III. ECOLOGICAL FEATURES OF CHHATTISGARH

In this Chapter, we present an analysis of the ecological data on Chhattisgarh on both spatial and numeric basis. We will look at soil, slope, forest cover, geo-hydrology and rainfall. We analyze each feature/variable separately, and in relation to each other. We then understand how each contributes to the mitigation or exacerbation of drought vulnerability. We treat the spatial data statistically and convert it to numeric variables, first, for each ecological unit first and then for each administrative unit of a Block. We use GIS software for the conversion and amalgamation of the spatial data, which follows ecological boundaries (landform, watersheds, rivers, etc.), with numeric data for an administrative unit like a block or district so that both spatial and numeric data could be analyzed together. Finally, we assign weights on the basis of the contribution of the variables contribution to drought vulnerability, and then categorize and rank the blocks.

3.1 AGRO-METEOROLOGICAL ANALYSIS OF RAINFALL DATA

Methods of drought identification have been concerned with the identification of meteorological droughts (rainfall shortfall in relation to the normal mean and deviation by a certain percentage), hydrological droughts (reduction in water from surface and sub-surface drainages, namely, groundwater and streams) and agricultural droughts (loss of soil-moisture balance and consequent water stress and threat to plant growth). We analysed daily rainfall data for the last fifty years in order to estimate the chances of drought occurrence, and to assess the nature of the agro-meteorological problem.

Drought identification methods have been classified as follows (Cancelliere *et al* 1995):

1. **Single interval value criteria**, which determine both onset and termination of a drought by checking whether a single value of a hydrologic time series lies above or below a given threshold, which is generally the mean as in run analysis (Yevjevich 1967).
2. **Cumulative value criteria,** which determine onset and termination by comparing the cumulated values of the hydrologic variable over an appropriate time period with a set of reference values, which are generally a function of mean values (Herbst et al 1966).
3. **Compound criteria,** where the onset is identified through a single value criterion while termination takes into account the partial or total recovery from the previous deficit condition (Correia *et al* 1987).

3.1.1 Run Analysis

Perhaps, the most common method for identification of droughts is use of run analysis, because of its simplicity and generality of application. According to this method a drought period is defined as a consecutive number of intervals where the value of the selected variable lies below a given threshold or truncation level, which is typically the mean value. Deficits or surpluses are defined, respectively, as the negative or positive deviations from such a threshold. The drought period is called a negative run, and it can be characterized by means of three basic indices: length or drought duration, run sum or total deficit of the run and mean intensity defined as the ratio between run sum and length. These three indices capture the extent and severity of water stress.

Since threshold can be viewed as a water demand level, it could be either the mean, or a percentage of the mean, or a linear combination of the mean and the standard deviation (Yevjevuch 1967). Within an agro-meteorological approach, the threshold can be defined as the minimum daily/weekly rainfall required during the growing period to maintain soil moisture at the requisite level for plant stabilization and growth. This would obviously depend on the crop, as well as soil and thermal regime for each area. For Chhattisgarh we have taken 50 mm per week as the threshold level, since paddy is the main *kharif* crop and this is the average requirement under the prevailing production conditions. We then mapped percentage frequency distributions of the deficit runs and correlated these with the monthly, seasonal and annual rainfall.

3.1.2 Carry-Over Effect

Herbst (1966), Mohan and Rangacharya (1991) and Srinavas and Philipose (1993) suggested a method, which estimates agricultural drought in a more direct manner. They made two assumptions. The first assumption is that short periods with limited deficits are a normal feature for most of the climates; therefore, onset of drought must be consequent to a heavy deficit. The second assumption is that drought termination does not necessarily coincide with the occurrence of a surplus interval, since such a surplus may not be adequate to recover from drought condition. On the basis of these premises, different tests are considered to determine onset and termination of drought.

The method was intrinsically conceived to identify droughts on a monthly time scale, but we have used it on, both, a monthly and weekly time scale. As the aim of such a method was to identify agricultural droughts, it included a preliminary evaluation of effective rainfall as the sum of actual rainfall and the weighted deviation from the mean of previous month's rainfall, with the weight describing the carry-over effect.

3.1.3 Recovery Time Criterion

A method that takes into account the recovery from drought conditions was proposed by Correia et al (1987). Drought is assumed to start with the first interval below a threshold, called critical level, which usually is quite lower than the average. The end of drought does not coincide with the end of the negative run, since a certain amount of surplus must accumulate to recover from drought conditions. The accumulated surplus is computed with respect to a higher threshold (generally the average), called recovery level, and it must equal a fixed percentage of the previous cumulated deficit in order to determine end of drought. Thus, identifying drought duration involves two sub-periods, one describing the deficit condition, and the other representative of the recovery time from drought effects.

3.1.4 Commencement Of Sowing Rains (CSR)

Rainfall is a vital factor in preparation of land and sowing, and its reliability directly influences the conditions for sowing. Hence identification of specific periods of rainfall is of immense importance. For this purpose water balance technique[17] is the most suitable approach, but due to paucity of adequate data on soil moisture and evapo-transpiration, it is not easily computable. The preparation of a sowing rain commencement chart, by using long-term rainfall data and by adopting a criteria[18] that will contribute to the building of a moisture profile in the soil, is useful in rainfall analysis. The starting dates of the first spell are identified and then a frequency table of the first dates of spell of CSR is prepared. Then mean and median values for individual station are calculated and used to map the spatial distribution of the dates of CSR. This technique is used to map the probable time by which summer monsoon rains in a region would build up enough soil moisture to commence sowing. In order to measure the variability of the mean and median dates, the standard deviation and semi-inter-quartile range (SIQR)[19] were also calculated. The data is then processed to identify the years in which rainfall of 30mm, i.e., equal to or greater than the total quantum in the first CSR, has occurred on any day between the first and second inter-spell period identified for each stations. The interval between the first date of the first spell and the date of occurrence of 30mm (or more) or the first date of the second spell is then compiled station wise. The inter-spell duration is again classified into frequency distribution charts with specified ranges.

3.1.5 Inter Spell Duration And Dry Spells

The inter-spell duration is calculated to assess and identify the probability of occurrence of next favourable rain spell for the commencement of the re-sowing in case of non-occurrence of the first CSR. The first step involves aggregation and compilation of the inter-spell duration and total rainfall occurrence during this period. The second step comprises determination of frequency distribution of inter-spell duration of specified periods during the months of June, July and August[20].[21]

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[17] It takes into account precipitation, evapo-transpiration and soil moisture index to arrive at a balance between the water income and water loss.

[18] First, we must identify the rain-spell, which represents the transition from the pre-monsoon conditions. Secondly the spell chosen should be such that the total rainfall, which has occurred, is adequate and penetrates into the soil to the required depth and level and also build a moisture profile after evapo-transpiration and percolation. The criteria used for Chhattisgarh state were ‘a spell of at least 50mm of rain in a period of 7 days with 2 mm or more on any five of these seven days’. The criterion of how much rain is required in the CSR depends on bio-climatic factors like soil and temperature.

[19] Defined as half the difference of the upper and the lower quartiles: ½ (Q_3-Q_1).

[20] These are the three main months for sowing, re-sowing and monsoon occurrence.

[21] CSR and interspell duration: rationale and calculations

a. Identify the first and second spells and the quantum of rain fall of at least 30mm of rain in a period of 7 days with 2 mm or more on any five of these seven days for the months of June, July and August.
b. On the basis of the first starting dates of the spell prepare a percentage frequency distribution table, i.e. the percentage of years when the CSR 1 started on say for instance 1st June, and so on.
c. Calculate total rainfall occurring in the first and second CSR.
d. Make a frequency table showing the percentage of years when the rainfall in the first CSR was 30 to 49mm and 50 to 70 mm.
e. Calculate the variability of the mean and the median dates of first day of CSR, standard deviation and the inter quartile range.

3.1.6 Normal Rainfall

The data source for normal rainfall was Climate of Madhya Pradesh, 1981, (IMD), which had to be updated and recalculated using our data sets. In this, we analyzed the patterns of annual, seasonal and monthly rainfall, rainy days and rainfall intensity.[22]

3.1.7 Findings

Analysis of the rainfall data shows that, except for Kawardha and Rajnandgaon and a few pockets in Bilaspur, Raipur and Durg, the problem *vis-a-vis* rainfall is not one of low annual average or low seasonal average, but of its timeliness, distribution and reliability.

Blocks in the lower reaches of the long narrow district of Rajnandgaon, the southern part of Durg, all the blocks in Kawardha had low average annual and seasonal rainfall. Blocks in the central part of the state, adjoining Janjgir Champa, Raipur and Bilaspur formed another cluster of low average annual and average seasonal rainfall.

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f. Identify the days where rainfall is equal to or greater than 25mm between the first and the second CSR spell period. Then, calculate the gap between the first date of the first CSR or the first date of the second spell of 25mm or more, whichever is earlier. On the basis of this calculation, percentage frequency distribution of interspell duration is made.
g. The compilation of the inter-spell duration helps identify areas in terms of water stress into three ranges. These can be defined as those areas with a three to one chance of inter spell duration exceeding a high of 20 days, medium level of 15 days, moderate amount of 10 days and a low of 7 days during the months of June, July and August[21]. (Calculated from the percentage distribution of inter spell duration)
h. Calculate the percentage frequency distribution of consecutive dry days (defined as days having less than 2.5 mm of rainfall) (7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19… days >= 7 days)
i. Run a correlation between modal length of dry spell period and annual and seasonal rainfall in *Kharif*.

[22] The methodology and rationale was as follows:

a. Calculate total annual rainfall, standard deviation and coefficient of variation between actual and normal annual rainfall.
b. Run a correlation between actual annual rainfall and the coefficient of variation of actual annual rainfall from normal annual rainfall.
c. Calculate total monthly rainfall for the months of June, July, August, September and October.
d. Calculate standard deviation and coefficient of variation between actual and normal monthly rainfall for all months from Jun-Oct.
e. Run a correlation between actual monthly rainfall and the coefficient of variation of actual monthly rainfall from normal monthly rainfall for all months from Jun-October.
f. Calculate total seasonal rainfall for *Kharif* season by aggregating rainfall in the months of June, July, August and September.
g. Calculate standard deviation and coefficient of variation between actual and normal seasonal rainfall.
h. Run a correlation between actual seasonal rainfall and the coefficient of variation of actual seasonal rainfall from normal seasonal rainfall.

