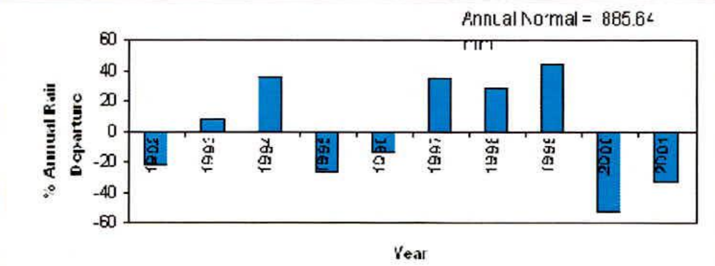

Fig. 4.2b: Mohkhed

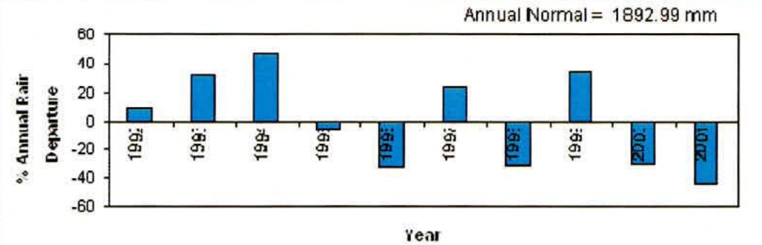

Fig. 4.2c: Tamia

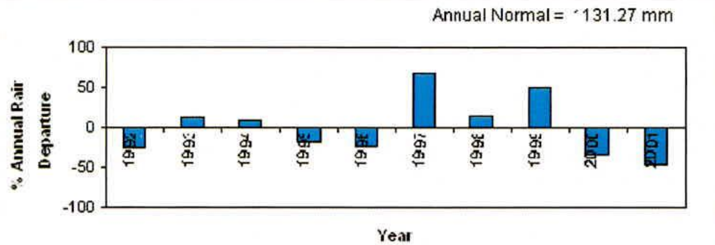

Fig. 4.2d: Amarwara

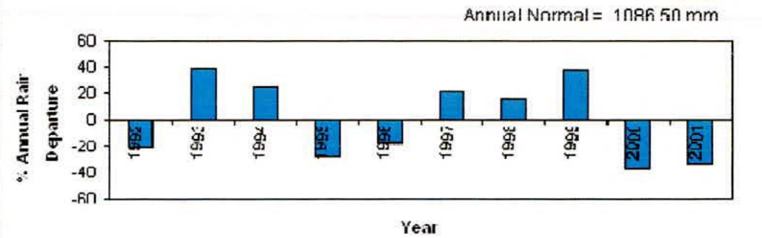

Fig. 4.2e: Chaurai

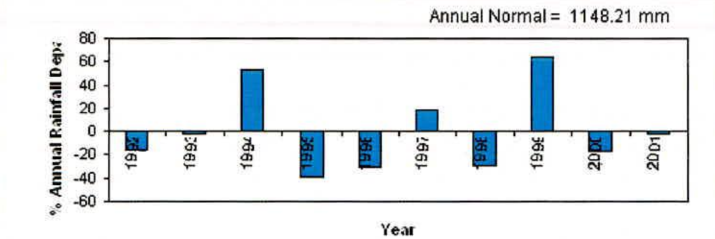

Fig. 4.2f: Harai

Fig. 4.2 (a-f): Percentage annual rainfall departure in different blocks of Chhindwara district

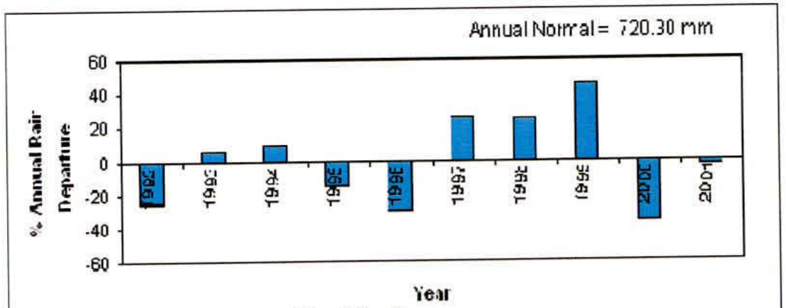

Fig. 4.2g: Sausar

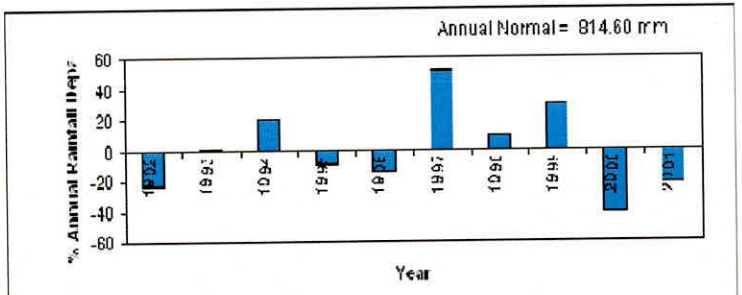

Fig. 4.2h: Pandhurna

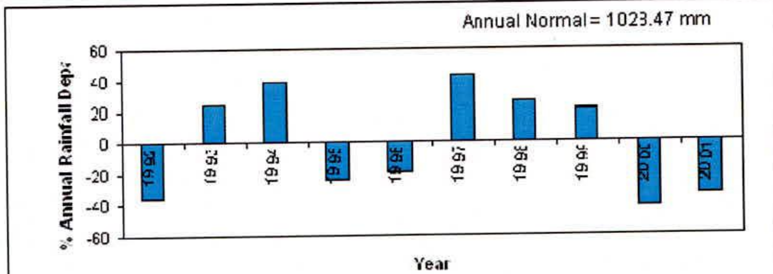

Fig. 4.2i: Bicchua

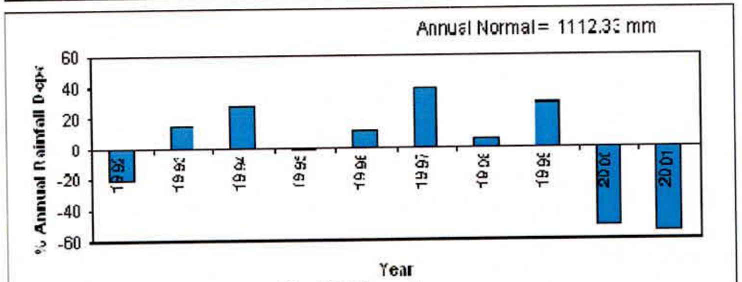

Fig. 4.2j: Parasia

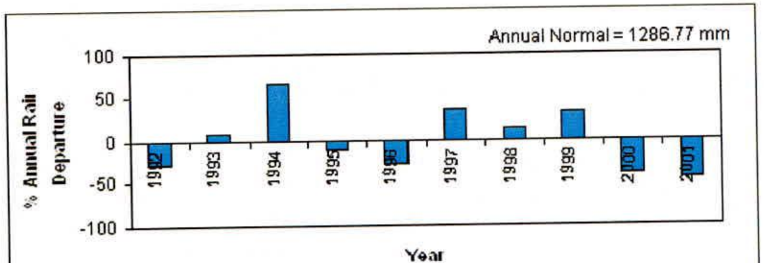

Fig. 4.2k: Jamai

Fig. 4.2 (g-k): Percentage annual rainfall departure in different blocks of Chhindwara district

