Identification of Meteorological and Hydrological Droughts in Central India

R.V. Galkate[1], R.P. Pandey[2], T. Thomas[1] and R.K. Jaiswal[1]

1.Scientist, National Institute of Hydrology, GPSRC, Sagar – 470001
2.Scientist, National Institute of Hydrology, Roorkee – 247667

Abstract

Central part of India is facing the problems of recurrent droughts which are unpredictable phenomena both in their occurrence and duration; hence prevision and preparation against droughts are key elements for minimizing their impact. The present paper examines the meteorological, hydrological and agricultural aspects of drought in Chhindwara district of Madhya Pradesh located in central part of India. Assessment of meteorological and hydrological drought situation has been carried out through rainfall analysis and stream flow analysis using flow duration curve technique respectively. 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. In Chhindwara district approximately one out of every four to five year has been observed as a drought year and in some years deficiency in annual rainfall is observed up to 65%. The years 2000 and 2001 were severe meteorological drought years as most of the blocks of the district were under drought. Major part of the district has been found as a drought prone area where the probability of occurrence of rainfall equivalent to 75% of normal annual rainfall was less than 80%. 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) were observed during the monsoon season with duration of 12 to 17 and 13 to 27 days. The maximum crop water requirement has been observed for rice and sugarcane during two CDS in the district. Low flow analysis has been carried out for the stream flow data of Hirankheri G/D site on Pench river. The maximum 75% dependable flow has been observed in August whereas the minimum 75% dependable flow has been observed in May. It is seen that the severity of low flow 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 indicating severe hydrological drought in the region.

Key Words: Meteorological droughts, hydrological droughts, drought prone area, critical dry spells, supplemental irrigation, low flow

Introduction

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). Meteorological drought is usually defined by the measure of the departure of precipitation from the normal and the duration of the

dry period. 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).

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 country 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. 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 (Verma and Sarma, 1989). Low stream flows and reduced reservoir storages are indicative of drought situations. The rainfall deficiency is reflected in the resulted stream flow and studied using flow duration curves technique.

Study Area

Chhindwara district of Madhya Pradesh is located on a section of the Satpura plateau and extends between the parallels of latitude 21° 28′ to 22° 49′ N and the longitude 78° 20′ to 79° 24′ E. The geographical area of Chhindwara district is 11815 sq. km. The district has 11 Development Blocks namely, Chhindwara, Parasia, Junnardeo, Tamia, Amarwara, Chourai, Bicchua, Harrai, Mohkher, Sausar and Pandhurna. 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. The average annual rainfall in the district is 1324 mm. The oldest geological 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 major five types of soils present in the district are alluvial, Silty, lateritic, sandy and black cotton soil. Soyabean, wheat, sorghum, groundnut and cotton are the major crops cultivated in the district. River network and locations of raingauge stations and gauge discharge sites in district are shown in Figure 1.

Assessment of Drought

According to WMO (1975) Meteorological drought is characterized 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%. The rainfall data of all the eleven blocks of Chhindwara district were analyzed to study rainfall distribution and the magnitude and frequency of drought in terms of rainfall deficiency.

Seasonal rainfall departure

In the district the entire cultivation is governed by quantity, distribution and time of onset of effective monsoon. In order to compute the deficiency in seasonal rainfall, the seasonal rainfall departure has been carried out. Normal rainfall of the monsoon season was calculated as the arithmetic mean of the rainfall during June to September. India meteorological Department defined seasonal drought as the period with the seasonal rainfall deficiency more than 25% from its normal value. From the seasonal rainfall departure analysis, the drought years have been identified and its average frequency of drought is presented in Table 1.

Table 1: Frequency of drought years in Chhindwara district for Seasonal rainfall

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

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% (CWC, 1982). Percentage probability of occurrence of rainfall equivalent to the 75% of normal is presented in Table 2.

Table 2: Probability distribution analysis of annual rainfall in Chhindwara district

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

From the analysis of rainfall data it is observed that the mean annual rainfall in Chhindwara district is 1324 mm and it 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 (37.7%).