Table 3.1: Rainfall Variables

Codes	Block name	Seasonal rainfall intensity	Annual rainfall intensity	Average seasonal rainfall	Average annual rainfall	Inter spell gap 8 to 20 days	Inter spell gap greater than 8 days	Commence ment of sowing rain 15 to 28 June
101	Jagdalpur	20.06	18.81	1243	1530	12.77	24.00	48.94
102	Londigura	20.53	19.49	1263	1477	15.00	34.00	33.00
103	Darbha	20.53	19.49	1263	1530	18.18	22.73	22.73
104	Tokapal	20.53	19.49	1263	1530	15.38	29.00	52.50
105	Bastanar	20.53	19.49	1263	1530	22.00	26.00	54.00
106	Bastar	20.53	19.49	1263	1530	18.00	33.00	23.00
107	Bakaband	20.53	19.49	1350	1539	19.00	39.00	25.00
108	Kondagaon	19.21	18.23	1221	1426	21.05	21.05	47.37
109	Pharasgaon	20.53	19.49	1263	1530	25.00	27.00	66.00
110	Keshkal	23.73	22.75	1295	1499	11.11	13.89	42.11
111	Baderajpur	20.53	19.49	1243	1530	12.00	15.00	45.00
112	Narayanpur	19.47	18.60	1207	1393	12.50	12.50	57.50
113	Orcha	20.53	19.49	1243	1530	14.00	16.00	51.00
114	Makdi	20.53	19.49	1243	1530	11.00	13.00	43.00
201	Bilha	21.10	19.39	1150	1287	19.05	21.43	43.18
202	Masturi	20.29	18.88	656	956	11.00	17.00	47.00
203	Takhatpur	20.29	18.88	1122	1324	0.00	9.00	14.29
204	Mungeli	18.68	17.30	998	1156	20.93	20.93	45.45
205	Patharia	21.84	20.47	1114	1236	13.00	20.00	29.00
206	Lormi	18.72	17.54	1035	1203	10.53	21.05	36.84
207	Kota	19.70	18.27	1161	1297	20.69	20.69	33.33
208	Gaurela-2	20.29	18.88	1122	1295	12.00	29.00	30.00
209	Gaurela-1	19.23	17.99	1148	1367	16.67	38.00	58.33
210	Marwahi	20.29	18.88	1122	1295	11.00	23.00	29.00
301	Dantewada	19.06	18.20	1143	1412	12.50	15.63	53.13
302	Bijapur	22.45	21.03	1195	1658	13.16	18.42	50.00
303	Kuwakonda	21.61	20.36	1437	1527	15.00	14.00	54.00
304	Katekaleyan	21.61	20.36	1313	1527	17.00	18.00	43.00
305	Bheramgarh	21.61	20.36	1313	1527	19.00	26.00	51.00
306	Bhopal Patnam	23.62	22.02	1313	1592	20.51	25.64	43.59
307	Asur	21.61	20.36	1400	1527	14.00	27.00	35.00
308	Konta	19.86	19.14	1313	1386	28.21	30.77	56.41
309	Sukma	20.94	19.68	1313	1504	50.00	50.00	66.67
310	Chhindgarh	23.70	22.25	1282	1611	40.00	39.00	73.00
311	Gedam	21.61	20.36	1434	1527	23.08	38.46	53.85
312	jagdalpur	21.61	20.36	1313	1527	12.77	24.00	48.94
401	Dhamtari	24.56	22.48	1313	1389	14.29	14.29	60.71
402	Kurud	23.40	22.00	1116	1237	12.00	20.00	37.93
403	Magarlod	25.20	23.67	1197	1342	13.89	16.67	54.05
404	Sihawa (Nagri)	23.70	21.74	1253	1400	12.50	16.67	58.33
501	Durg	22.42	20.60	1079	1264	25.00	25.00	54.55

Codes	Block name	Seasonal rainfall intensity	Annual rainfall intensity	Average seasonal rainfall	Average annual rainfall	Inter spell gap 8 to 20 days	Inter spell gap greater than 8 days	Commence ment of sowing rain 15 to 28 June
502	Dhamdha	23.23	21.55	1084	1243	39.47	44.74	55.26
503	Gunderdehi	24.53	30.87	1199	1734	19.44	33.33	52.63
504	Patan	19.86	18.50	1030	1182	30.77	30.77	26.67
505	Sanjari Balod	26.04	24.30	991	1121	16.00	20.00	37.00
506	Doundi	22.80	21.95	1057	1193	6.00	9.00	33.33
507	Gurur	22.80	21.95	1429	1601	8.00	10.00	16.67
508	Dondilohara	22.62	21.14	1127	1304	16.67	33.33	66.67
509	Bemetara	20.72	19.10	1094	1251	30.00	30.00	38.64
510	Saja	22.80	21.95	777	898	29.00	40.00	47.00
511	Berla	22.84	20.92	1044	1187	22.86	25.71	35.14
512	Navagarh	22.45	20.98	1176	1318	26.47	32.35	50.00
601	Akaltara	22.44	20.85	1384	1507	17.00	39.00	61.00
602	Baloda	22.44	20.85	1592	1741	18.00	23.00	49.00
603	Nawagarh	22.33	20.77	1141	1359	12.50	12.50	23.53
604	Pamgarh	22.44	20.85	678	887	5.00	8.00	27.00
605	Bamhnidih	22.44	20.85	1253	1388	8.82	8.82	58.82
606	Shakti	22.55	20.91	1338	1500	9.52	14.29	45.24
607	Jaijaipur	22.44	20.85	1207	1281	16.00	15.00	35.00
608	Malkharoda	22.44	20.85	1537	1642	15.00	17.00	33.00
609	Dabhra	22.44	20.85	1310	1394	27.00	16.00	29.00
701	Jashpur	20.18	18.85	1457	1713	15.15	15.15	38.24
702	Manora	20.18	18.85	1392	1591	24.00	19.00	40.00
703	Bagicha	20.18	18.85	1200	1350	33.33	33.00	50.00
704	Duldula	20.18	18.85	1392	1591	30.00	21.00	63.00
705	Kunkuri	20.18	18.85	1560	1800	13.33	15.56	37.78
706	Kasavel	20.18	18.85	1392	1591	5.00	8.00	36.00
707	Pathalgaon	20.18	18.85	1350	1500	10.71	14.29	32.14
708	Farsabahar	20.18	18.85	1392	1591	11.11	11.11	43.24
801	Kanker	21.62	20.13	1106	1302	8.57	8.57	43.59
802	Charama	23.53	21.87	1140	1178	10.00	13.00	40.00
803	Sarana(Narharpur)	23.53	21.87	1182	1207	11.11	14.81	50.00
804	Bhanupratappur	25.11	23.35	1544	1722	10.26	10.26	47.50
805	Durg Kodal	23.53	21.87	1371	1729	15.00	17.00	22.00
806	Antagarh	23.51	21.93	1514	1708	16.67	23.33	37.50
807	Koaliboda	23.53	21.87	1965	2282	12.00	15.00	33.00
901	Pandariya	19.05	18.13	981	1154	26.67	26.67	35.29
902	Kawardha	17.26	16.45	890	1071	9.09	50.00	33.33
903	Sahaspur Lohara	18.76	17.57	870	1000	6.00	49.00	40.00
904	Bodla	18.36	17.38	750	870	0.00	38.00	45.45
1001	Korba	21.81	20.62	1402	1586	16.67	22.22	38.89
1002	Katghora	22.06	20.30	1403	1574	11.63	11.63	51.16
1003	Pondi	19.81	18.53	1141	1347	2.00	11.11	77.78
1004	Pali	21.81	20.39	1329	1509	31.71	34.15	43.18

Codes	Block name	Seasonal rainfall intensity	Annual rainfall intensity	Average seasonal rainfall	Average annual rainfall	Inter spell gap 8 to 20 days	Inter spell gap greater than 8 days	Commence ment of sowing rain 15 to 28 June
1005	Kartala	22.38	21.18	1370	1528	37.50	50.00	44.44
1101	Sonhat	22.00	20.78	1150	1360	25.00	29.00	100.00
1102	Baikunthpur	21.08	19.04	1238	1433	3.13	6.25	42.42
1103	Manendragarh	21.50	20.00	1200	1430	6.00	7.00	78.00
1104	Khadgawan	21.50	20.00	1200	1450	16.00	18.00	67.00
1105	Bharatpur	22.76	20.88	1251	1389	13.79	13.79	31.25
1201	Mahasamund	25.33	23.44	1249	1456	18.92	21.62	39.47
1202	Bagbahara	24.01	22.28	1300	1450	0.00	20.00	100.00
1203	Pithora	23.98	22.35	1312	1474	20.00	20.00	45.00
1204	Saraipali	22.72	21.05	1218	1362	21.05	31.58	45.45
1205	Basna	24.01	22.28	1150	1400	5.88	11.76	38.89
1301	Raigarh	24.27	22.52	1340	1507	13.79	13.79	53.33
1302	Pusaur	23.50	21.90	1174	1311	12.00	17.00	43.00
1303	Kharsia	23.50	21.60	1183	1369	9.38	9.38	53.13
1304	Gharghoda	23.50	21.90	1604	1803	8.57	8.57	51.43
1305	Lailunga	23.50	21.90	1449	1455	33.00	37.00	59.00
1306	Tamnar	23.50	21.90	1307	1532	29.00	39.00	61.00
1307	Sarangarh	23.09	21.23	1208	1371	22.86	22.86	47.22
1308	Sarai Lengha	23.31	21.62	1350	1500	37.00	40.00	76.00
1309	Dharmjaigarh	22.61	21.13	1425	1595	16.13	22.58	50.00
1401	Dharsiwa	23.20	21.17	1173	1319	19.57	21.74	56.52
1402	Arang	25.07	23.07	1217	1349	19.05	19.05	38.10
1403	Tilda	25.15	23.50	1149	1268	7.41	20.51	43.33
1404	Abhanpur	25.20	23.15	1044	1143	50.00	50.00	33.33
1405	Simga	22.16	20.75	1050	1200	10.53	15.79	42.11
1406	Bhatapara	24.28	22.37	1100	1285	0.00	0.00	0.00
1407	Balodabazar	22.97	20.95	1108	1237	19.51	24.39	41.46
1408	Palari	26.55	24.52	900	1050	13.16	20.59	36.59
1409	Kasdol	22.78	22.07	1050	1200	20.00	20.00	60.00
1410	Bilaigarh	24.57	22.89	1090	1250	30.77	30.77	50.00
1411	Rajim	24.49	23.08	1150	1250	18.18	27.27	33.33
1412	Gariyaband	24.19	22.62	1330	1497	17.65	17.65	42.86
1413	Chhura	25.35	23.67	1110	1250	3.85	15.38	55.17
1414	Mainpur	23.83	22.25	1110	1250	24.00	28.00	40.74
1415	Deobhog	20.61	19.68	1110	1266	15.00	20.00	46.15
1501	Rajnandgaon	21.68	20.15	1118	1299	23.08	37.50	51.85
1502	Dongargaon	20.99	19.93	1137	1298	7.69	7.69	30.77
1503	Chhuriya	20.94	19.62	1023	1173	0.00	6.00	100.00
1504	Khairagarh	19.86	18.55	967	1135	11.11	27.27	44.44
1505	Chhuikhadan	18.92	17.80	905	1067	31.25	41.67	27.78
1506	Dongargarh	20.94	19.62	949	1115	5.00	15.00	50.00
1507	Mohla	20.94	19.62	1100	1176	8.00	28.00	57.00
1508	Amba Chauki	22.99	21.50	1018	1172	23.53	38.46	52.94

Codes	Block name	Seasonal rainfall intensity	Annual rainfall intensity	Average seasonal rainfall	Average annual rainfall	Inter spell gap 8 to 20 days	Inter spell gap greater than 8 days	Commencement of sowing rain 15 to 28 June
1509	Manpur	20.94	19.62	996	1365	12.00	18.00	39.00
1601	Rajpur	23.78	21.90	1136	1366	7.00	10.00	43.00
1602	Ambikapur	23.78	21.90	1443	1642	50.00	50.00	50.00
1603	Lakhanpur	23.78	21.90	1284	1404	47.00	26.00	56.00
1604	Udeypur	23.78	21.90	1400	1550	38.00	27.00	53.00
1605	Lundra	23.78	21.90	1394	1463	8.00	0.00	40.00
1606	Sitapur	23.78	21.90	1187	1431	10.00	4.35	62.50
1607	Batauli	23.78	21.90	1284	1404	7.00	7.00	62.00
1608	Mainpat	23.78	21.90	900	1000	9.00	10.00	49.00
1609	Surajpur	23.78	21.90	1007	1160	12.50	18.75	42.86
1610	Odgi	23.78	21.90	1284	1404	20.00	20.00	39.00
1611	Bhaiyathan	23.78	21.90	1284	1404	17.00	18.00	54.00
1612	Ramanujnagar	23.78	21.90	1284	1404	14.00	12.00	45.00
1613	Premnagar	23.78	21.90	1300	1400	10.00	18.00	37.00
1614	Pratappur	23.78	21.90	1518	1608	12.50	12.00	55.56
1615	Ramchandrapur	23.78	21.90	1171	1119	30.00	16.00	46.34
1616	Balrampur	23.78	21.90	1450	1550	29.00	10.00	40.00
1617	Wadraf nagar	23.78	21.90	1364	1616	13.00	8.00	44.00
1618	Kusmi	23.78	21.90	1469	1407	12.90	12.90	45.16
1619	Shankargarh	23.78	21.90	1240	1303	0.00	0.00	0.00

Source: Indian Meteorological Department, Pune, 1951-2002.