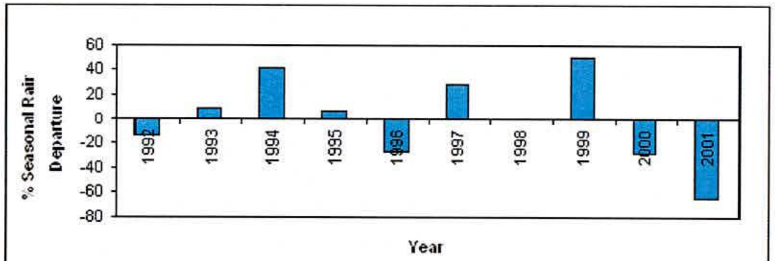

Fig. 4.3 a: Chhindwara

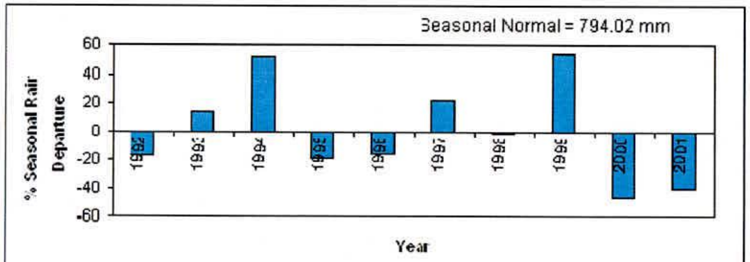

Fig. 4.3b: Mohkher

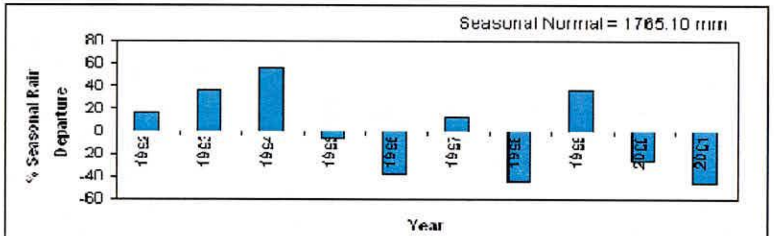

Fig. 4.3c: Tamia

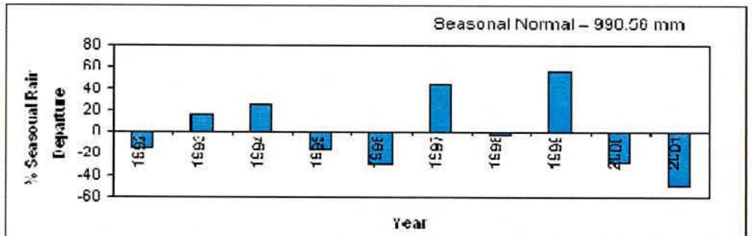

Fig. 4.3d: Amarwara

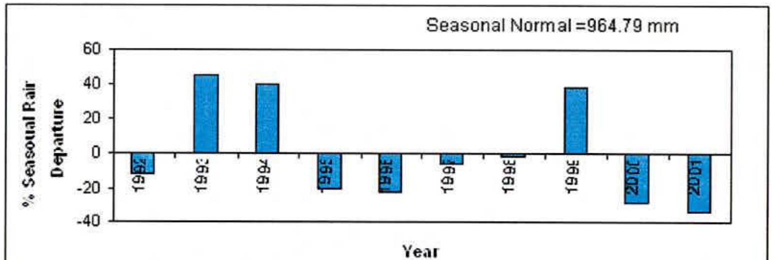

Fig. 4.3e: Chaurai

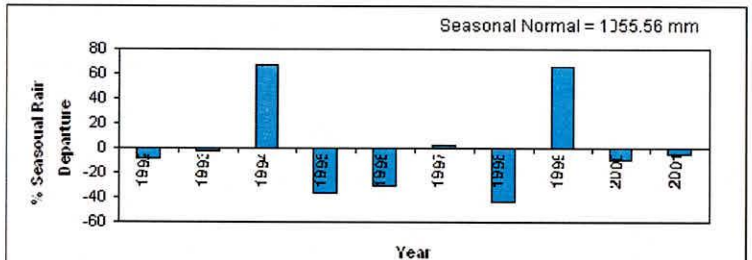

Fig. 4.3f: Harai

Fig. 4.3 (a-f): Percentage seasonal rainfall departure in different blocks of Chhindwara district

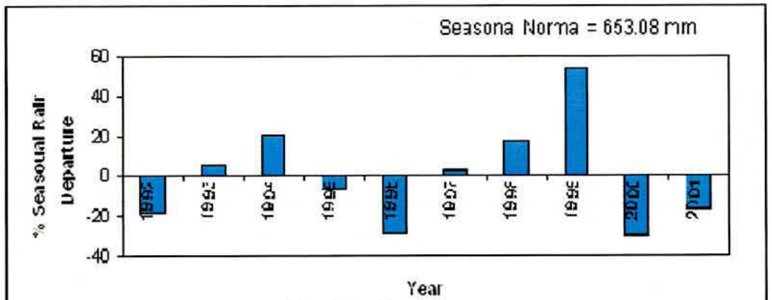

Fig. 4.3g: Sausar

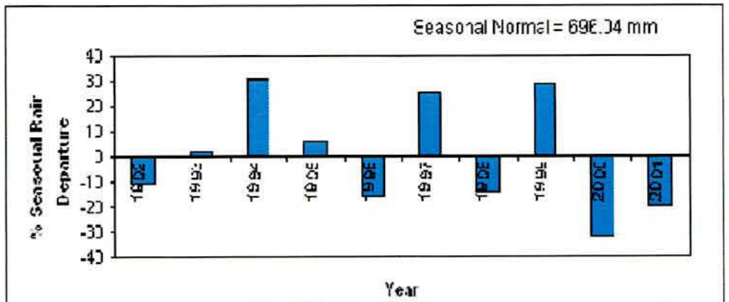

Fig. 4.3h: Pandhurna

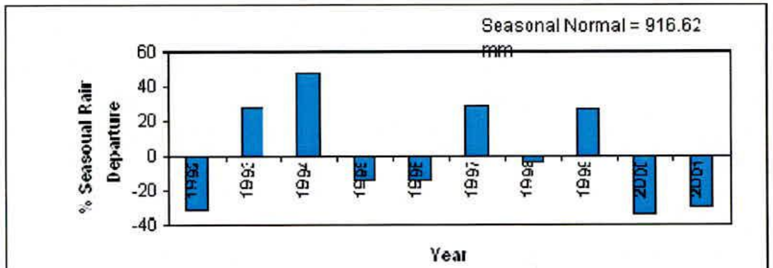

Fig. 4.3i: Bicchua

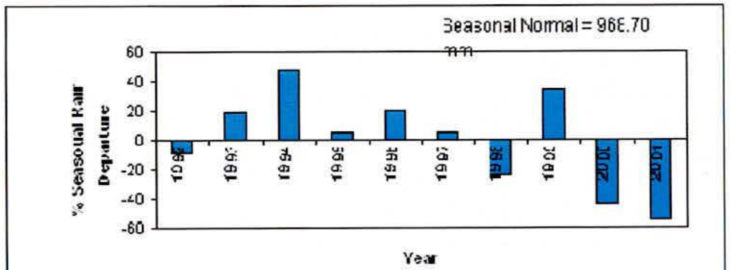

Fig. 4.3j: Parasia

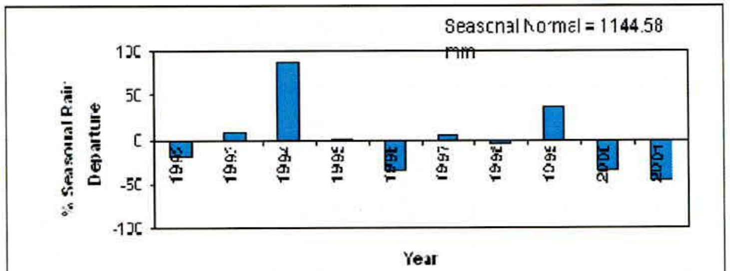

Fig. 4.3k: Jamai

Fig. 4.3 (g-k): Percentage seasonal rainfall departure in different blocks of Chhindwara

5.0 PROBABILITY DISTRIBUTION OF ANNUAL RAINFALL

The probability analysis of annual rainfall is important to predict the relative frequency of occurrence in different group interval of annual rainfall with reasonable accuracy. The estimated probability of an event is taken as the relative frequency of occurrence of the event when the number of observations is very large. The percentage probability of occurrence of 75% of mean annual rainfall has been worked out to delineate the drought proneness of various blocks of the district Chhindwara. An area can be considered as drought prone if the probability of occurrence of 75% of normal rainfall is less than 80% (Central Water Commission, 1982). Percentage probability of occurrence of rainfall equivalent to the 75% of normal is presented in Table 5.1.

6.0 ONSET OF EFFECTIVE MONSOON AND CRITICAL DRY SPELL

In Chhindwara district the major crops like soyabean, sorghum, maize, paddy, cotton, groundnut, blackgram, etc. are grown during kharif season. The selection of crop varieties and time for seedbed preparation are governed by onset and length of monsoon. Therefore, the onset, termination, and distribution of rains during monsoon season plays very significant role in the success of agricultural crops in this region. In order to identify the onset and withdrawal of effective monsoon and critical dry spells, the rainfall data have been analysed using the methodology as described below.

6.1 Onset of Effective monsoon (EMO)

The date of onset of effective monsoon (EMO) can be defined as the date of commencement of a wet spell satisfying the following criteria (Verma and Sarma, 1989; Sahoo, 1993).

I) The first day's rain in 7 days spell is not less than average daily evapotranspiration (ET).

ii) At least four out of seven days are rainy days with not less than 2.5 mm of rain each day.

iii) The total rain during the 7 days spell is not less than (5ET+10) mm.

Using above definition the rainfall record have been analysed to identify the date of EMO in respective years.

6.1.1 Mean Date of EMO

The mean date of onset of effective monsoon is calculated as follows:

The mean date of onset of effective monsoon, its standard deviation and mean date of withdrawal

$$D_m = \sum_{i=1}^{n} \frac{X_i}{n} \qquad \text{......(1)}$$

Where, D_m = mean date of effective monsoon

X_i = date of onset of effective monsoon in i^{th} year (i=1, 2,.....n)

n = total number of years for which rainfall date is being analysed

6.1.2 Standard Deviation (σ) of EMO

Standard Deviation of the date of onset of effective monsoon from its mean date is calculated as follows:

$$\sigma = \left[\frac{\sum_{i=1}^{n} X_i^2 - \left(\sum_{i=1}^{n} \frac{X_i}{n} \right)^2}{n-1} \right]^{\frac{1}{2}} \qquad \text{......(2)}$$

The mean date of onset of effective monsoon, its standard deviation and mean date of withdrawal of effective monsoon are presented in Table 6.1.

6.1.3 Median Date of EMO

The dates of EMO Xi (i=1, 2,.....n) for n number of years are arranged in ascending order. If n, the number of years is odd, the middle value is considered as the median date of EMO. In case n is even, the median date is the arithmetic mean of two middle values.