The seasonal rainfall departure analysis shows that the drought frequency varies from 2 to 3 out of period of 11 years in the district except in Pandhurna block. This indicates the possibility of occurrence of drought year out of every four to five years. It is also observed that in year 2000 all the blocks except Harrai were under 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, five 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 in Pandhurna block where the probability of occurrence is 83%.

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. The dry spells which occur within the rainy season causes severe effect on agriculture and normal life pattern of the region hence the analysis of dry spell within monsoon season is very important especially for rainfed agriculture in the country.

Reference evapotranspiration (*ETp*)

The potential reference evapotranspiration (*ETp*) has been estimated using modified Penman method (1963). Average daily reference evapotranspiration has been calculated for 52 standard weeks of the year 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).

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 criteria that the first day's rain in seven days spell is not less than average daily evapotranspiration (*ETp*), at least four out of seven days are rainy days with not less than 2.5 mm of rain each day and the total rain during the seven days spell is not less than (5ET+10) mm. (Verma and Sarma, 1989). Using these criterions the rainfall records have been analyzed to identify the date of EMO in respective years. The mean date of onset of effective monsoon, its standard deviation and mean date of withdrawal of effective monsoon are presented in Table 3.

Table 3: Mean 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

Critical dry spell (CDS)

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 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. Based on the above definition, all the dry spells after the date of onset of effective monsoon 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).

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 in Chhindwara district are presented in the Table 4. 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.

Table 4: 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

From the analysis of Table 3 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.

The critical dry spells (CDS) analysis shows the occurrence of on an average only two CDS every year 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.

Supplimental Irrigation Requirement (*ETcrop*)

Crop evapotranspiration

In order to take in to account the effect of crop characteristics and its growth stages on potential reference evapotranspiration (*ETp*), the crop-evapotranspiration also called crop water requirement (*ETcrop*) is calculated by multiplying the crop coefficient (*Kc*) with the reference evapotranspiration (*ETp*) as given below:

$$ETcrop = Kc \times ETp \quad (1)$$

The selection procedure for appropriate *Kc* values taken in to account the crop characteristics, sowing time, crop development rate, length of growing season and general climatic condition. Crop coefficient (*Kc*) values for different growing phases of crops are obtained from a Guide for Estimating Irrigation Water Requirements, Govt. of India (1984).

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). Effective rainfall during the probable critical dry spells (CDS) in different blocks in Chhindwara has been estimated using evapotranspiration/precipitation ratio method (Table 34 in FAO Paper No. 24, by Doorenbos and Pruitt, 1977).

Irrigation Requirement (IR)

In kharif season normally crop failure happen due to water stress during critical dry spells. The crop water requirement (*ETcrop*) of major crops in the district has been estimated for two critical dry spells using equation 1. The irrigation requirement (*IR*) of crop has been obtained as the difference between crop water requirement (*ETcrop*) and the effective rainfall (*ER*). The irrigation requirement of selected crops has been estimated using equation given below:

$$IR = ETcrop - ER \quad (2)$$

The irrigation requirement (*IR*) of major crops during both critical dry spell is presented in Table 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 within short time period, preferably within 7 to 10 days.

Table 5: Total supplemental irrigation Requirement (IR) for major crops during 1st and 2nd critical dry spells

Sl. No	Station	Rice	Maize	Sor-ghum	Sugar-cane	Cotton	Ground-nut	Soya-bean
1	Chhindwara	88.47	40.39	39.40	102.54	42.63	21.31	10.95
2	Mohkher	106.54	54.44	53.68	113.22	59.43	33.62	21.25
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	**
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
8	Pandhurna	111.70	69.06	56.05	122.78	94.36	42.09	21.95
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	**
11	Jamai	62.58	38.45	35.19	81.90	60.90	23.84	**

(** No irrigation required)

From the analysis it is observed that the of water requirement (*ETcrop*) during second CDS is higher than the first CDS, this is due to the fact that during second CDS maximum crops are either in development stage or in mid-season stage and the average duration of second CDS is longer than that of the first CDS. 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 total irrigation requirement of 122.78 mm during both 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.

Stream Flow Analysis

During the rainfall deficient condition the deviation from normal values is greater for stream flows than the rainfall. The low stream flows 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. Low flow analysis is mainly concerned with the magnitude of low flow, its duration and frequency of occurrence. Low flow analysis has been carried out for the flow data of sites Hirankheri on Pench 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. Monthly flow duration curves drawn for June month for site Hirnakheri is shown in the Figure 2.