Areas of low rainfall also encounter variability of rainfall, or a highly unreliable and risky achievement of the norm or average rainfall. In other words, areas with low rainfall are also marked by higher fluctuations (coefficient of correlation is -0.75). Another difficulty with the rainfall pattern is the high rainfall intensity, reflecting a more uneven daily distribution of rainfall. Basically, high rainfall intensity implies that precipitation is concentrated in a few showers or a few days. This could result in waterlogging in poorly drained areas, rapid runoff in areas with high slopes and less evenly distributed soil moisture regimes. *Ceteris paribus*, this results in a shorter growing period.

By far, the most critical factor, in determining stable growing period and productive agriculture and land use planning, is the commencement of sowing rains and the inter-spell gap. *Analysis of the rainfall data indicated late onset of sowing rains in most parts of Chhattisgarh.* In no block did we find commencement of sowing rains prior to mid-June. In most cases, it was between 15 and 20 June. Much of the southern part and the northwestern parts were areas with a high frequency of commencement (>50 per cent) between the 15 and 20th June. The inter-spell gap, which is a good indicator of distress in the early stages after sowing, plagues most of Kawardha, parts of Rajnandgaon, southern Durg and some of the more rugged and slopping parts of Dantewada in the south, and Surguja and Raigarh in the north.

Chhattisgarh is endowed with high rainfall. Areas of chronic shortfall are few and localized. The rainfall is typically late in coming, very heavy when it comes, concentrated in a few days and bouts, and early in termination. This rainfall pattern combines with high gradients, hard rock sub-surface characteristic and low percolation to result in massive and rapid run-off of rainwater**.** The weekly distribution of rainfall is very important, and once seepage, percolation and evapo-transpiration are accounted for, the stable rainfall period is less than the length of growing period. This causes potential water shortage for rain-fed rice at various stages and discourages adoption of modern rice technology. Hence, the imperative of protective irrigation for drought proofing favours the sandy/sandy-loamy rice tracts, and so do traditional practices.

The rainfall data basically points towards the importance of sound water management practices. By and large, the precipitation that does take place creates instability for agriculture because it is late in coming and unevenly distributed across the growing period. Soil moisture stress is often on account of unevenly distributed rainfall, rather than inadequate rainfall. Interventions that prevent this from having a detrimental impact on output include water management practices and cropping patterns suitable to the soil and slopes in the region.

There is another reason why rainfall analysis is vital. As we shall see below, surface irrigation (canals and tanks together) accounts for 50 to 80 per cent of the net irrigated area. Hence, the quantum, distribution and timing of rainfall are all important determinants of the ability of agriculture to withstand meteorological droughts and prevent their translation into agricultural drought[23].

From the preceding section, it becomes clear that we need

1. To understand the historic patterns of annual and monthly normal and actual rainfall and its impact on agricultural productivity
2. To understand the distribution of annual and monthly rainfall in the number of days and hence the rainfall intensity, i.e., rainfall per rainy day.
3. To analyse the optimum values so as to take effective measures for drought proofing to keep the relevant factors within this optimal range

3.1.8 Normal Rainfall

We have daily rainfall data from 116 stations, for different durations. In the case of the plains, which were considered actively by irrigation planners in the past, records are available for forty to fifty years. These are also the areas where most of the stations are concentrated. In the other areas, data is available for 20 to 30 years. For almost all the blocks, we have monthly rainfall data for at least 10 years from the district administration (Revenue Department).

Rainfall in June is extremely important for commencement of sowing. The type of paddy grown in areas without supportive irrigation facilities has a lot to do with expectations and experiences around rainfall. For long duration paddy, weeding and *biasi* operations as well as plant growth need at least 50mm rain per week, without a gap of more than 7-9 days between the rainy days,

[23] Sub-optimal water balance in the soil relative to the water requirement during the crucial growing period resulting in soil moisture stress in the plant and low productivity

through the months of June-September. The September rain is of particular importance for traverse inter-cropping or *utera*, when the second crop under dry conditions is sown in between the still standing *kharif* crop of rice.

Bearing these in mind, we examined the broad trends emerging from the data on normal rainfall and average number of rainy days. We analysed the annual, monthly and seasonal data for the months of June to September, the main agricultural season Table 3.2. In addition, we calculated monthly, seasonal and annual rainfall intensity, simply by dividing the rainfall by the number of rainy days in the relevant period. A high figure indicates concentrated rain in heavy downpours, and a low figure would signal the opposite, namely more evenly distributed rainfall.

Table 3.2:District-Wise Seasonal (June-Sept) And Annual Rainfall, Corresponding Rainy Days And Spatial Variability.

Districts	Average districts statistics				Spatial variability in each districts			
	Seasonal Rainfall		Annual Rainfall		Seasonal Rainfall		Annual Rainfall	
	Rainfall	Rainy days	Rainfall	Rainy days	Rainfall	Rainy days	Rainfall	Rainy days
Raipur	1277	51	1384.9	62	1054-1385	43-56	1195-1549	54-69
Durg	1020.4	50	1186.9	63	940-1264	46-55	1121-1359	55-67
Rajnandgaon	1021.8	52	1232	65	850-1142	50-54	1108-1332	63-67
Raigarh	1413.6	63	1516.7	78	1268-1468	55-65	1445-1726	68-92
Bilaspur	1219.3	58	1391.7	71	957-1403	53-64	1190-1544	66-75
Surguja	1200.5	61	1493.2	76	1015-1262	52-61	1344-1657	64-76
Bastar	1315.5	61	1532.2	76	1130-1637	53-67	1371-1788	68-83

1. The distribution of rainfall in Chhattisgarh is orographically determined, adding yet another dimension to drought proofing. This means that there are pockets, which fall in rain-shadow areas and would tend to suffer from chronic drought proneness. These are precisely the areas where a large part of the cultivation is on highlands and midlands.

2. The total annual rainfall varied from 1076 mm in Marand, in Surguja, to 1897 mm in Bhatagaon, in Durg, with a mean value of 1397 mm for the entire state. The standard deviation (Pearson's method) was 163.31. The significance of these figures (in the context of drought) can be appreciated from a simple arithmetical calculation. With an average rainfall of 1100 mm, no village in India should go without water for drinking and cooking. If a village, of say 1200 people, could capture half this rainfall on just 1.2 hectares of land, it would have about 6.57 million liters to use through the year. If rainfall were just half the normal, the village would need 2.4 hectares to collect the same amount.

3. On the whole, the rainy season accounted for over 80 per cent of the annual rainfall and over 75 per cent of the annual rainy days. The average for the state was 87 per cent and 81 per cent, respectively. Mean rainfall was 1215.37mm with a standard deviation of 142.7, and mean number of rainy days 54.1 with a standard deviation of 6.1. This translates into a rainfall intensity of 22.57mm per rainy day, and an arithmetic average rainfall of 71 mm per week, well over the 50 mm per week requirement for rice. Even

for the worst station with a seasonal rainfall of 907.7 mm, namely Kawardha, the arithmetic weekly average was 53 mm. Hence, there is no reason why proper natural resource management and agricultural practices, in combination with protective irrigation, cannot reduce vulnerability even of such areas to drought.

4. If we look at the monthly normal rainfall, the maximum rainfall in the monsoon was in the months of July and August. This was on account of a higher number of rainy days, since the rainfall intensity increased only slightly from June (22.10 mm per rainy day), to July (23.44 mm per rainy day), to August (23.6mm per rainy day). September (219.9 mm) had slightly higher rain than June (208.69 mm), but marginally better-distributed rainfall, as the rainfall intensity was lower at 20.14 mm per rainy day. These were with respect to the state average.

5. The maximum rainfall across stations was almost double the minimum, with highest variation and standard deviation (60) in July. Rainfall in June had a mean value of 208.68 mm, but a maximum of 330.60 mm and minimum of 155.50 mm in Keskal (Bastar) and Kawardha, respectively. The rainfall in July was twice as much as that in June, representing the seasonal peak, closely followed by August and a June-like magnitude in September. Standard deviation from this mean was highest in the months of high rainfall, in July and August, whereas it was lower in the months of low rainfall. The maximum rainfall in July was in Bhanupratapur and Gandai, and in Kawardha and Ambikapur in August.

6. In all months, except in June and September, all the stations recorded an average monthly rainfall greater than 200 mm. If properly stored this can meet the average weekly requirement of 50 mm in all places, including several DPAP blocks, even after accounting for losses due to percolation and evapotranspiration in over 90 per cent cases.

3.1.9 Soil Moisture Regime

The soil moisture regime is the main climatic constraint for rice production in the state. The concept is based on water balance procedure, which is the balance between water need or Potential EvapoTranspiration (PET) and water supply or rainfall. PET is the amount of water lost by evaporation and transpiration, from a soil covered with vegetation, under permanent adequate moisture supply, and is a function of temperature and day length. According to the Thornthwaite system, when rainfall equals the water need, the total amount of water available from rainfall is used up for evapo-transpiration and the soil moisture remains at its base level, say field capacity. When the water supply (by rainfall) exceeds the water need, all the water is not used for evapo-transpiration; partly it infiltrates into the soil.

When the soil water retention reaches the field capacity, the additional water from precipitation percolates to deeper layers (leaching of the salt), and the amount is considered (in the water balance system) as the real water surplus. Part of this water surplus percolates into the ground water table and the rest runs off to the rivers.

When the water supply is less than the water need, water from the soil moisture is drawn up by the roots for evapo-transpiration until the wilting point is reached. If the roots cannot draw the total amount of water needed from the stored soil moisture, a real water deficit will occur. At the end of the dry season, the reservoir of soil moisture should be recharged and must be filled up to the field capacity before there can again be a surplus (Thornthwaite, 1948, 1955).

As far as the monthly distribution of deficits and surpluses in soil moisture was concerned, the surpluses were located in the months of July, August and September. There was a small deficit in the winter *rabi* season, followed by very high deficits from February to June. However, there were sharp variations in the extent or quantum of humidity and aridity, and hence in moisture, varying from low negative values for Gariaband, Khairagarh, Pithora, Sakti and Sarangarh, to medium negative values for Pathri, Rajim and Raipu, to highly negative moisture indices for Manpur, Rajpur and Garrauli.

3.1.10 Water Balance

Rice is a semi-aquatic, water-guzzling plant, and in rain-fed conditions its growth and development are entirely a function of the stability and quantum of rainfall during the growing period. With a daily loss of 3-4 mm of water, each on account of evapotranspiration and percolation, the rice crop requires approximately 50mm of water per week, with less than 100 per cent coefficient of variation. This then determines the stable rainfall period for rice cultivation. Rice is the major crop grown during the wet season in the Chhattisgarh region; most of it is grown under rain fed conditions. The region has an average annual rainfall of about 1400 mm, 90 per cent of which is received during the monsoon months of June-September. Of the three agro-climatic zones in the region, rice is grown in about 80 per cent of the net sown area in the Chhattisgarh Plains. In the Bastar Plateau and in the Northern Hills, it occupies 69 and 60 per cent of the net sown area, respectively.