6.1.4 Quartile Deviation (q)

The quartile deviation (q) or semi-inter-quartile-range can be calculated as follows:

$$q = \frac{q_3 - q_1}{2} \qquad \text{..........(3)}$$

Where,

q_1 = first quartile dividing the observation X_i (i=1, 2,.......n) in to fourth q_1 and three-fourths above.

q_3 = third quartile dividing the observations into a fourth above and three-fourth below.

The median date of onset of effective monsoon, median date of withdrawal of effective monsoon and semi-inter quartile range of date of onset of effective monsoon are presented in Table. 6.2.

6.2 CRITICAL DRY SPELL (CDS)

The analysis of dry spell within monsoon season is very important especially for rainfed agriculture in the country. Generally, a dry spell is defined as the interval of dry days between two consecutive wet spells. Dry days are considered as days having rainfall less than 2.5 mm. If a single rainy day having at least 5ET rainfall after a dry spell can wet the soil profile up to the desired depth and is taken as a wet day for breaking the dry spell, then two consecutive rainy days whose total rainfall is 5ET or more can be considered as two-day wet spell for the same purpose (Varma, and Sarma, 1989). This is based on the following fact derived from experience that an effective wet spell of two consecutive rainy days can leave more moisture in the soil profile than that of one effective rainy day having equal amount of total rainfall. This is because of more chances of water loss as surface runoff in the later case.

Further, three or more rainy days occurring in a week, not necessarily consecutively, having at least a total rainfall of 5ET is also considered a wet spell. In view of the above discussion, the definition of a wet spell can be summarized as:

* A rainy day with rainfall equal to or more than 5ET or
* A spell of two consecutive rainy days with rainfall totaling at least 5ET or
* A 7 days period having at least 3 or 4 rainy days with a total rainfall not less than 5ET.

The intervening period of dry days between any two consecutive wet spells is considered as dry spell. Based on the above definition, all the dry spells after the date of onset of effective monsoon are identified for first year of record. Similarly, depending on the crop variety and crop duration all the dry spells during crop growing season are identified. If the duration of any of these dry spells exceeds certain period and moisture stress is experienced by crops under rainfed conditions, then this dry spell is called as 'critical dry spell'. Occurrence of critical dry spells depends upon the rainfall pattern, crop-soil complex of the region under consideration (Ashok Raj, 1979 and Sahoo, 1993). Subsequently, the critical dry spells are identified in the similar manner for all the years of rainfall record.

For calculating the duration of CDS, an appropriate approach is to divide the crop growth period into some important growth phases according to water demand as evapotranspiration of crop varies according to growth stages. For paddy crop the critical stages for water demand are tillering and flowering while for maize crop the critical stages for water demand are early vegetative stage, tasselling and silking stage. In order to predict probable period of CDS the Median dates of beginning of 1st and 2nd CDS for crop growing season have computed. The corresponding week of the month to which median date belongs, has been taken as the probable period of commencement of critical dry spells. The probable period of commencement of critical dry spells and their duration are presented in the Table 6.3. On the basis of crop-soil combination the minimum length of a dry spell is considered as 10 days that become critical to the crop.

7.0 ESTIMATION OF EVAPOTRANSPIRATION AND IRRIGATION REQUIREMENT

7.1 Crop Evapotranspiration

The potential crop evapotranspiration (*ETp*) has been estimated using modified Penman method (1963). The *ETp* (mm/day), for 52 standard weeks, has been calculated based on mean air temperature (maximum and minimum), dry bulb and wet bulb temperature, wind velocity, relative humidity (maximum and minimum), sun shine hours and using the standard table values given by Doorenbos and Pruitt (1977). The ETp estimates are made using meteorological data recorded at Jawaharlal Nehru Krishi Vishva Vidyalay, Zonal Agricultural Research Station, Chhindwara. The estimates of *ETp* for standard weeks are given in Table 7.1.

In order to account for the effect of crop characteristics on *ETp*, the crop-evapotranspiration (*ETcrop*) are made as follows.

$$ETcrop = Kc \times ETp \qquad \text{.........(4)}$$

Where, *ETcrop* = crop-evapotranspiration, mm/day

ETp = reference evapotranspiration, mm/day
Kc = crop coefficient

The factors affecting the values of the crop coefficient (Kc) are mainly the crop characteristics, sowing period, rate of crop development, length of growing season and climatic condition. Particularly following sowing and during the early growth stage, the frequency of rain or irrigation is important. The crop growing season has been divided in to four stages (i) initial stage (ii) crop development stage (iii) mid season stage and (iv) late season or ripening stage. Crop coefficient (*Kc*) values for different growing phases of crops are obtained from a Guide for Estimating Irrigation Water Requirements, Govt. of India (1984) and are presented in Table 7.2. The sample estimates of consumptive use (*ETcrop*) for different time interval during growing season of paddy crop is presented in Table 7.3. Similarly, the consumptive use (*ETcrop*) for other selected crops have been computed and given in Appendix A-J.

7.2 Effective Rainfall (*ER*)

Effective rainfall means useful or utilizable rainfall. The annual or seasonal effective rainfall is the part of total rainfall, which is useful directly and indirectly for the crop production at the site where it falls. Total rainfall is not effective as part of it may be lost by surface runoff, deep percolation and evaporation etc. Rainfall for any period vary from year to year and therefore, rather than using mean rainfall data, a dependable level of rainfall should be selected for analysis i.e. the depth of rainfall that can be expected 3 out of the 4 years (Doorenbos and Pruitt, 1977). With a dry soil surface and little or poor vegetative cover, rain up to 8 mm/day may all be lost by evaporation; rains of 25 to 30 mm may be only 60% effective with a low percentage of vegetative cover (USDA, 1969; Doorenbos and Pruitt, 1977; Sahoo, 1993). As per the guidelines suggested by U.S. Department of Agriculture, (1969), monthly effective rainfall has been computed using evapotranspiration/precipitation ratio method (Table 34 in FAO Paper No. 24, by Doorenbos and Pruitt, 1977). Effective rainfall during the probable duration of critical dry spells (*CDS*) for different blocks in Chhindwara has been estimated using interpolation technique and is presented in Table 7.4.

7.3 Irrigation Requirement (*IR*)

In kharif season normally crop failure happen due to water stress during critical dry spells. The crop water requirement (*ETcrop*) for first two critical dry spells has been estimated as given in Table 7.5. The irrigation requirement (*IR*) of crop has been obtained as the difference between crop water requirement (*ETcrop*) and the effective rainfall. The irrigation requirement of selected crops have been estimated for critical dry spell durations and the results are presented in Table 7.6

$$IR = ETcrop - ER \qquad \text{.........(5)}$$

For appropriate planning of supplemental irrigation for Kharif crop, it is important to have careful consideration of crop variety and its critical growth stages, analysis of critical dry spells and availability of stored water etc. A decision on the timing of supplemental irrigation to kharif crop is difficult to take due to unpredictable occurrence of rainfall. Irrigation to Kharif crop at pre-decided time may drastically reduce the beneficial effects applied water. It will be prudent to wait for the dry spell to enter into the critical stages of crop growth and start irrigation. This irrigation should be completed in as short a time as possible preferably in 7 to 10 days.

8.0 STREAM FLOW ANALYSIS

The surface water deficits are reflected through low stream flows and reduced reservoir storages. During the deficient rainfall condition the deviation from normal is greater for stream flows than the rainfall. The low stream flows and reduced reservoir storages are indicative of drought situations. When the flows are not sufficient enough to meet the required demand of water, it is considered that the drought has set in. The drought severity, frequency and duration can be studied by the analysis of stream flow. In low flow analysis hydrologists are mainly concerned with three main characteristics (i) magnitude of low flow (ii) duration of low flow and (iii) frequency of occurrence of low flow. To carry out the low flow studies in Chhindwara district, flow data at sites Hirankheri and Chand on Pench river and Ramakona on Kanhan river have been analysed.

8.1 Flow Duration Curves

Low flow data are normally specified in terms of the magnitude of low flow for a given time interval within a year or a season. In analysing the stream flow drought, one of the simplest techniques is to construct a flow duration curve for the given river. The flow duration curve shows graphically the relationship between any given discharge and the percentage of time the discharge exceed. In other words, it is cumulative frequency curve that shows the percentage of time during which specified discharge were equaled or exceeded during the period of record. The curve can be drawn for daily or monthly flow data or for any consecutive N days or month period. Monthly flow duration curves are drawn for sites Hirnakheri, Chand and Ramakona and are shown in Figure 8.1 to 8.3. The dependable flow volume at 70, 75, 80 and 90% probability levels at all three sites are obtained from flow duration curves and results of which are presented in Table 8.1 to 8.3. The flow volumes at 75 % probability are considered as truncation level to obtain deficiency volume and its severity for each event of low flow condition. Severity is the total deficit or cumulative deficient runoff volume below the truncation level during the period of the event of low flow condition. Thus the departure analysis has been carried out and the events of low flow condition persisting for more than ten days period are identified and are presented in Table 8.4 to 8.6.