The flow volumes at various probability levels were obtained from flow duration curves. 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 conditions persisting for more than ten days period were identified. The magnitude of severity of low flow events and their durations at site Hirnakheri are shown in Table 6.

Table 6: Severity of low flow and its duration at site Hirnakheri
(Flow data of period from July, 1989 to Oct, 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	2.8	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

From the low flow analysis at Hirankheri, it can be seen that the maximum 75% dependable flow is 28.0 m^3/s in August whereas the minimum 75% dependable flow is 1.45 m^3/s in May. 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 Hirankheri 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 Hirankheri.

Conclusions

The mean annual rainfall of Chhindwara district is 1324 mm and the deficiency of annual rainfall varies up to 65% in various blocks of Chhindwara district. The drought frequency analysis indicated that approximately one out of every four to five year is a drought year, which needs to be taken care of while planning for irrigation and other water resources development projects in the district. Seasonal rainfall departure analysis indicated that the years 2000 and 2001 were severely affected years as most of the area of these districts was under drought. As the probability of occurrence of rainfall equivalent to 75% of normal rainfall has been observed less than 80% in most of the blocks, 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. On an average only two critical dry spells (CDS) have been observed during the monsoon season. The first CDS has been occurred in last week of June whereas second CDS occurred in August or 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. The maximum crop water requirement has been observed for rice crop and sugarcane during first and second CDS respectively. Crop water requirement during second CDS has been observed higher than the first CDS, since during second CDS, crops are under development stage or mid-season stage and also as the average duration of second CDS is longer than that of the first CDS.

The low flow analysis indicated that the maximum 75% dependable flow has been seen in August whereas the minimum 75% dependable flow in May. At Hirnakheri the severity of low flow varied from 0.48 to 46.49 MCM and the duration of low flow epoch ranges from 10 to 39 days. Years 1991 and 1997 were observed as runoff deficit years.

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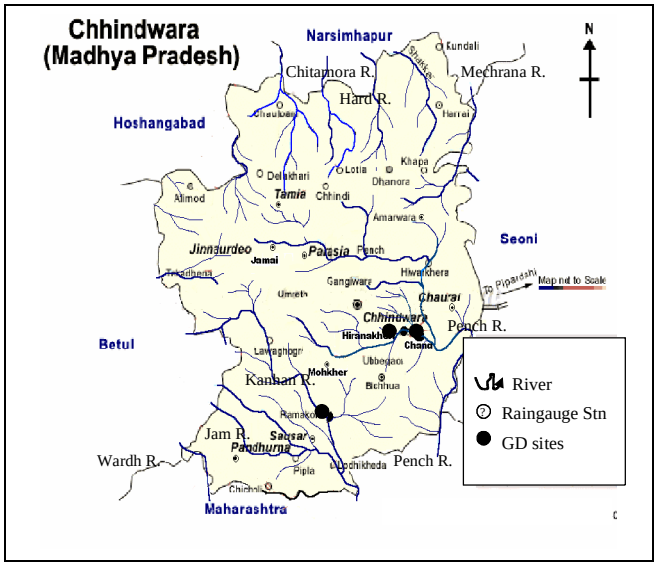

Figure 1: River network, location of raingauge stations and gauge discharge sites in Chhindwara district

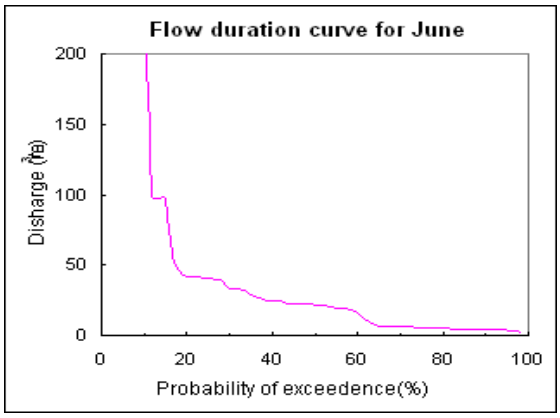

Figure 2: Flow duration curves for June month at Hirnakheri