The southwest monsoon starts in mid-June and withdraws by mid-September, whereas the rice crop flowers in mid-October and matures by mid-November. As a water management practice, farmers construct 1.0-1.5 m high bunds (dykes) in rice fields and accumulate water up to 30-40 cm high in these fields. To cope with such water accumulation they grow tall varieties and use the method of rice cultivation called the broadcast *biasi*. The main purpose of *biasi* is (a) to reduce the rice plant population which becomes high due to use of the broadcasting method; (b) to reduce the weed population that grows and competes with rice until the *biasi* operation; and (c) to create semi- puddle conditions to reduce the percolation losses.

Given such typical rice growing systems and water management practices, the water balance of the bunded rice fields was analysed. In this area, there is great soil variability in soil types, ranging from lateritic to clayey soil, through sandy-loam and clay-loam (See section on Soils). All these soils are found in almost every village. Rice is grown in almost all soils, except lateritic soils. Water balance computations were carried out for all the three types of soils where rice is grown.

Table 3.3: Water Balance Of Different Districts										
District	Parameter	Sandy loam (*Matasi*)			Clay loam (*Dorsa*)			Clayey soils (*Kanhar*)		
	(mm)	Excess	Normal	Deficit	Excess	Normal	Deficit	Excess	Normal	Deficit
Raipur	Rainfall	1813.50	1142.20	763.20	1813.50	1142.20	763.20	1813.20	1142.20	763.20
	Percolation	1032.60	434.90	137.10	730.80	389.60	76.10	220.20	312.60	26.30
	Runoff	85.10	0.00	0.00	262.90	0.00	0.00	398.30	27.20	0.00
Rajnandgaon	Rainfall	2002.30	1232.20	682.40	2002.30	1232.20	682.40	2002.30	1232.20	682.40
	Percolation	958.00	535.80	59.20	850.70	475.80	8.30	621.60	405.70	0.00
	Runoff	75.20	0.00	0.00	323.10	10.00	0.00	724.10	29.70	0.00
Durg	Rainfall	1736.90	1136.70	862.70	1736.70	1136.70	862.70	1736.90	1136.70	862.70
	Percolation	981.20	450.50	244.80	390.50	390.50	193.80	580.50	314.80	137.60
	Runoff	0.00	0.00	0.00	0.00	0.00	0.00	375.70	24.80	6.20
Bilaspur	Rainfall	1475.60	1201.00	804.30	1475.60	1201.00	804.30	1475.60	1201.00	804.30
	Percolation	970.90	462.10	153.20	499.40	390.10	103.20	399.40	348.30	52.70
	Runoff	18.50	0.00	0.00	143.80	22.00	0.00	244.40	13.90	0.00

3.1.11 Storage Index

It is interesting to note that in this area there are numerous tanks, which are used for irrigation as well as domestic purposes. For example, in just Raipur district there are about 12,500 tanks, while in Bilaspur district there are more than 14,500 tanks. Most of the tanks are situated just below the lateritic soil, which are usually barren and are used as a catchment area for these tanks. The rainwater so collected is used to irrigate the rice fields, especially areas with sandy-loam soils situated adjacent to these tanks. In order to assess the runoff potential in the catchment area during excess, normal and deficit rainfall years, a storage index was developed as follows:

$$\text{Storage Index (SI)} = \frac{\text{Total surplus water (mm)}}{\text{Normal rainfall (mm)}} \times 100$$

Table 3.4 shows the indices of storage for different parts of Raipur district.

Table 3.4 Storage Indices In Different Stations Of Raipur District During Normal, Excess and Deficit Years				
Block/rainfall station	Storage index			Normal (mm)
	Excess	Normal	Deficit	
Raipur	87.6	39.6	3	1149.4
Dhamtari	86.4	35.4	2.3	1388.4
Simga	63.5	27.6	2.5	1185.7
Balodabazar	74.9	33.8	3.5	1269.2
Gariyaband	83	40.2	6.6	1521.3
Arang	78.3	34.4	8.2	1342.6
Rajim	72.8	35	10.5	1351.8
Saraipali	75.5	35.7	0	1389
Mahasamund	89.3	38.4	5.5	1367.6
Deobhog	67.4	25.5	2.7	1345.2
Kured	75.3	27.9	0	1276
Bindram	76.8	24.2	0	1353.1
Kusrangi	80.4	32.7	0	1327.4
Khairadatan	66.3	30.2	0.5	1376.5
Pithora	73.7	37.1	8.2	1532.6
Lakholi	78.8	27.4	0	1404
Rudri	68.5	32.8	0	1462.3
Murramsilli	77.1	35	2.6	1550.1
Bhatagaon	75	34.4	11.4	1453.2
Kondapur	72.5	30.2	0	1422.1
Kanki	62.9	32.1	2.4	1394.1

The primary objective of analyzing the climatic data was to develop soil-site suitability models for different crops, based on matching the soil and climate requirements of different crop with the soil-site conditions of the mapped areas. The length of growing period (LGP) or the moisture availability period is a key parameter that helps in assessing climatic suitability for attaining maturity within the available LGP. Table 3.5 lists the range of crops possible under different soil-moisture situations. The importance of this for drought proofing cannot be over-emphasised. Often, the expression of a rainfall shortage or meteorological drought as an agricultural drought largely depends on land use and land based activities, and water use practices in the normal and the drought years.

Table 3.5: Field Crops For Various Growing (Moisture Availability) Period Under Various Degrees Of Risk In India

G.P. (days)	Feasibility of crop growth under assured and different degrees of risk conditions					
	Assured crop in 8 out of 10 years	Crop harvest in 6-8/10 years (slight risk)	Crop harvest in 4-6/10 years (moderate risk)	Crop harvest in 2-4/10 years (severe risk)	Double cropping	
					Assured	Risky
<60		Moth	Greengram, blackgram	Clusterbean	-	-
60-90	Moth	Greengram, blackgram, seteria	Pearlmillet, sesamum, clusterbean	Soyabean, Hy.sorghum (very early)	-	-
90-120	Pearlmillet, minor millets, groundnut, soyabean (early maturing)	Finger millet, maize, sorghum cowpea	Hy-sorghum (medium), soybean	Early paddy; finger millet	-	-
120-150	Finger millet, maize, sesamum, sorghum, early & medium paddy	Medium paddy, early pigeonpea	Medium pigeonpea, early cotton, medium paddy	Early pigeonpea, medium to late paddy	-	-
150-180	Early cotton, early pigeonpea, late paddy	Pigeonpea (improved) cotton, sorghum (local)	Medium pigeonpea, late paddy	Late paddy	-	Toria
180-210	Cotton, pigeonpea (early improved)	-	Cotton, late pigeonpea	Medium pigeonpea, late cotton	Torio	Early Brassica
210-240	All *Kharif* crops specially	-	-	Late pigeonpea	Toria early Brassica	Pea, blackgram in paddy fields
240-270	All crops	-	-	-	Torio gram, pea, Brassica	Gram, mustard, paddy (second crop)
>270	All crops	-	-	-	Gram mustard (second crop)	Late paddy (second crop)

Source: NBSS-LUP 1988

3.1.12 Rainfall And Productivity

While the previous section looked at the normal data, this section presents our findings on actual rainfall in relation to agriculture.

Rice is grown in about 3.8 million hectares, mostly under rainfed conditions and by broadcast method of sowing, and bushening about 30-40 days after sowing (locally called *biasi*). The productivity of rice is very low (1-1.5 t/ha) in the Chhattisgarh region. Studies reveal that there is a significant decreasing trend of rainfall in some pockets of each of the eight districts. Yet the productivity of rice has increased marginally, due to technological developments (Table 3.6) (Baghel and Sastri, 1993; Sastri and Urkurkar, 1995).

Table 3.6:Growth Rates (Percent/Year) Of The Area And Productivity Of Some Important Crops In Different Districts Of Chhattisgarh Region

Districts	**Rice**		**Wheat**		**Chickpea**		**Groundnut**		**Linseed**		**Pigeonpea**	
	A	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**	**A**	**P**
Raipur	0.56	3.63	-1.18	2.87	15.45	1.93	1.8	2.79	-8.17	6.68	-2.24	2.61
Durg	0.8	2.55	-2	3.94	6.59	4.55	34	2.61	-4.89	3.78	-2.92	5.54
Rajnandgaon	0.82	0.78	-1.93	4.13	7.32	2.88	7	3.61	-3.67	4.6	-0.99	3.58
Bilaspur	0.44	5.39	-1.79	6.76	2.2	1.54	26	3.88	4.96	4.03	-1.54	3.88
Raigarh	1.18	2.38	-6.47	4.73	0	1.77	4.6	4.36	4.57	3.21	0.43	3.12
Chhattisgarh Plains	0.71	2.69	-1.13	5.9	5.6	2.47	6.3	3.29	-3.14	4.44	-1.35	3.51
Bastar Plateau	1.32	1.85	-2.57	2.35	0.72	2.63			-4.48	3.9	3.22	6.1
Northern Hills	1.21	3.62	3.66	4.01	-1.17	2.48	20	3.44	2.53	3.74	3.52	4.26

A= Area
P=Productivity

In about 40 per cent of all rain-fed, lowland rice-growing areas, scarcity of water is a critical limitation to increasing productivity. These areas are characterized by a unimodal rainfall pattern, in that one rice crop may suffer serious water stress during the crop growth period, and in the post rice period there maybe little or no cropping for lack of water. The multiple effects of water insufficiency constitute a major obstacle to efficient and effective use of production inputs. As discussed earlier, generally insufficiency of water results from uneven distribution of rains, significant gaps between rain events, and field water losses, rather than from low annual or seasonal rainfall totals.

A sustainable improvement in productivity of rain-fed rice cultivation has remained a major challenge to rice scientists. Generation of appropriate technology may be expedited with a clearer understanding of the problems related to water availability for crop production, and systematically addressing them.

3.1.13 Instability Of Crop Performance

There is a great deal of instability in crop yields. This is due to not only the effects of water stress on crop growth, but also the influence of water scarcity on the farmer's decision regarding use of inputs.

3.1.14 Multiple Effects Of Water-Insufficiency

The full potential of managed rainwater in alleviating production constraints in rainfed farming has not received adequate research attention. A favorable water regime in the field is desirable for almost all farming activities: for land preparation, to plant a crop, to manage weeds, to enable efficient use of fertilizer, to promote nutrient uptake, to reduce nutrient losses, to maintain soil softness for deeper root growth, to avoid soil cracking in rice, and so on. Irreversible cracks in the soil, caused by a dry spell, may disrupt the water economy for the rest of the growing period. In case of rice efficiency of fertilizer use is reduced if the soil-water status cannot be maintained above saturation for about a week from its application. In addition, loss of applied nitrogen increases due to processes of nitrification and de-nitrification under alternate drying and submergence of the soil. Similarly, in eastern India uncontrolled weed growth seriously constrains crop performance if farmers fail to perform timely weed control for want of adequate rains, by *biasi* (also called *beusani*, *biyasi* or *bidahani*). After drought, weed control is the most important constraint to raising productivity of lowland rice in eastern India.

In this light, we have analysed the rainfall data for:

1. Stable rainfall period
2. Inter-spell period

The stable rainfall period for rice cultivation in the districts of Chhattisgarh is as shown in Table 3.7.

Table 3.7: Stable Rainfall Periods In Some Districts Of Chhattisgarh

District	Stable rainfall		Average weekly rainfall (mm) during this period
	Period	Duration (Days)	
Raipur	22-Jun to 13-Sep	84	75.2
Bilaspur	22-Jun to 15-Sep	86	82.9
Durg	21-Jun to 6-Jul	16	69.6
	31-Jul to 11-Sep	43	
Rajnandgaon	22-Jun to 24-Aug	64	85.5
Jagadalpur	21-Jun to 26-Sep	96	78.2

We find that there is a wide range in the stable period, from 59 days in Durg to 98 days in Jagdalpur. There is also a break and consequent instability in Durg, with a 26 day gap in between. There is wide variation also in the monthly rainfall in the critical months of July and August. At the district level as per earlier units, the rainfall pattern in these two months favoured *biasi* in Chhattisgarh, Durg and transplantation in parts of Bastar. In the blocks too there is variation in rainfall in these critical months. As stated above, other critical factors are the intensity of the rainfall, and the frequency and length of dry spells. The rice crop is able to survive for 7 to 10 days without rainfall because of the high dikes that have been constructed, or the farm bunds. However, two features of the rainfall pattern that are immensely disadvantageous to paddy cultivation are: frequent and long gaps between rain spells (Table 3.8) and concentration of rainfall in a few heavy downpours.