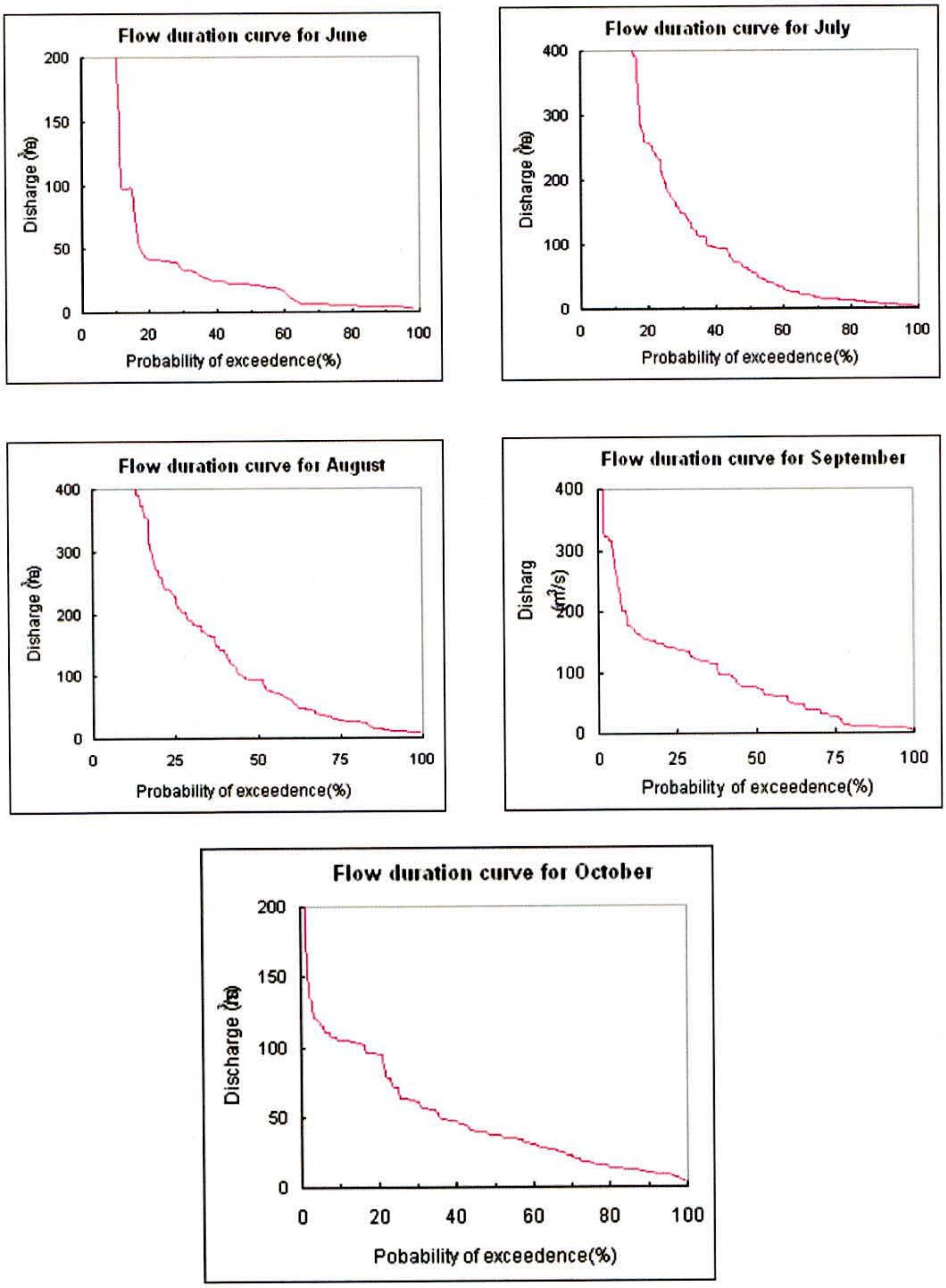

Fig. 8.1: Flow duration curves for seasonal flow (m^3/s) at Hirnakheri

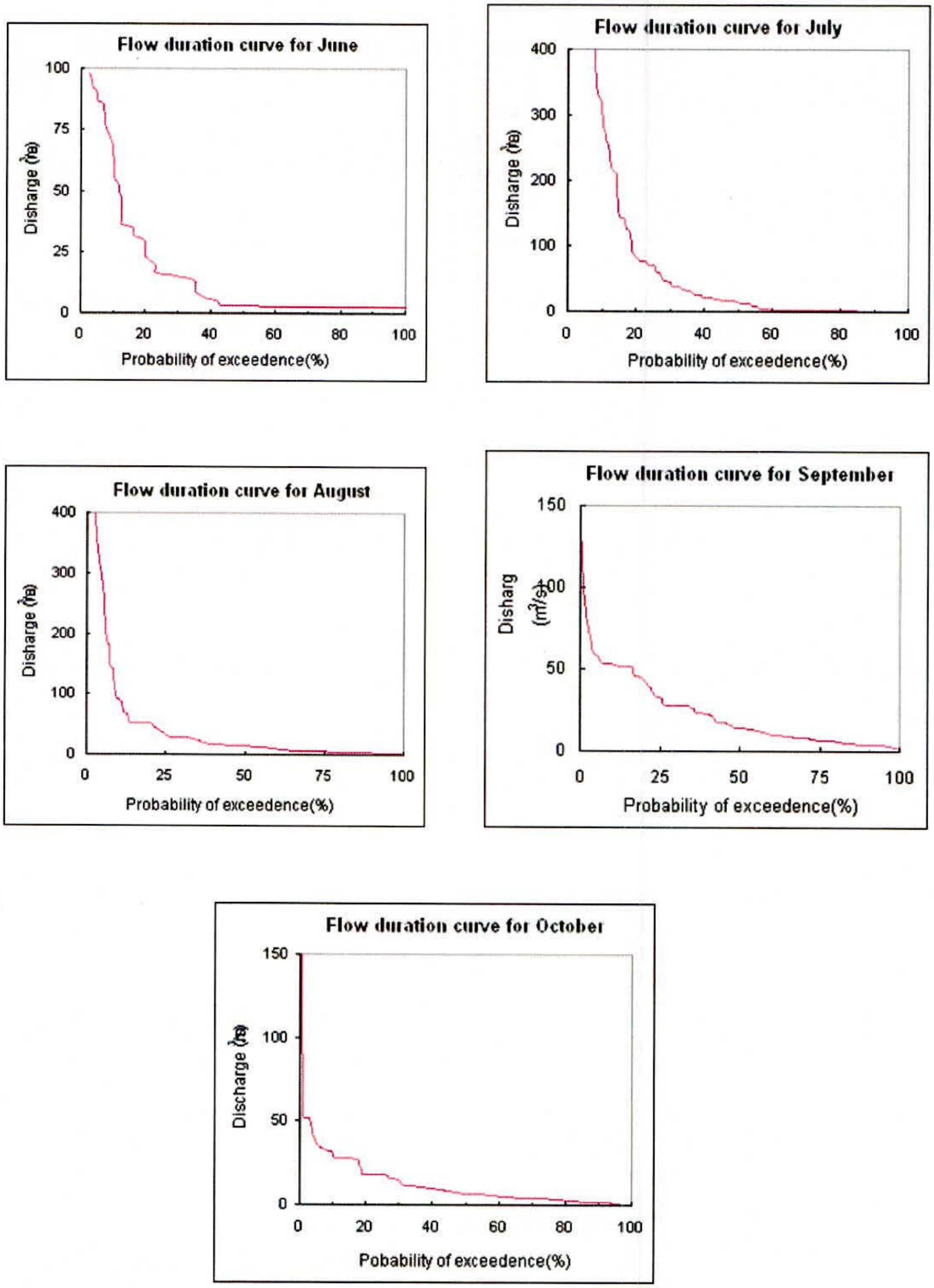

Fig. 8.2: Flow duration curves for seasonal flow (m^3/s) at Chand

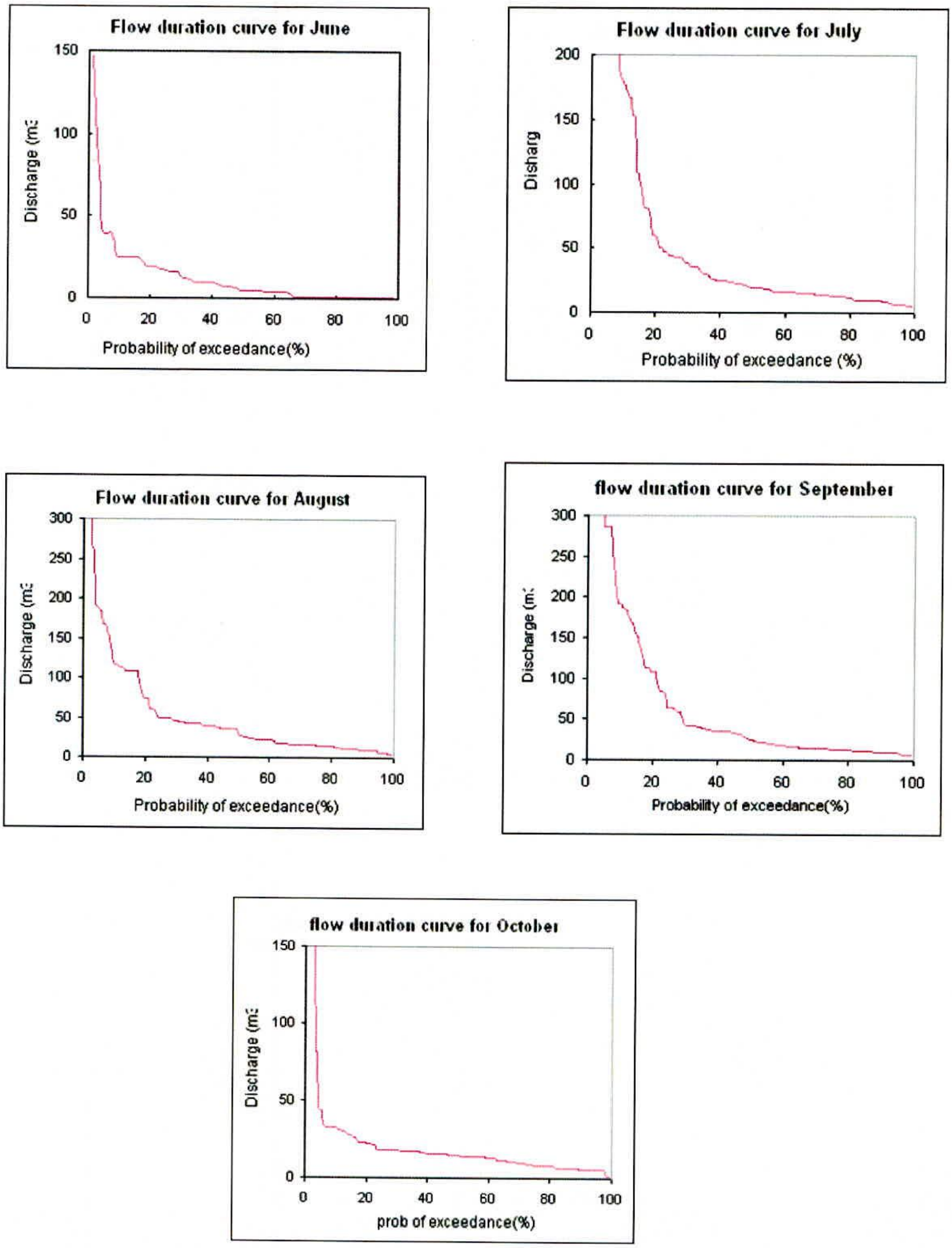

Fig. 8.3: Flow duration curves for seasonal flow (m^3/s) at Ramakona

9.0 RESULTS AND DISCUSSION

Assessment of Drought

The mean annual rainfall in Chhindwara district varies from 720 mm at Sauser to 1893 mm at Tamia, which is indicative of wide variation in the rainfall distribution pattern over the district. The coefficient of variation of annual rainfall is highest at Amarawara with 37.7%. The rainfall of the district generally increases from the southwest to northeast. The mean annual rainfall of Chhindwara district is 1324 mm. The mean annual rainfall of the district seems to be better as compared to that of the other drought prone districts in the country. However uneven distribution of rainfall and poor development of the available water resources has caused severe drought hardship from time to time in the district.

The annual rainfall departure analysis shows that the deficiency of annual rainfall varies up to 65% in the different blocks of Chhindwara district. It is observed that except for Pandhurna and Parasia, the drought frequency varies from 3 to 4 out of period of 11 years for all the remaining blocks. This clearly shows that approximately one out of every three to four year is drought year, which is rather an alarming situation.

The annual and seasonal rainfall departure analysis shows that in year 2000 all the blocks except Harrai faced drought condition and about 92% area of the district was under drought. Similarly in 2001, eight blocks of the district leading to 75% of the area was affected by drought, whereas in 1996, six blocks of the district were subjected to drought conditions.

The probability distribution analysis of annual rainfall shows that the probability of occurrence of rainfall equivalent to 75% of the normal annual rainfall in different blocks of the district varies from 61% to 83%. The average value of probability of occurrence of rainfall equivalent to 75% of normal for district as a whole is estimated about 69%. All the blocks in the district can be considered to be drought prone as the probability of occurrence of rainfall equivalent to 75% of normal annual rainfall is less than 80%, except for Pandhurna (probability of occurrence 83%).

Effective Monsoon and Critical Dry Spells

From Table 5.1, it is concluded that the mean date of onset of effective monsoon (EMO) in Chhindwara district varies from 13th June at Tamia to 21st June at Bichhua and Parasia with an average standard deviation of 10.36 days. This shows that there is moderate variation in the dates of onset of effective monsoon in different years. The date of withdrawal of EMO in Chhindwara district varies from 19th September to 1st October. The knowledge of mean date of onset of effective monsoon is important to the farmers to be prepared for primary tillage operations and timely seedbed preparation.

From the analysis for the critical dry spells (CDS), only two CDS per year was observed on an average during the monsoon season. The first CDS is observed generally in last week of June whereas second CDS has been observed in August and September. The average duration of first CDS varies between 12 to 17 days whereas the duration of second CDS varies from 13 to 27 days. As a period of 10 days of dry spell may prove to be critical for the crop, it is essential to make provisions for supplemental irrigation during these critical dry spell periods by creating additional storage wherever necessary.

Crop Water Requirement

The blockwise results of water requirement (ETcrop) during the first and second critical dry spell (CDS) are shown in Table 7.6. It is seen that during first CDS, the maximum crop water requirement is 113.19 mm for paddy at Parasia. The maximum crop water requirement during second CDS is 152.28 mm for sugarcane at Pandhurna. Generally the water requirement except for rice has been observed to be more during second CDS as compared to first CDS. This is due to the fact that during second CDS maximum crops are under development stage and mid-season stage and also the average duration of second CDS is more than that of the first CDS.

Irrigation Requirement