Table 3.8:Frequency Of Dry Spell In Raipur District Of Different Duration

Month		**July**				**August**				**September**				**October**			
Number of continuous dry days		**7**	**8**	**9**	**10**	**7**	**8**	**9**	**10**	**7**	**8**	**9**	**10**	**7**	**8**	**9**	**10**
Raipur	40 Years	3	2	2	0	1	1	1	1	11	6	3	1	53	44	40	36
Dhamtari	27 Years	7	6	6	5	8	5	3	1	15	11	9	8	42	39	36	32
Bhaiapara	27 Years	4	2	1	1	10	7	4	1	25	24	17	15	35	33	32	32
Saraipali	40 Years	4	3	2	1	5	0	0	0	3	6	6	6	32	27	27	25
Mahasamund	39 Years	5	4	3	2	7	3	2	1	21	14	10	8	52	41	39	37
Gariabund	40 Years	4	3	3	2	9	5	5	2	15	13	12	11	45	39	34	31
Baloda Bazar	40 Years	4	2	2	1	8	4	4	3	26	19	12	12	52	47	44	42

3.2 DRAINAGE AND BASIN ANALYSIS

This section begins with the methodology adopted for drainage classification and is followed by a brief description of the main drainage basins and rivers in the state, which collect the runoff from different catchments of the area. We then discuss the morphometric analysis undertaken. Essentially, the aim was to classify drainage systems based on the extent of their contribution to drought vulnerability of the area. In other words, based on their ability to cause drought due to rapid run-off of rainwater. The final objective was to group together areas amenable to a common set of interventions for drought proofing because of similar underlying causes.

The watershed was chosen as the basic spatial unit of study. Along with this, appropriate physiographic and morphometric parameters were taken into account to enable proper micro-watershed analysis for planning and management. A watershed is an area that holds the water from precipitation and is then drained by a river and its tributaries. Put simply, a watershed is all the land and water area that contributes runoff to a common point. It can be considered as a `resource region' where the ecosystem is closely interconnected around a basic resource - water. The watershed or river basin is, therefore, an ideal planning and management unit. A watershed above any point on a defined drainage channel refers to all the land and water areas that drain though that point. An elevated line, which forms a division between two areas drained by separate streams, systems or bodies of water, marks it.

The digitized drainage network of the state was divided into micro-watersheds, with water divides or ridges as boundaries, in most cases on the basis of third order streams, except where the resulting watersheds covered too large an area. The basic morphometric analyses carried out was stream ordering, stream frequency, bifurcation ratio, drainage density and stream length ratio. These were then interpreted on the basis of the inherent potential that different watersheds hold for high or low runoff rates, since high run-off is detrimental to drought proofing. *Ceteris paribus*, high run off rates are a cause of soil erosion, low soil moisture retention, low groundwater recharge and low water harvesting capability of the watershed area. This gets compounded in areas with low vegetation, light soils and rainstorms. Each variable was assigned a weight accordingly, and finally expressed as a composite index. The watershed level characteristics were converted to block level values through aggregation and computing weighted averages across all watersheds falling fully/partially within the block, with the percentage of area covered by each as weights.

3.2.1 Major Drainages And Basins In Chhattisgarh

River Mahanadi, draining the vast central region of Chhattisgarh state, forms the most important and biggest water body of the state. This river system collects almost all the rainwater of the basin and carries it to the Bay of Bengal. The volume of water varies considerably between the rainy and the dry season. The Mahanadi, after collecting a number of streams in the Kanker *tehsil*, flows towards the north traversing Raipur district in a northeast direction for about 204 kms, until it is met from the west by its biggest tributary, the **Seonath**.

The portion of Mahanadi Basin located in Chhattisgarh is divided further into a few more basins. The Chhattisgarh Basin lies in the central districts, in the north are the Raigarh basin, Hasdo-Rampur basin and the Korba, and in the south is the Kanker basin. The **Chhattisgarh Basin,** formed by the Mahanadi and its main tributary Seonath, drains the central districts of Rajnandgaon, Durg, Raipur and southern Bilaspur, and is the most extensive and agriculturally rich region in the state. It is referred to as the `rice bowl' of the country and supports a large chunk of the population of the state. Paradoxically, this is also the area of greatest drought related distress.

Most of the tributaries of Mahanadi join in from the western and northern side. The major ones among these are *Maini*, *Kelo, Mand*, *Baroi* and *Hasdo*, a powerful river and the second most important tributary of Mahanadi after Seonath. The plains to the northwest of Seonath are entirely dissected by a large number of streams emptying into the main river. With all its tributaries, the Seonath also is an important river system that drains large parts of Rajnandgaon, Kawardha and Durg. Its main tributaries are *Arpa, Kurung reservoir and river, Miniari reservoir and river, Sakri-Hanp, Kartha and Surhi,* two important tributaries that heavily drain Kawardha, Rajnandgaon and Durg, and *Kharkhara and Tandula* tributaries in Durg district. *Tandula* is not only an important tributary, but also forms a big reservoir in the district, from which a canal carries water towards the northeast of Durg. *Kharum* and *Jamunia* are two other important tributaries near Raipur. Though the contribution of the tributaries from the eastern side of the Mahanadi is lesser, both in number and in volume, three important rivers deserve a mention here. A small river, *Silari,* is important as it links a big reservoir, *Maramsilli,* in the southwest of Raipur district to Mahanadi. River *Pairi,* running down from Raipur uplands, drains a significant portion of the entire undivided Raipur district. *Jonk* and *Lath* are the other two rivers.

The **Rihand** is another major river-body in the state, rising in the south of Surguja and flowing northwards, draining the Surguja Basin. In fact it is a tributary of Son, which in turn merges with the Ganga. Before meeting Son, it is joined by three main tributaries during its course northwards in Surguja district. These are *Gungata*, *Mahan* and *Moran*. In the eastern part of Surguja is the **Kanhar** river, which flows for only for a few kilometers in this district, before joining the Son river in the state of Uttar Pradesh.

The third river system draining the state is that of the **Indravati**. The river and its tributaries are located in the Bastar area. Like the Rihand, Indravati too is a tributary of Godavari. Originating from Orissa it divides the area into two halves. Its major tributaries are *Narangi*, *Baordhig*, *Nibra*, *Kotr*i, and a stream, the Chintavagu. Besides the Indravati and its tributaries, there are three important streams in the Bastar area, all direct tributaries of Godavari. These are *Talperu*, *Chinta*, and *Sabari*. In the Dandakaranya region lying to the south of Indravati most of the rivers are perennial, though with highly fluctuating regime. Due to rapid run-off and evaporation, the land dries up very quickly after the monsoons. A very negligible amount of their water is used for agriculture.

Thus, we find that there are many basins and sub-basins in the region, especially in the southern and eastern parts of the state. The rivers draining these basins usually carry huge volumes in the rains, but are usually flowing in deep gorges in hilly areas. These offer a rich potential for rainwater harvesting and surface irrigation projects that protect *kharif*.

3.2.2 Demarcation And Measurement Of The Catchment Area

Catchment area is an important feature used to characterize a basin, since it influences the water yield and the number and size of streams. It includes all the upstream land and water surface area, which drains to a specific location on the stream. We can speak of catchment areas for a whole stream system, or catchment areas for a particular point on a stream (such as at a gauging station or study site). The topographic divide, a theoretical line that passes through the highest points between the reference stream system and that adjacent to it, demarcates the area. In other words, catchment area boundaries are located by using the contour lines on a topographical map. These can be supplemented with stereo pairs of aerial photographs. Boundaries are drawn by following the ridge tops, which appear, on topo-maps as downhill-pointing V-shaped crenulations. The boundary should be perpendicular to the contour lines it intersects. The tops of mountains often marked as dots on a map, and the location of roads, which follow ridges, are other clues. In areas of little relief, it will be difficult to locate boundaries precisely.

A surface water body, drainage and watershed map, delineating 1708 micro-watersheds was prepared, using Survey of India topographical maps, on a scale of 1:250,000. Watersheds were marked for the entire state on the basis of ridge line/water divides. Generally, the watersheds were marked on the basis of third order streams, except for those areas where the number of first order steams was very high or where the catchment area were very large. Topology was created for each watershed and its area was calculated, giving a unique identity to individual watershed polygons. The watershed level analysis was then aggregated to block level values by summation and computing weighted averages of all the watersheds lying wholly or partly within each block, with the proportion of area covered by each as their weights.

3.2.3 Physical And Morphometric Characteristics Of Watersheds

The physical features of any watershed are important factors in its hydrological characteristics and have been expressed in many ways. The physical measures used by us are discussed below.

Stream Frequency

This represents the total number of channels required to drain a unit area of the watershed. Higher values imply greater slopes, lower permeability and greater structural control. This is particularly so for **First Order Stream Frequency**.

Seasonal Nature of the Streams

The definitions of perennial, intermittent and ephemeral streams are not very useful as they are not applicable under all conditions. They apply to the general nature of the water flow of a stream under average conditions. The Chhattisgarh region is characterized by non-perennial streams, which actually are rain-fed rivers. They carry water only during and immediately after rain. During the dry season either they may cease to flow entirely, or there is hardly any water in most of the drainage channels. Clearly, watersheds with a higher proportion of area drained by non-perennial streams will tend to have lower soil moisture retention and water harvesting capability than those areas where perennial streams pre-dominate. *Ceteris paribus*, areas with proportionately more perennial streams should be less drought vulnerable.

Stream Patterns

Catchment areas can be described by their stream channel patterns, as viewed from maps or from the air. Each stream has its characteristic channel, based on the topographical obstacles encountered, as it seeks the `path of least resistance' in its journey towards the sea. Stream patterns may develop randomly on uniform soils, or in response to weaknesses in the underlying geology (McKnight, 1990; 1985). In Chhattisgarh most of the drainage pattern has been structurally guided, and arises from the presence of hard underlying rocks, as well as pronounced zones of faults and fractures. This means that the channel form is controlled by geology, the flow is confined within rock outcrops, and the channel morphology determined by the relative strength and weakness of the bed material. *Dendritic pattern* is found in areas of relatively uniform geological structure in the river valleys. *Trellis pattern* usually develops on alternating bands of hard and soft strata. *Rectangular pattern is* common in areas with right-angled faults and/or joints, such as in granitic bedrock areas.

Stream Orders and Stream-Ordering Methods

Stream ordering is a widely applied method for classifying streams. Stream order is an indicator of the degree of branching, or bifurcation, within a basin. Horton has classified stream order by assigning order 1 to small, unbranched, finger-tip tributaries, order 2 to those streams which have branches of the first order only, order 3 to streams with branches of second and lower orders, etc. Thus the order of the main stream indicates the extent of branching in the basin. This classification is the inverse of the European system, in which the main stream is always classified as first order and the extreme tributaries as the highest order. Its use in classification is based on the premise that the order number has some relationship to the size of the contributing area, to channel dimensions and to stream discharge (Strahler 1974).

Strahler’s method has been widely accepted as least subjective and is commonly used by stream biologists. In this system all the small, exterior streams are designated as first order, `those which carry wet weather streams and are normally dry' (Strahler, 1952, p. 1120). A second-order stream is formed by the junction of any two first-order streams; third-order by the junction of any two second-order streams. Here, only one stream segment has the highest order number, rather than the whole parent stream.

We used Strahler’s method to classify the entire drainage network for the state. The database for the first to eighth order of streams was generated as separate coverage. The main purpose of this exercise of stream ordering was to calculate the bifurcation ratio, total stream length, average stream length and length ratio.

Stream Length

Stream length will influence the area of stream habitat in a catchment, as well as the travel time of water in a drainage system and availability of sediment for transport. In general, more permeable layers and gentler slopes support longer and higher order streams than sub-basins with steeper slopes or impermeable layers. Stream length is most often obtained from measurements of the drainage lines on topographic maps. The actual length of channel containing surface water changes constantly, hence the map measure should be considered only as a standardized index.

The length ratio[24] followed the pattern of the drainage density: areas with low drainage density tended to have a low drainage length ratio. This tendency can be attributed to the fact that in areas with high slope the number of first order streams required to feed into the next order channel was much greater. Moreover, in areas with fine drainage pattern the ratio was very high, between 10.1 and higher. In other parts (central belt and isolated pockets in the south and northeast) it was less than 10.1. The first three categories covered about 87 per cent of the total area of the state and the latter three covered the remaining 13 per cent (Table 3.9).

Table 3.9*: *Stream Length Ratio (First And Second Order)

Class Interval	Code	Frequency
< 2.1	1	374
2.1 - 4.1	2	698
4.1 - 10.1	3	454
10.1 - 20.1	4	94
20.1 - 35.1	5	26
> 35.1	6	16

Maximum: 112.34
Minimum: 0.209

The second and the third order stream length ratio was much lower than the previous category (Table 3.10). About 46 per cent of the watersheds had a ratio lower than 3.0. Whereas, for the first and the second order, the ratio was as high 2.1 to 10.1 for about 67.44 per cent of the total watersheds.

Table 3.10: Stream Length Ratio (Second And Third Order)

Class Interval	Code	Frequency
< 0.7	1	288
0.7 - 1.5	2	256
1.5 - 3.0	3	244
3.0 – 10.0	4	288
10.0 - 35.0	5	124
> 35.0	6	13

Maximum: 87.143
Minimum: 0.0130
Range: 87.1309

Thus, it is observed that the existing laws of the drainage basin geometry, which postulate that as the stream order increases (a) the number of streams decreases, (b) the average stream length increases and the (c) average slope decreases, are applicable to this region.

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[24] Line-in-polygon overlay was done separately for each stream order layer with the watershed polygon layer. From this overlaying the frequency of streams of a particular order and total length of streams of that particular order within the watershed were calculated. From this calculation length ratio was calculated for each watershed, weights were assigned to this indicator and the average length ratio was computed at the block level. This process was repeated for each of the stream orders and, finally, a master table was created through relational database joins.

Bifurcation Ratio

Horton (1945) introduced the term bifurcation ratio (R^b), where bifurcation means dividing in two.

$$R^b = \frac{\text{Number of stream segments of a given order}}{\text{Number of stream segments of next highest order}}$$

According to Strahler (1952), high bifurcation ratios (exceeding 5) indicate structurally controlled drainages. The bifurcation ratio for a given drainage density is generally controlled by the basin shape, and across areas shows little variation (ranging between 3 and 5) in homogeneous bedrock. In areas where the drainage has strong structural guidance the ratio tends to increase substantially.

The bifurcation ratio between the first and second order streams followed the general trend of the region, namely, areas with higher slope and higher degree of exposed rocks tended to have a higher ratio. Most of the rimland area had a very high ratio. In the central plains, where the top soil layer is thicker and the role of structure in guiding the drainage pattern is comparatively less, the bifurcation ratio was also low (Table 3.11).

Table 3.11: Average Block Bifurcation Ratio (First And Second Order)

Class Interval	Code	Frequency
< 3.3	1	16
3.3 – 3.8	2	26
3.8 – 4.2	3	25
4.2 – 4.5	4	24
4.5 – 5.0	5	29
> 5.0	6	27

Maximum: 6.844
Minimum: 0.0020
Range: 6.8420

Drainage Density

As far as drainage basin processes are concerned , perhaps drainage density is the most useful single index. The density of a stream network reflects the climate patterns, geology, soils and vegetation cover of a catchment. Drainage density represents the amount of channel required to drain one unit of catchment area. The converse, namely the amount of drainage area needed to maintain one unit of channel length, is termed the **constant of channel maintenance** (Schumm 1956).

Drainage density (R_D) is calculated by dividing the total stream length for the basin (ΣL) by the catchment area (A):

$$R_D = \frac{\Sigma L}{A}$$

A finely divided network of streams, with short lengths and steep slopes, characterizes drainage basins with high drainage density. In contrast, a basin with low drainage density is less strongly textured. Stream lengths are longer, the valley sides flatter and the streams further apart. Drainage density is highest in semi-arid areas where surface runoff from intense thunderstorms erodes sparsely vegetated slopes.

The drainage density[25] followed a characteristic pattern of high density in the range of >= 1.224 to 0.6035 km./sq. km. in the northernmost part, the rim land extending to the south and the south-central part of the state. This category covered about 7.59 per cent of the total state area, with 320 watersheds falling under this category. (Table 3.12)

In the central low-lying areas and in some pockets in the northeastern and southeastern part of the state the drainage density was lowest, between 0.3965 to 0.6035 km./sq. km. It covered about 66.23 per cent of the total area and 741 watersheds. The remaining 26.13 per cent of the state formed an intermediate zone between these two areas, with a density range of 0.8035 to 0.8105 km./sq. km. and encompassed about 647 watersheds. Thus, areas with high drainage density had a smaller watershed. In other words, the number of water channels required to feed the next higher order channel was very high.

Table 3.12: Drainage Density of the Watersheds

Class Interval	Code
< 0.3965	1
0.3965 – 0.6035	2
0.6035 – 0.8105	3
0.8105 – 1.0175	4
1.0175 – 1.2245	5
> 1.2245	6

Maximum: 1.4372
Minimum: 0.1895
Range: 1.2477

Comparison of the drainage density of the watersheds with the block level aggregation showed that about 80.95 per cent of the blocks had a drainage density between 0.28 km./ sq. km to 0.73 km/ sq.km (Table 3.13). Moreover, the smaller variations also got generalized in the block level scenario. Blocks with higher slope tended to have a greater drainage density, thus increasing the peak of the hydrograph as the lag time decreased with the rapid drainage of the surface runoff water.

[25] Drainage density in the region was calculated by using line-in-polygon overlay analysis, between the complete drainage coverage and the watershed coverage. During this overlay the map features and the associated attributes are integrated to produce new composite maps. The attribute data associated with each line segment type identity is merged. The resultant table will contain data on both the attributes. The computer generates unique identity for the individual line segments contained within each watershed polygon and, subsequently, specifies the length of each line segment. From this attribute file, through multiple grouping and filtering of the database, the summation of length of all the drainage channels within each watershed was obtained to feed into drainage density calculations. After the drainage density calculation, the administrative map containing the block boundaries and the watershed coverage was used for polygon-on-polygon overlay analysis to identify the number and area of the watersheds falling within each block. Finally, through a database query, both by polygon and line, the summation of the weighted (proportion of the area falling with the block) index as the product of each individual watershed’s value and area was obtained and used in ranking the blocks.

Table 3.13: Drainage Density of the Blocks

Class Interval	Code	Frequency
< 0.28	1	5
0.28 – 0.43	2	27
0.43 – 0.58	3	57
0.53 – 0.73	4	35
0.73 – 0.88	5	20
> 0.88	6	3

Maximum: 1.0413
Minimum: 0.1334
Range: 0.9079

Overlay analysis of the slope map with the watershed clearly showed that areas with high drainage density and high stream length ratio also tended to have higher slope. About 22.8 per cent of the watersheds had a slope greater than 2.5 degree (Table 3.14). Thus the slope, drainage density and the stream length ratio had a high degree of correlation, and tended to move in the same direction.

Table 3.14: Slope of the Watersheds

Class Interval	Code	Frequency
< 0.2	1	210
0.2 – 1.0	2	517
1.0 – 1.5	3	264
1.5 – 2.5	4	236
2.5 – 4.0	5	227
> 4.0	6	136

Maximum: 9.7024
Minimum: 0.0000
Range: 9.7024

3.2.4 Run-Off And Drainage Characteristics: A Summing Up

When precipitation occurs in a catchment, a certain amount of time elapses before stream level begins to rise. Either the water may be intercepted by vegetation, or trapped by depressions in the land surface, or get absorbed by the soil, or it may evaporate. Any excess water will make its way to the stream as overland flow (surface runoff) or subsurface inter-flow. Some micro-watersheds produce sudden and swollen channels after intense rainstorms, *viz*., temporally peaked water discharge with great depth, which rise and fall quickly. Streams that exhibit this type of behaviour are termed **flashy**. In contrast, **sluggish** streams are those, which have the runoff spread over a longer time period. In general, the tendency to be flashy is more in streams in smaller catchment areas than those in larger ones. Similarly, flashy behaviour is exhibited by runoff from sudden, intense thunderstorms than those from snowmelt events or low-intensity rainfall.

The drainage density affects the time taken by water to reach a given point on the stream (the time of concentration). A catchment with well-developed drainage system will have a shorter time of concentration than one with many marshy areas, lakes, reservoirs and other surface depressions (Petts and Foster, 1985). Drainage efficiency is also related to the bifurcation ratio.

Stream systems with low bifurcation ratio tend to produce flood-like situations with marked peaks, while those with high ratio produce lower peaks, which are spread over longer time periods. Additionally, the condition and shape of the channel itself, whether wide and shallow, or narrow or deep, and the presence of vegetation in and along the channel also has an effect. A stream with a steeper longitudinal profile will show more rapid response, and will produce higher peak discharges than one, which is not as steep. Since vegetation affects infiltration rates, its removal can cause direct runoff to increase. Urbanization leads to increased total runoff, higher peak discharges, more frequent flooding and shorter times of concentration (Morisawa, 1985).

Hence, we can make the following conclusions from the above analysis.

1. Run-off $\propto$ Drainage Density
2. Run-off $\propto$ Bifurcation Ratio
3. Run-off $\propto$ Stream frequency
4. Run-off $\propto$ First order stream density
5. Run-off $\propto$ First order stream frequency

In other words,

1. *Ceteris paribus,* the higher the **drainage density**, higher the run-off rate, and conversely, the lower the drainage density, the lower the run off rate. The opposite holds true for the constant of channel maintenance.
2. *Ceteris paribus*, the higher the **bifurcation ratio**, higher the run-off rate, and conversely, the lower the bifurcation ratio, the lower the run off rate.
3. *Ceteris paribus*, the higher the **stream frequency**, the higher the run-off rate, and conversely, the lower the stream frequency, the lower the run off rate.
4. *Ceteris paribus*, the higher the **first order stream frequency and first order stream density**, the higher the run-off rate, and conversely, the lower the first order stream frequency and first order stream density, the lower the run off rate.

3.3 LANDFORM AND SLOPE

Landform and geomorphology are very crucial features for this study. There is a close relationship between geological structure and landform, on the one hand, and landform and soil, on the other. Further, geo-hydrological features too derive, to some extent, from landform. For this reason, classification of the surface landform becomes imperative.

Terrain captures the surface features and slope of the landscape, which are important determinants of drainage and soil characteristics. Slope is a fundamental determinant of land capability, run-off rates, soil erosion and groundwater recharge. Landforms have a structural and morphological origin, while slope represents the elevation or steepness of the landscape between any two adjoining points and the rate at which this changes. The broad landform[26] classification is based on the categories generated by the NBSSLUP[27] database on the soils of Madhya Pradesh.

On the basis of regional topography Chhattisgarh region is divided into three agro-ecological regions, the Northern Hills, the Central Plains and the Bastar Plateau. A sub-regionalisation, solely based on dominant landforms and local topography, alters this big picture, though largely for the central belt.