It is observed that the total irrigation requirement for rice during the two critical dry spells varied from 62.15 mm at Tamia to 111.70 mm at Pandhurna. It can also be seen that the sugarcane crop has maximum irrigation requirement of 122.78 mm during two CDS at Pandhurna and minimum of 63.17 mm at Chourai. Maize, sorghum and cotton are other important crops in the district, which require supplemental irrigation during the dry spells. It is also seen that there is no need of supplemental irrigation at many blocks for crops like pearl, millet, vegetable etc. except at Sausar.

Low Flow Analysis

Low flow analysis for monthly flow data has been carried out and flow duration curves were established. With the help of these curves the probability of occurrence of particular flow at the site can be established, which is helpful for planning of water resources projects. From the low flow analysis at Hirnakheri, it can be seen that the maximum 75% dependable flow is 28.0 cumecs in August whereas the minimum 75% dependable flow is 1.45 cumecs in May. At Chand the maximum 75% dependable flow is in December (9.21 cumecs) whereas the minimum 75% dependable flow is in April (0.46 cumecs). Similarly at Ramakona the maximum 75% dependable flow is in August (15.27 cumecs) and minimum 75% dependable flow is in May (0.57 cumecs).

Analysis has also been carried out to obtain deficit volume and severity of low flow at all these three sites. It is seen that the severity of low flow at Hiranakheri varies from 0.48 to 46.49 MCM and duration of low flow epoch ranges from 10 to 39 days. The year 1991 experienced maximum five events of low flows with total severity of 58.41 MCM and total duration of 102 days. The maximum severity with 46.49 MCM for 12 days duration has been observed in 1997. Therefore it can be concluded that 1991 and 1997 are years of deficit runoff volume at Hirnakheri.

The severity of low flow at Chand varies from 0.32 to 9.42 MCM and duration of low flow epoch ranges from 11 to 55 days. The years 1990 and 1997 observed maximum three events of low flow epoch each. In 1990 the total severity was 1.61 MCM for duration of 35 days and in 1997 the total severity was 9.04 MCM for duration of 44 days. The maximum severity with 9.42 MCM for 55 days duration has been observed in 1989.

The severity of low flow at Ramakona varies from 0.17 to 10.46 MCM and duration of low flow epoch ranges from 10 to 36 days. The year 1991 has observed total three events of low flow epoch with total severity 20.59 MCM for duration of 59 days.

10.0 CONCLUSIONS

The mean annual rainfall of Chhindwara district is 1324 mm and the deficiency of annual rainfall is varies up to 65% in various blocks of Chhindwara district. The drought frequency analysis indicated that approximately one out of every three to four year is drought year, which needs to be taken care of while planning for irrigation and other water resources development projects in the district. The year 2000 and 2001 was most severely affected as most of the area of the district was under drought as revealed from the annual and seasonal rainfall departure analysis. As the probability of occurrence of rainfall equivalent to 75% of normal rainfall is less than 80% in most of the blocks, so Chhindwara district as a whole can be considered as drought prone.

The mean date of onset of effective monsoon (EMO) in Chhindwara district varies from 13th June to 21st June and there is moderate variation in the dates of onset of effective monsoon in different years. The date of withdrawal of EMO varies from 19th September to 1st October. In the district on an average only two critical dry spells (CDS) have been observed during the monsoon season. The first CDS generally occurres in last week of June whereas second CDS occurres in August and September. The average duration of first CDS varies between 12 to 17 days whereas the duration of second CDS varies from 13 to 27 days. It is essential to make provisions for supplemental irrigation during these critical dry spell periods by creating additional storage wherever necessary. The maximum crop water requirement is observed for rice and sugarcane during first and second CDS respectively and since during second CDS, maximum crops are under development stage and mid-season stage and also as the average duration of second CDS is more than that of the first CDS, the water requirement is more.