3.3.1 Landform

The central Chhattisgarh basin is characterised by two major landform types, the gently sloping Chhattisgarh Plain and the undulating Rimland. The elevation of the plain ranges from about 250m on the eastern margin to about 330m in the west. The gentle gradient of the Chhattisgarh Plain is largely due to its geological structure with flat to gently dipping Cuddapah sedimentary formations. Around this plain, the land rises steeply in almost every direction except the southwest, where it merges gradually into the granitic and gneissic peneplain of northwestern Bastar district. In the east the Chhattisgarh Plain narrows down into a corridor between the Raigarh Hills on the north and the Raipur Uplands on the south, through which the Mahanadi flows eastwards[28]. The southwestern parts of the district comprising the central plains, Manpur and Mohla blocks of Rajnandgaon district and Doundi of Durg district have a more graded and uneven terrain. The southeastern parts of the central belt, Nagri block of Dhamtari district and Garyaband, Mainpur and Chhura blocks of Raipur too are more rugged with higher gradient. Similarly, Pithora and Kasdole in the adjoining district of Mahasamund have a more hilly topography.

Surguja area has a defined alternating basin-and-gorge topography. The whole surface of Surguja is an assemblage of flat-topped plateaus (Deogarh Hills and Sonhat Plateau) with an elevation of 600-900m, the flat basin of Surguja, and laterite capped plateaus, or the Pats (Joshpur, Jamira and Mainpat). All these are above 1000m in elevation, and there are other minor topographic

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[26] Polygon-on-polygon spatial overlay of the landform and the block boundaries was done to generalize the type of landform features within a block. Higher weights were assigned to landform categories that were less drought prone.
[27] NBSSLUP (1996): Soils of Madhya Pradesh for Optimising Land Use, National Bureau of Soil Survey and Land Use Planning and Department of Agriculture, Government of Madhya Pradesh, Bhopal.
[28] RLSingh (ed), ‘ India: A Regional Geography’, National Geographic Society of India, Varanasi, 1997.

forms, like knolls, hills, ridges, spurs, gorges, etc. Surguja basin has an elevation of 450-600m, forming the part of lower Gondwana basin[29]. Surguja basin of upper Rihand, though extensive, is less accessible. It is well suited for growing rice. In contrast to the Surguja Basin, the Deogarh Uplands are highly dissected and inaccessible. This area is drained by the tributaries of the Son, and has a highly scattered tribal population that lives predominantly by agriculture and harvesting forest produce[30].

The Northern Hills have lesser variation in topography, and most blocks remain within the category of mountainous, rugged or high slopes. Wadrafnagar and Ramchandrapur are the two blocks, which are marked by relatively lower gradient, but the terrain remains largely undulating.

Variations in topography and surface forms in the blocks falling in Kanker, Bastar and Dantewara districts (carved out of the erstwhile district of Bastar) are typical of most plateaus. Apart from the rivers what remains of the Bastar area is a rugged and dissected series of hills and plateaus. Indravati Plateau, Parasgaon Plateau and Bastar Hills lie to the north of Indravati. Bijapur Upland, Dantewara Plateau, Bailadila Hills and Gollapalli Hills occupy the southern part of the district. Several blocks in Bastar, and Chhingaon and Konta in Dantewara have gently rolling or slightly undulating topography, with the other blocks in the three districts exhibiting higher slopes (Table 3.15).

Table 3.15: Landform Weights

Landforms	Codes	Weights Assigned
Dissected	d	3
Gently sloping	g	7
Hummocky	h	4
Level	l	10
Rolling	o	6
Plateau	p	8
Ridges	r	2
Undulating	u	5
Valleys	v	9
Rocky out crops	x	1

About 25.32 per cent of the state comprises undulating topography interspersed with rolling plains (3.62 per cent of the state) and hummocky landform (18.79 per cent of the state). These three landform categories are found clustered together, and usually a landform that has been exposed to prolonged denudation tends to exhibit these types of residual features, namely, hummocks and rolling plains. An undulating topography is found in the southern parts of Mahasamund and of Raigarh districts. An extension of this undulating landform stretches southeastwards bordering the valleys and the level region of the central Chhattisgarh basin.

About 6.67 per cent of the state is under ridges, which is highly dissected. These areas are spread over the northern parts of Surguja districts, in the southern parts of the Garyaband and Mainpur blocks in Raipur district, and the Nagri block area of Dhamtari. About 4.11 per cent of the northern part of the state is covered by flat-topped plateau, essentially in the southern parts of Korea and Surguja and northern parts of Bilaspur districts. 17.91 per cent of the state comes

[29] RLSingh- op. Cit.
[30] RLSingh- op. Cit.

under the flat or level topography, which is largely found in the Chhattisgarh Basin in the central belt of the state. These plains mainly adjoin the river valleys of Godavari, Mahanadi and Sabri river. Besides these, small localized patches are found scattered all over the state, usually alongside bigger and more perennial tributaries of the main rivers. These flat areas are highly fertile, and sites of intensive agricultural practices. Along with these flat plains, valleys form the intervening areas and about 17.46 per cent of the state comprises river valleys. These areas are also cultivated during the dry season when the soil moisture content is high. From the point of view of agriculture, the landform of the state can be broadly divided into the uplands covering about 25.54 per cent of the state, the midlands covering about 34.98 per cent of the state and the low land covering about 39.48 per cent of the state.

Table 3.16: Block wise Landform

Land form		
Class Interval	Code	Frequency
< 4.53	1	8
4.53 – 5.56	2	24
5.56 – 6.59	3	41
6.59 – 7.62	4	29
7.62 – 8.65	5	18
> 8.65	6	27

Maximum: 9.6814
Minimum: 3.5025
Range: 6.1789

The categorization of the blocks according to broad landform types shows that 21.77 per cent of the blocks come under the category of highland areas. These are in Surguja, Korea, Kawardha, Kanker, Raipur and Mahasamund districts. About 47.62 per cent of the blocks comprise undulating to rolling topography and are situated in the southern parts of Dantewara, Bilaspur, parts of Durg, Rajnandgaon, and scattered over other parts of the state. About 30.61 per cent of the blocks are considered to be flat, or fairly low-lying areas, with gentle undulations at places (Table 3.16).

3.3.2 Slope

Slopes are exceptionally difficult to study as they are transitional, both in process and in form. According to Bloom[31], slopes are irregular surfaces that cannot be described by simple mathematical equations. Even the best topographical maps are only approximations of infinite irregularities of the hill slopes. As mentioned earlier, slope is a major determinant of erosion, run-off rate, soil depth and land use pattern. Depending on the soil depth, stoniness, etc., the degree of slope acts as the limiting factor on land use for agricultural practices, cropping pattern, plantations, and even on land reclamation. Usually, soils tend to be shallow on very steep slopes, and erosion is more severe. The upper convex and straight segments of the slope profiles are largely controlled by mass wasting, especially creep. In most cases the soils tend to be lighter in texture than those on the level low lands. Although soils on steeper lands provide better water and air drainage than that on lowlands, water losses by high runoff rates may act as a limiting factor for crop production. Moreover, on steeper slopes the scope for irrigation is very limited

[31] Bloom A L (1979): Geomorphology: A systematic Analysis of Late Cenozoic Landforms, Prentice-Hall, New Delhi, pp. 187-188.

and difficult, and in most cases, more expensive. In contrast, the low-lying areas with gentler slope and undulations tend to have deep to medium and heavy textured soils, and better scope for innovations in irrigation

Thus, slopes and terrain or topography determine several key factors in water resource development and drought vulnerability, which includes erosion, run-off rate of rainwater, soil depth, soil moisture, groundwater recharge etc. Areas with steeper slopes are more expensive as far as development of irrigation potential and provision of drinking water are concerned. Vegetation is a powerful tool to offset the detrimental effects of steep slopes.

In our methodology, the average slope for a block was calculated by using percentage area under each slope value as the weight. A block that has high elevations but not a great degree of variation in elevation, may not necessarily fall in the highest average slope category. Similarly, a block with a small percentage of its area under high slopes may again not fall under the highest average slope category. On the other hand, in blocks that may not have dramatically high elevation or even slopes, but have a large percentage of their sloping area, the average slope may be high. Therefore, caution must be exercised while interpreting and using the average slope data.

In Bastar Division average slopes rise more sharply as we move westwards and southwards from Kondagaon. The northeastern blocks of the division, covering almost half of Bastar district, were ones with gentler and lesser slopes. Blocks in the southern part of Dantewara (which has an undulating terrain) had high average slope that declined in value from Kuakonda through Sukma to Konta. In the west, Orcha and Behramgarh too had high slopes. In the Central plains, the belt running along the northwest border of the state from Dongargarh in Rajnandgaon to Gourella in Bilaspur, through Bodla and Pandariya Block of Kawardha have an undulating topography and moderate to high slopes. Almost the entire northern hills regions had a high average slope, the areas with the highest slope lying in the northeastern part of the state, covering Kusmi, Shankargarh and Balrampur in Surguja and Bagicha and Manora in Jashpur. Bhaiyathan, Surajpur and Ramanujnangar in Surguja had low average slopes. The central parts of Bilaspur district and the new district of Korba, carved out of erstwhile Bilaspur, had far higher average slopes than the agro-climatic region of Central Plains. Marwahi and Gaurella in the northern part of Bilaspur too had high slopes. Most of the blocks fall in the range of moderate slope values. As much of Chhattisgarh is a plateau area, the relative elevation in comparison to the surrounding states is high, but the terrain is more of rolling to undulating plains, with localized high altitude ridges.

From this discussion it should be evident that the regionalisation based on contiguity and agro-climatic factors gets fundamentally modified and altered once the unit of analysis becomes more aggregated. The reasons for this are obvious. These intra-zonal variations also demonstrate the importance of working at a lower level of dis-aggregation, for creating typologies for interventions for drought proofing and for identifying the more drought-vulnerable areas.

Table 3.17: Percentage Slope

Class Interval	Code	Frequency
< 1.3	1	66
1.3 – 2.6	2	29
2.6 – 3.9	3	31
3.9 – 5.2	4	11
5.2 – 6.5	5	7
> 6.5	6	3

Maximum: 8.3188
Minimum: 0.0791
Range: 8.2397

Table 3.18: Degree Slopes

Class Interval	Code	Frequency
< 0.7	1	64
0.7 – 1.4	2	28
1.4 – 2.1	3	32
2.1 – 2.8	4	11
2.8 – 3.5	5	8
> 3.5	6	4

Maximum: 4.6314
Minimum: 0.0453
Range: 4.5861

3.3.3 Slope And Landform: The Interface

Landform characteristics should be seen in relation to slope. As already mentioned, we have characterized the dominant ecological features of the land and surface falling within an administrative boundary, by using percentage area under each value as a weight to calculate the overall block-level value. In the case of landform, the highest weights were assigned to the areas most suitable for stable and productive agriculture, and block level aggregation was done using these values. Plains and valleys had the highest weight, while rugged mountains had the lowest weight (Table 3.17 & 3.18). Blocks having higher values were closer to valleys and plains, whereas those with lower values were closer to ridges. On the other hand, in the case of slope, lower values represent lower average slopes, and signal areas with less undulation. Therefore, one would expect the correlation coefficient between surface form and slope to be negative and significant. This is because if slope is positively correlated to surface form, namely, if more rugged and undulating surface forms are also marked by higher slopes, the manner in which we have assigned weights to landform would imply that flatter landforms have higher values, the inverse of slope.