The low flow analysis indicates that generally the maximum 75% dependable flow is in August whereas the minimum 75% dependable flow is in May. The severity of low flow varies from 0.48 to 46.49 MCM, 0.32 to 9.42 MCM and 0.17 to 10.46 MCM at Hiranakheri, Chand and Ramakona respectively. Similarly the duration of low flow epoch ranges from 10 to 39 days, 11 to 55 days and 10 to 36 days at Hiranakheri, Chand and Ramakona respectively. The runoff deficit years are 1991 and 1997 at Hirnakheri, 1990 and 1997 at Chand and 1991 at Ramakona.

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Table 4.1: Block wise rainfall distribution in Chhindwara district

SI. No.	Name of Block	Mean annual rainfall (mm)	Coefficient of Variation (%)	Standard Deviation
1	Chhindwara	960	36.05	34.61
2	Mohkher	886	34.16	30.25
3	Tamia	1893	33.24	62.92
4	Amarwara	1131	37.17	42.05
5	Chaurai	1086	30.37	33.00
6	Harrai	1148	35.15	47.36
7	Sausar	720	26.90	19.38
8	Pandhurna	815	28.11	22.90
9	Bichhua	1028	33.73	34.69
10	Parasia	1112	32.51	36.16
11	Jamai	1287	37.10	47.74

Table 4.2: Frequency of drought years for annual rainfall

SI. No.	Name of block	Mean annual rainfall (mm)	Average drought frequency	Years with more than 25% deficiency in annual rainfall
1	Chhindwara	960	4	1992, 1996, 2000, 2001
2	Mohkher	886	3	1995, 2000, 2001
3	Tamia	1893	4	1996, 1998, 2000, 2001
4	Amarwara	1131	4	1992, 1996, 2000, 2001
5	Chaurai	1086	3	1995, 2000, 2001
6	Harrai	1148	3	1995, 1996, 1998
7	Sausar	720	3	1992, 1996, 2000
8	Pandhurna	815	1	2000
9	Bichhua	1028	3	1992, 2000, 2001
10	Parasia	1112	2	2000, 2001
11	Jamai	1287	4	1992, 1996, 2000, 2001

Table 4.3: Frequency of drought years for Seasonal rainfall

SI. No.	Name of block	Mean seasonal rainfall (mm)	Years with more than 25% deficiency in seasonal rainfall
1	Chhindwara	781	1996, 2000, 2001
2	Mohkher	794	2000, 2001
3	Tamia	1765	1996, 1998, 2000, 2001
4	Amarwara	991	1996, 2000, 2001
5	Chaurai	965	2000, 2001
6	Harrai	1065	1995, 1998
7	Sausar	653	1996, 2000
8	Pandhurna	696	2000
9	Bichhua	917	1992, 2000, 2001
10	Parasia	969	2000, 2001
11	Jamai	1145	1996, 2000, 2001

Table 5.1: Block wise probability analysis of annual rainfall

SI. No.	Name of block	Mean annual rainfall (mm)	Rainfall at 75% probability level (mm)	Probability of occurrence of rainfall equivalent to 75% of normal (%)
1	Chhindwara	960	678	64
2	Mohkher	886	631	69
3	Tamia	1893	1291	61
4	Amarwara	1131	821	63
5	Chaurai	1086	766	68
6	Harrai	1148	813	70
7	Sausar	720	530	73
8	Pandhurna	815	629	83
9	Bichhua	1028	676	70
10	Parasia	1112	800	74
11	Jamai	1287	884	62

Table 6.1: Average dates of onset and withdrawal of effective monsoon

SI. No.	Name of block	Mean date of onset of monsoon	Standard deviation of onset (days)	Mean date of withdrawal of monsoon
1	Chhindwara	18 June	13	26 Sept
2	Mohkher	15 June	9	27 Sept
3	Tamia	13 June	5	29 Sept
4	Amarwara	14 June	10	30 Sept
5	Chaurai	15 June	7	01 Oct
6	Harrai	19 June	12	24 Sept
7	Sausar	18 June	11	25 Sept
8	Pandhurna	19 June	12	25 Sept
9	Bichhua	21 June	11	24 Sept
10	Parasia	21 June	13	19 Sept
11	Jamai	17 June	11	22 Sept

Table 6.2: Median dates of onset and withdrawal of effective monsoon

SI. No.	Name of block	Median date of onset of monsoon	Semi- inter quartile rang of onset (days)	Median date of withdrawal of monsoon
1	Chhindwara	14 June	2	26 Sept
2	Mohkher	16 June	4	29 Sept
3	Tamia	15 June	4	28 Sept
4	Amarwara	13 June	5	3 Oct
5	Chaurai	15 June	3	28 Sept
6	Harrai	17 June	6	24 Sept
7	Sausar	19 June	9	26 Sept
8	Pandhurna	16 June	10	23 Sept
9	Bichhua	19 June	9	26 Sept
10	Parasia	18 June	10	20 Sept
11	Jamai	15 June	4	21 Sept

Table 6.3: Occurrence of Critical Dry Spell (*CDS*) during monsoon season

Sl. No.	Name of Block	First *CDS*		Second *CDS*	
		Probable period of commencement	Average length in days	Probable period of commencement	Average length in days
1	Chhindwara	June -IV Week	16	Aug- IV Week	24
2	Mohkher	June- IV Week	15	Aug- III Week	22
3	Tamia	June- IV Week	15	Sept- III Week	19
4	Amarwara	June- IV Week	13	Aug- II Week	19
5	Chaurai	July- II Week	12	Sept- III Week	21
6	Harrai	June- IV Week	13	Aug- III Week	13
7	Sausar	June- IV Week	13	Aug- II Week	19
8	Pandhurna	June- IV Week	14	July- IV Week	27
9	Bichhua	July- II Week	17	Sept- III Week	20
10	Parasia	June- IV Week	17	Aug- I Week	17
11	Jamai	July- I Week	15	Sept- II Week	21

Table 7.1: Average daily reference crop evapotranspiration (*ETp*) for 52 standard weeks in mm/day

Week No.	ETp	Week No.	ETp	Week No.	ETp
1	2.10	19	7.19	37	4.48
2	2.20	20	7.33	38	4.51
3	2.21	21	7.45	39	4.57
4	2.24	22	7.44	40	4.11
5	2.40	23	6.79	41	4.10
6	3.28	24	6.43	42	4.05
7	3.36	25	6.70	43	3.97
8	3.49	26	6.70	44	3.97
9	3.65	27	5.60	45	3.29
10	4.54	28	5.46	46	3.19
11	4.66	29	4.80	47	3.08
12	4.79	30	4.79	48	2.93
13	4.89	31	4.80	49	2.19
14	5.31	32	4.62	50	2.11
15	5.63	33	4.72	51	2.09
16	5.82	34	4.67	52	2.10
17	6.01	35	4.61		
18	6.14	36	4.40		

Table 7.2: Crop coefficients (*Kc*) values during the growing stages of different crops

Sl. N.	Crop	*Kc* values during different crop development stages				
		Initial	Crop development	Mid season	Late season	At harvest
1	Paddy	1.10-1.15	1.10-1.50	1.10-1.30	0.95-1.05	0.95-1.05
2	Soyabean	0.30-0.40	0.70-0.80	1.00-1.15	0.70-0.80	0.40-0.50
3	Sorghum	0.30-0.40	0.70-0.75	1.00-1.15	0.75-0.80	0.50-0.55
4	Cotton	0.40-0.50	0.70-0.80	1.05-1.25	0.80-0.90	0.65-0.70
5	Maize	0.40-0.50	0.70-0.90	1.05-1.20	1.00-1.15	0.95-1.10
6	Pearl-millet	0.25-0.30	0.40-0.70	1.05-1.10	1.00-1.05	0.40-0.70
7	Black gram	0.25-0.30	0.40-0.70	1.00-1.10	1.00-1.10	0.50-0.80
8	Vegetable	0.25-0.40	0.50-0.60	0.60-0.70	0.50-0.70	0.50-0.70
9	Seasamum	0.25-0.30	0.40-0.60	0.90-1.15	0.80-1.10	0.70-0.90
10	Groundnut	0.30-0.40	0.40-0.80	0.80-1.00	0.80-0.90	0.70-0.80
11	Sugarcane	0.50-0.60	0.60-0.90	1.00-1.15	1.10-1.20	1.00-1.20

(Source: Water Management Division, Ministry of Irrigation, Government of India.1984).

Table 7.3: Crop water requirement (*ETcrop*) for different time interval during growing period of Rice crop.

Sl. No.	Standard Week	*ETp* (mm/day)	*Kc*	*ETcrop* (mm)
1	25	6.70	1.10	51.56
2	26	6.70	1.10	51.59
3	27	5.60	1.10	43.13
4	28	5.46	1.10	42.01
5	29	4.80	1.10	36.98
6	30	4.79	1.05	35.24
7	31	4.80	1.05	35.25
8	32	4.62	1.05	33.98
9	33	4.72	1.05	34.67
10	34	4.67	1.05	34.35
11	35	4.61	0.95	30.62
12	36	4.40	0.95	29.26
13	37	4.48	0.95	29.80
14	38	4.51	0.95	29.96
Total water requirement of Rice = 518.40 mm				

Table 7.4: Effective rainfall during two Critical Dry Spell (*CDS*)

SI. No.	Name of block	Duration of *CDS* (days)		Effective Rainfall during *CDS* (mm)	
		1st *CDS*	2nd *CDS*	1st *CDS*	2nd *CDS*
1	Chhindwara	16	24	44	65
2	Mohkher	15	22	49	55
3	Tamia	15	19	68	52
4	Amarwara	13	19	44	62
5	Chaurai	12	21	73	63
6	Harrai	13	13	44	43
7	Sausar	13	19	32	42
8	Pandhurna	14	27	43	66
9	Bichhua	17	20	81	32
10	Parasia	17	17	53	58
11	Jamai	15	21	50	65

Table7.5: Water Requirement (*ETcrop*) for selected major crops during critical dry spells

Sl. No.	Station	Effective CDS	Water requirement (*ETcrop*) in mm										
			Rice	Maize	Sorghum	Sugar cane	Cotton	Groundnut	Soyabean	Sesamum	Pearl milet	Vegetable	Black gram
1	Chhindwara	1st	107.03	40.87	38.92	97.30	56.43	38.92	43.79	67.14	76.87	36.97	45.73
		2nd	90.44	108.53	109.48	114.24	95.20	91.39	76.16	104.72	**	57.12	34.27
2	Mohkher	1st	99.66	38.05	36.24	90.60	52.55	36.24	40.77	62.51	71.57	34.43	42.58
		2nd	110.88	120.38	121.44	126.72	110.88	101.38	84.48	116.16	**	63.36	84.48
3	Tamia	1st	99.66	38.05	36.24	90.60	52.55	36.24	40.77	62.51	71.57	34.43	42.58
		2nd	82.49	98.99	99.85	104.20	82.49	81.62	60.78	**	**	43.42	**
4	Amarwara	1st	88.55	33.81	32.20	80.50	46.69	32.20	36.23	55.55	63.60	30.59	37.84
		2nd	94.16	102.24	83.40	107.62	95.96	84.30	67.26	103.13	30.49	56.50	98.65
5	Chaurai	1st	68.80	36.04	32.76	65.52	67.49	39.31	32.76	75.35	70.76	42.59	51.76
		2nd	89.97	107.97	108.92	113.65	89.97	89.03	66.30	**	**	47.36	**
6	Harrai	1st	88.55	33.81	32.20	80.50	46.69	32.20	36.23	55.55	63.60	30.59	37.84
		2nd	57.67	69.21	69.82	72.85	57.67	57.07	42.50	**	**	30.36	**
7	Sausar	1st	83.60	31.92	30.40	76.00	64.60	30.40	34.20	52.44	60.04	41.80	35.72
		2nd	94.16	102.24	83.40	107.62	95.96	84.30	67.26	103.13	30.49	56.50	98.65
8	Pandhurna	1st	87.45	33.39	31.80	79.50	67.58	31.80	35.78	54.86	62.81	30.21	37.37
		2nd	133.25	144.67	133.25	152.28	135.78	119.29	95.18	145.94	43.15	79.95	139.59
9	Bichhua	1st	97.46	51.05	46.41	92.82	95.60	55.69	46.41	106.74	100.25	60.33	73.33
		2nd	85.69	81.18	99.22	108.24	76.67	82.08	54.12	**	**	**	**
10	Parasia	1st	113.19	43.22	41.16	102.90	87.47	41.16	46.31	71.00	81.29	56.60	48.36
		2nd	84.25	91.47	74.62	96.29	85.86	75.43	60.18	92.28	27.28	50.55	88.26
11	Jamai	1st	88.20	46.20	42.00	84.00	86.52	50.40	42.00	96.60	90.72	54.60	66.36
		2nd	89.38	107.25	108.19	112.90	89.38	88.44	65.86	**	**	**	**

** No irrigation required as crop period is over

Table7.6 : Irrigation Requirement (*IR*) for selected major crops during critical dry spells

SI. No.	Station	Rice	Maize	Sorghum	Sugar-cane	Cotton	Ground-nut	Soyabean	Sesamum	Pearl Milet	Vegetable	Black Gram
1	Chhindwara	88.47	40.39	39.40	102.54	42.63	21.31	10.95	62.86	**	**	**
2	Mohkher	106.54	54.44	53.68	113.22	59.43	33.62	21.25	74.67	**	**	23.06
3	Tamia	62.15	17.04	16.09	74.80	15.04	**	**	**	**	**	**
4	Amarwara	76.71	30.05	9.60	82.12	36.65	10.50	**	52.68	**	**	30.48
5	Chaurai	42.77	28.01	25.68	63.17	41.46	12.34	**	**	**	**	**
6	Harrai	59.22	16.02	15.02	66.35	17.36	2.27	**	**	**	**	**
7	Sausar	103.76	60.16	39.80	109.62	86.56	40.70	27.46	81.57	16.53	24.30	60.37
8	Pandhurna	111.70	69.06	56.05	122.78	94.36	42.09	21.95	91.79	**	1.16	67.96
9	Bichhua	70.15	19.23	32.63	88.06	59.27	24.77	**	**	**	**	**
10	Parasia	86.44	23.69	4.78	88.19	62.32	5.59	**	52.28	**	**	25.63
11	Jamai	62.58	38.45	35.19	81.90	60.90	23.84	**	**	**	**	**

Table 8.1: Derived truncation level at different dependability levels at Hirnakheri

Month	Dependable Flow (m^3/s))			
	At 75% dependability	At 70% dependability	At 80% dependability	At 90% dependability
June	5.50	6.50	5.20	3.95
July	14.00	16.00	11.80	6.53
August	28.00	36.50	25.50	11.91
September	26.01	32.01	12.30	9.87
October	16.20	21.40	13.70	10.40
November	10.97	10.97	10.90	9.10
December	3.58	6.71	3.51	2.60
January	12.23	12.60	12.06	6.30
February	9.23	9.60	9.05	6.71
March	3.58	3.74	3.51	2.60
April	2.65	2.70	2.62	2.06
May	1.45	1.46	0.93	0.91

Table 8.2: Derived truncation level at different dependability levels at Chand

Month	Dependable Flow (m^3/s))			
	At 75% dependability	At 70% dependability	At 80% dependability	At 90% dependability
June	7.60	7.61	7.14	5.0
July	1.57	1.72	1.33	0.74
August	6.10	6.15	5.10	3.13
September	7.11	8.08	6.13	4.48
October	3.68	4.07	2.82	1.59
November	3.01	4.60	1.12	0.93
December	9.21	10.24	8.92	6.38
January	3.6	3.90	3.35	0.99
February	2.58	2.69	2.48	2.33
March	1.77	2.35	1.72	0.78
April	0.46	0.56	0.39	0.38
May	--------------------------No flow------------------------------------			

Table 8.3: Derived truncation level at different dependability levels at Ramakona

Month	Dependable Flow (m^3/s))			
	At 75% dependability	At 70% dependability	At 80% dependability	At 90% dependability
June	0.80	0.86	0.77	0.59
July	13.00	14.23	11.52	8.35
August	15.27	15.66	13.83	9.60
September	13.68	15.27	12.78	9.60
October	8.02	9.60	7.87	5.80
November	5.81	6.34	5.80	4.03
December	1.10	1.20	1.07	0.90
January	3.10	3.21	2.63	1.71
February	1.57	2.63	1.40	1.20
March	3.05	3.10	2.93	1.71
April	0.70	0.74	0.69	0.60
May	0.57	0.59	0.56	0.54

Table 8.4: Severity of low flow and its duration at Hirnakheri
(Flow data from July, 1989 to October, 1998)

Sl. No.	Event	Onset of Event	Termination of Event	Severity (MCM)	Duration (days)
1	I	01/01/90	10/01/90	4.96	10
2	II	01/01/91	11/01/91	5.44	11
3	III	14/02/91	28/02/91	2.80	15
4	IV	01/07/91	24/07/91	9.83	24
5	V	31/08/91	30/09/91	37.26	31
6	VI	10/11/91	30/11/91	3.08	21
7	VII	01/12/92	31/12/92	2.31	31
8	VIII	07/08/93	20/08/93	17.88	14
9	IX	01/03/94	31/03/94	2.29	31
10	X	18/04/94	30/04/94	0.48	13
11	XI	10/10/95	31/10/95	12.52	22
12	XII	01/07/98	10/07/98	8.48	10
13	XIII	05/08/98	13/09/98	46.49	39
14	XIV	19/09/98	30/09/98	13.95	12
15	XV	09/10/98	31/10/98	10.15	23

Table 8.5: Severity of low flow and its duration at Chand
(Flow data from June, 1989 to October, 1998)

Sl. No.	Event	Onset of Event	Termination of Event	Severity (MCM)	Duration (days)
1	I	11/09/89	25/09/89	3.56	15
2	II	06/10/89	30/11/89	9.42	55
3	III	19/01/90	31/01/90	0.33	13
4	IV	09/02/90	28/2/90	0.32	20
5	V	19/03/90	30/2/90	0.96	12
6	VI	28/09/95	8/10/95	0.79	11
7	VII	10/10/95	31/10/95	5.09	22
8	VIII	01/08/96	19/08/96	3.84	17
9	IX	01/07/97	11/07/97	0.80	11
10	X	06/08/97	21/08/97	4.40	16
11	XI	19/12/97	30/12/97	3.25	12
12	XII	14/07/98	27/07/98	0.34	14
13	XIII	30/08/98	12/09/98	3.27	14

Table 8.6: Severity of low flow and its duration at site Ramakona
(Flow data from June, 1989 to May, 1996)

Sl. No.	Event	Onset of Event	Termination of Event	Severity (MCM)	Duration (days)
1	I	9/12/90	31/12/90	0.17	13
2	II	01/07/91	13/07/91	6.63	13
3	III	24/08/91	02/09/98	3.50	10
4	IV	10/09/91	16/10/91	10.46	36
5	V	04/01/92	17/01/92	1.35	14
6	VI	03/03/92	15/03/92	1.64	13
7	VII	20/11/95	30/11/95	2.87	11
8	VIII	16/01/96	12/02/96	2.39	27
9	IX	01/06/96	14/06/96	0.23	14

Appendix A: Crop water requirement (ETcrop) for different time interval during growing period of Maize

Sl. No.	Standard Week	ETp (mm/day)	Kc	ETcrop (mm)
1	26	6.70	0.42	19.70
2	27	5.60	0.42	16.47
3	28	5.46	0.42	16.04
4	29	4.80	0.42	14.12
5	30	4.79	0.55	18.46
6	31	4.80	0.63	21.15
7	32	4.62	0.89	28.80
8	33	4.72	1.06	35.00
9	34	4.67	1.14	37.30
10	35	4.61	1.14	36.75
11	36	4.40	1.14	35.11
12	37	4.48	1.14	35.76
13	38	4.51	1.14	35.95
Total water requirement of Maize crop = 449.49 mm				

Appendix B: Crop water requirement (ETcrop) for different time interval during growing period of Groundnut

Sl. No.	Standard Week	ETp (mm/day)	Kc	ETcrop (mm)
1	26	6.70	0.30	14.07
2	27	5.60	0.30	11.76
3	28	5.46	0.45	17.19
4	29	4.80	0.45	15.13
5	30	4.79	0.60	20.14
6	31	4.80	0.78	26.18
7	32	4.62	0.85	27.51
8	33	4.72	0.90	29.72
9	34	4.67	0.95	31.08
10	35	4.61	0.95	30.62
11	36	4.40	0.95	29.26
12	37	4.48	0.90	28.23
13	38	4.51	0.86	27.12
14	39	4.57	0.72	23.05
15	40	4.11	0.60	17.26
16	41	4.10	0.55	15.77
Total water requirement of Groundnut crop = 449.49 mm				

Appendix C: Crop water requirement (ETcrop) for different time interval during growing period of Sorghum

Sl. No.	Standard Week	ETp (mm/day)	Kc	ETcrop (mm)
1	27	5.60	0.40	15.68
2	28	5.46	0.40	15.28
3	29	4.80	0.40	13.45
4	30	4.79	0.50	16.78
5	31	4.80	0.60	20.14
6	32	4.62	0.70	22.65
7	33	4.72	0.75	24.77
8	34	4.67	0.93	30.43
9	35	4.61	1.05	33.85
10	36	4.40	1.15	35.42
11	37	4.48	1.15	36.07
12	38	4.51	1.15	36.27
13	39	4.57	1.10	35.21
14	40	4.11	0.80	23.02
15	41	4.10	0.60	17.20
16	42	4.05	0.50	14.18
17	43	3.97	0.50	13.91
Total water requirement of Sorghum crop = 404.31 mm				

Appendix D: Crop water requirement (ETcrop) for different time interval during growing period of Soyabean

Sl. No.	Standard Week	ETp (mm/day)	Kc	ETcrop (mm)
1	25	6.70	0.30	14.06
2	26	6.70	0.35	16.41
3	27	5.60	0.40	15.68
4	28	5.46	0.45	17.19
5	29	4.80	0.50	16.81
6	30	4.79	0.50	16.78
7	31	4.80	0.55	18.46
8	32	4.62	0.63	20.39
9	33	4.72	0.70	23.11
10	34	4.67	0.75	24.54
11	35	4.61	0.80	25.79
12	36	4.40	0.75	23.10
13	37	4.48	0.70	21.96
14	38	4.51	0.60	18.92
15	39	4.57	0.55	17.61
Total water requirement of Soyabean crop = 290.81 mm				

Appendix E: Crop water requirement (ETcrop) for different time interval during growing period of Sugarcane

Sl. No.	Standard Week	ETp (mm/day)	Kc	ETcrop (mm)
1	23	6.79	1.00	47.50
2	24	6.43	1.00	45.04
3	25	6.70	1.00	46.87
4	26	6.70	1.10	51.59
5	27	5.60	1.10	43.13
6	28	5.46	1.10	42.01
7	29	4.80	1.10	36.98
8	30	4.79	1.20	40.27
9	31	4.80	1.20	40.28
10	32	4.62	1.20	38.83
11	33	4.72	1.20	39.62
12	34	4.67	1.20	39.26
13	35	4.61	1.20	38.68
14	36	4.40	1.20	36.96
15	37	4.48	1.20	37.64
16	38	4.51	1.20	37.84
17	39	4.57	1.10	35.21
18	40	4.11	1.10	31.65
19	41	4.10	1.10	31.54
20	42	4.05	0.95	26.95
21	43	3.97	0.95	26.42
22	44	4.10	0.95	27.24
Total water requirement of Sugarcane crop = 841.53 mm				

Appendix F: Crop water requirement (ETcrop) for different time interval during growing period of Sesamum

Sl. No.	Standard Week	ETp (mm/day)	Kc	ETcrop (mm)
1	23	6.79		
2	24	6.43	0.20	9.01
3	25	6.70	0.20	9.37
4	26	6.70	0.20	9.38
5	27	5.60	0.42	16.47
6	28	5.46	0.69	26.35
7	29	4.80	0.96	32.27
8	30	4.79	1.15	38.59
9	31	4.80	1.15	38.60
10	32	4.62	1.15	37.21
11	33	4.72	1.15	37.97
12	34	4.67	1.15	37.62
13	35	4.61	1.10	35.46
14	36	4.40	0.67	20.64
15	37	4.48	0.40	12.55
Total water requirement of Sesamum crop = 361.50 mm				

Appendix G: Crop water requirement (ETcrop) for different time interval during growing period of Cotton

Sl. No.	Standard Week	ETp (mm/day)	Kc	ETcrop (mm)
1	24	6.43	0.22	9.91
2	25	6.70	0.24	11.25
3	26	6.70	0.35	16.41
4	27	5.60	0.58	22.74
5	28	5.46	0.85	32.46
6	29	4.80	0.95	31.94
7	30	4.79	1.03	34.57
8	31	4.80	1.03	34.57
9	32	4.62	1.08	34.95
10	33	4.72	1.08	35.66
11	34	4.67	1.07	35.01
12	35	4.61	1.05	33.85
13	36	4.40	1.00	30.80
14	37	4.48	0.95	29.80
15	38	4.51	0.85	26.81
16	39	4.57	0.62	19.85
17	40	4.11	0.40	11.51
Total water requirement of Cotton crop = 452.08 mm				

Appendix H: Crop water requirement (ETcrop) for different time interval during growing period of Vegetable

Sl. No.	Standard Week	ETp (mm/day)	Kc	ETcrop (mm)
1	26	6.70	0.30	14.07
2	27	5.60	0.30	11.76
3	28	5.46	0.35	13.37
4	29	4.80	0.55	18.49
5	30	4.79	0.65	21.81
6	31	4.80	0.65	21.82
7	32	4.62	0.65	21.03
8	33	4.72	0.65	21.46
9	34	4.67	0.65	21.27
10	35	4.61	0.60	19.34
11	36	4.40	0.55	16.94
12	37	4.48	0.50	15.64
13	38	4.51	0.45	14.19
Total water requirement of Vegetable =231.24 mm				

Appendix I: Crop water requirement (ETcrop) for different time interval during growing period of Black Gram

Sl. No.	Standard Week	Etp (mm/day)	Kc	ETcrop (mm)
1	25	6.70	0.30	14.06
2	26	6.70	0.30	14.07
3	27	5.60	0.30	11.76
4	28	5.46	0.47	17.95
5	29	4.80	0.63	21.18
6	30	4.79	0.79	26.51
7	31	4.80	0.93	31.22
8	32	4.62	1.10	35.60
9	33	4.72	1.10	36.32
10	34	4.67	1.10	35.99
11	35	4.61	0.80	25.79
12	36	4.40	0.36	11.09
Total water requirement of Black Gram crop =281.54 mm				

Appendix J: Crop water requirement (ETcrop) for different time interval during growing period of Pearl Millet

Sl. No.	Standard Week	Etp (mm/day)	Kc	ETcrop (mm)
1	25	6.70	0.30	14.06
2	26	6.70	0.30	14.07
3	27	5.60	0.42	16.41
4	28	5.46	0.79	30.17
5	29	4.80	1.05	35.30
6	30	4.79	1.08	36.24
7	31	4.80	1.08	36.25
8	32	4.62	1.08	34.95
9	33	4.72	0.66	21.79
10	34	4.67	0.34	11.12
Total water requirement of Pearl Millet crop =250.43 mm				