Though the direction of causality or the sign is negative as expected, the value of the correlation coefficient is not too high (-0.65). This is so because slope is an outcome of both, elevation and its rate of variation within a 'unit' area. Elevations may be high or low depending on landform, but the way they change within a landform unit may vary. This explanation notwithstanding, areas difficult to explain include Sihawa (Nagri) in Dhamtari district in the south, and the southern cluster of blocks in Jashpur comprising Pathalgaon, Farsabahar, Kasavel and Kunkuri in the north. The landform in these areas is classified under the category rugged and mountainous, but the average slope was low. A similar mismatch, although of a far lower order, was found in the contiguous blocks of southern Rajnandgaon (Manpur and Mohla) and western Kanker (Koelibeda). These were situations of high elevation landforms with low average slope.

There were few cases of the reverse situation, of low elevation landforms with high average slopes. Kota (Bilaspur) was one of the few. What seemed more prevalent was that more elevated landforms do not necessarily translate into higher average slopes. This further confirms the fact that while slope is a local characteristic, landform is a more sub-regional characteristic. The degree or extent of disaggregation results in situations wherein the correspondence between landform and slopes gets somewhat diluted.

3.4 SOIL CHARACTERISTICS AND SOIL MOISTURE RETENTION

The principal aims of soil mapping and analysis were two-fold. One was to study the distribution of soils across the state at the block level from the point of view of land capability, and the second was to identify trouble areas requiring special attention, as a warning against neglect. We have combined several determinants of land-use and soil planning, which is a major step forward. These include landform, slopes, forest cover, drainage and rainfall.

3.4.1 Data Base And Analysis

Both spatial and attribute data were used to analyse the distribution of soil types across the state. The maps were obtained from the National Bureau of Soil Survey and Land Use Planning[32], and the attribute data from the soil conservation departments in each district. The major lacuna with the database was that the data lacked the spatial coordinates. Hence, several known control points had to be identified, and on the basis of these points, the maps were joined and registered.

The NBSSLUP data base on the soils of Madhya Pradesh were developed using a three-tier approach of image interpretation, laboratory investigations, and cartography and printing. The soil resource maps were developed from image interpretation of the LANDSAT imagery on a scale of 1:250,000 and transfer of delineated physiographic units on to toposheets. On the basis of the landform layer several other thematic layers were also evolved to facilitate the process of land use planning. From this data base information on soil taxonomy, soil particle size class, parent material, land forms, soil depth, soil drainage, ground water condition, flooding and erosion were derived.

The landform layer formed the base coverage and all other thematic layers were based on sub-divisions of this layer. The thematic maps were created by polygon coverage and unique codes were assigned to the individual polygons. Though the base map was uniform, nine thematic layers were evolved, with several sub-groups within each theme. Polygon-on-polygon overlay approach was used and the thematic layers were separately overlaid on the block boundary map to obtain the proportion of each soil category within the individual blocks. The different soil types were compiled to obtain a master table on soils, showing the proportion of different soil types within the blocks. Then based on a detailed literature review and examples from similar exercises, weights were assigned to the various soil types. Higher weights were assigned to features that helped mitigate drought vulnerability. On the basis of these

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[32] *1.Soils of Madhya Pradesh: 9 Maps*
2. Soils of Madhya Pradesh for Optimising Land Use.

weights the proportion of each soil indicator within a particular block was calculated and then summed up to evolve a cumulative weight for the entire block.

3.4.2 Distribution Of Soils In Chhattisgarh

The soils of the region are deficient in important mineral nutrients like calcium and magnesium, nitrogen, phosphorous, lime and potash, which are concentrated in the lower parts of the soil layer. However, the tropical red and yellow soils or the red sandy soils of the region possess texture suitable for growing rice and millet crops. The soils of the Chhattisgarh Plain are considered its principal natural resource, and are the mainstay of the predominantly agricultural population of the region (Table 3.19).

Data on area under different soil types was available from eleven districts. We have derived data for the other districts from our maps. For the state as a whole, the predominant soil type is red and yellow loamy soil. The percolation/water retention capacity, as well as the productive capacity of different soils, varies.

The following types of soils are found in Chhattisgarh:

Kanhar (clayey): A low-lying deep bluish black soil with high moisture retention capacity. It is well suited for *rabi* crops, particularly wheat.

Matasi (sandy loamy): This is a yellow sandy soil, with an admixture of clay. It has limited moisture retention capacity. Though used for paddy, it is ideal for short duration maize and deep-rooted pulses. It is found in better-drained areas and at relatively higher altitudes.

Dorsa (clay-loam): This type of soil is intermediate in terms of soil moisture retention between *kanhar* and *matasi*. This is best described as loamy, and is a colour between brown and yellow. This is more or less an all-purpose soil, and is suitable for paddy.

Bhata (laterite): This soil is a coarse-textured, red sandy-gravelly soil, found on upland tops. It is deficient in minerals and other productivity enhancing nutrients, and is often suitable only for coarse millets. It is low in humus content and is often wasteland. It is a good locale for silvi-pastoral efforts.

Using an alternative detailed classification, we find that *Aqualfs-Ustalfs* are restricted to Bastar Division, and are mainly found along the valleys of Indravati River and its tributary Baordhig as well as the Sabari River Valley above Gallopalli Hills. The Kanker Basin, in the northern part of the district, spilling over in southeastern Durg and southwestern Raipur, is also composed of the same soil type. *Ustalfs-Rocky Outcrops* are spread over the remaining part of Bastar division except the Gallopalli Plateau and Chintavagu valley. In the districts of Raipur Division, it lies along the Mahanadi River up to a few kilometers on both the sides extending up to the eastern end of the river in the state in the southern tip of Raigarh. It is also found in the southern parts of Durg and the southern and western parts of Rajnandgaon. In the north, in Surguja district, it is found in the upper reaches of Hasdo-Rampur Basin and Surguja Basin. *Ustalfs-Ochrepts-Orthents* characterize the northeastern parts of erstwhile Rajnandgaon and northern parts of Durg. The extreme northwestern tip of erstwhile Raipur and the

Raipur Uplands also have the same type of soil. In the district of Bilaspur the soil type is confined in a small area to the northwest of Pendra Plateau and the north of Lormi Plateau. *Ochrepts-Usters-Ustalf* are mainly found in the east of central part of Rajnandgaon continuing in the central part of Durg and stretching further into the northwestern section of Raipur and the southeastern part of Bilaspur.

Orchepts-Orthents-Ustalfs occupies almost the entire districts north of Mahanadi. In Bilaspur, the soil forms little continuity in the eastern fringe of the district bordering Raigarh. Rest of it is spread in the south and southwestern part of the district. In Surguja it is located in the *tehsils* of Surguja and Wadrafnagar. *Orthents-Rock Outcrops* is mainly located in the erstwhile district of Surguja. Deogarh Hills, Sonhat Plateau, Korea Hills, Jashpur Pat and Jamira Pat are covered by this soil. In erstwhile Bilaspur it is located in the Chhuri Hills. *Orthents-Tropepts* are found only in Korba-Bilaspur's Korba Basin and north of Pendra Plateau. *Orthents-Ochrepts-Ustalf* too are only located in Bilaspur division, on the Pendra and Lormi Plateaus. *Ustalfs-Ochrepts* are scattered and found in the northeastern fringes of the Surguja district, bordering Chhotanagpur Plateau in Jharkhand, and continuing into the northeastern tip of the Raigarh district. The Gollapalli Hills in the southernmost tip of Bastar district is the only other region with this type of soil.

Table 3.19: Some Important Characteristics Of Soils Of Chhattisgarh

SN	Soil/land characteristic	Soil			
		Bhata (Entisols)	*Matasi* (Inceptisols)	*Dorsa* (Alfisols)	*Kanhar* (Vertisols)
1	Slope	Undulating rolling	Level gently undulating	Level gently undulating	Level
2	Colour	Reddish to dark reddish brown	Yellow	Brownish gray	Dark gray brown to black
3	Texture	Gravely, coarse loamy to sandy	Sandy loam	Silty clay	Clayey
4	Structure	Massive (structureless)	Angular blocky	Subangular to angular blocky	Angular blocky
5	Consistency	Non-sticky & non-plastic	Slight sticky	Sticky & very plastic	Very sticky and plastic
6	Lime concentration	Absent	Absent or very few	Present	Abundant
7	Other concentration	Ferruginous gravel	Few iron concretions	Numerous iron concretion through out	Numerous black iron concretions
8	Reaction with HCl.	Non-effervescene	Effervescence in last horizon	Effervescence through out	Effervescence throughout
9	Cracks	Absent	Few fine cracks	Wide vertical cracks	Very wide
10	Depth	Very shallow	Moderate	Medium to deep	Deep
11	Internal drainage	Rapid	Moderate	Moderate to slow	Slow
12	Important soil series	Lakholi	Chandkhuri	Arang-I	Arang-II

Source: NARP (1993), Gawande et al. (1963, 1968), Gawande and Biswas (1967) and Biswas and Gawande (1962).

Table 3.20: Soil Taxonomy

Soil Taxonomy	Local Name*	Codes	Weights Assigned
Entisol	*Bhata* (L)	1	2
Inseptisol	*Matasi* (L)	2	3
Vertisol	*Kanhar* (H)	4	5
Alfisol	*Dorsa* (M)	5	4
Rock outcrop		6	1

Note: Weights are assigned on the basis of readings from the following article:
Agro-climatic Regional Planning in India, pp25-26
* (L)- Light, (M)- Medium, (H)- Heavy

The alfisols or the *dorsa* soils cover about 41.24 per cent of the state, and are concentrated in the northern highlands or the southern plateau regions. About 19.81 per cent of the state is covered by the heavier soil type vertisol, or *kanhar,* which is concentrated in the central plains and the valleys of the Godavari river. The coarse textured entisol or *bhata* soil is found in about 18.76 per cent of the state, and is concentrated in the areas of high slope and dissected terrain. The inceptisol or the *matasi* soils are found in the midland areas of undulating and rolling to gently sloping topography. This soil type covers about 20.74 percent of the state area (Table 3.20).

After the aggregation of the data to get the block level picture, the data was generalized to give a single composite value to each block. The block level aggregation shows that about 86 of the blocks have predominantly *matasi* or *dorsa* soils. There are very few blocks that have predominantly *kanhar* soils (Table 3.21). Thus, most of the state comprises loamy to clay sandy soils with low humus content and was deficient in essential soil nutrients.

Table 3.21: Block Level Soil Taxonomy

Class Interval	Code	Frequency
< 2.81	1	3
2.81 – 3.25	2	26
3.25 – 3.64	3	41
3.64 – 4.13	4	45
4.13 – 4.57	5	11
> 4.57	6	21

Maximum: 5.0035
Minimum: 2.3689
Range: 2.6346

The genesis, type and distribution of soils are dependent on genesis and distribution of different types of landforms. About 24.65 per cent of the state is covered by soils that are coarse in texture. Much of the highlands and the ridges constitute coarse loamy to loamy sandy and skeletal loamy soils, mixed with pebbles and gravel, and areas such as rocky outcrops are devoid of any form of soil cover. The central plains and the intermontane colluvial plains comprise alluvial and colluvial soils. About 24.56 per cent of the state comprises the fine and clayey soils, and it is mainly concentrated within the central belts of the state, in the Chhattisgarh sub-basin area. The areas of older plains have heavy soils of clayey to fine textured soils underlain by *kankar* (hard) pan.

3.4.3 Soil Particle Size

Table 3.22: Soil Particle Size

Soil Particle Size Class	Codes	Weights Assigned
Clayey	c	8
Fine	f	7
Loamy Skeletal	k	6
Loamy	l	5
Fine Loamy	m	4
Clayey Skeletal	p	3
Coarse Loamy	r	2
Rocky Out Crop	x	1

Of all the soil characteristics, there is more variation in soil types than in soil depth. The really poor and light soils with high *bhata* or sand and sandy loam content are found in three large clusters in the western parts of the state. The first is the western part of the Bastar Plateau (covering almost the entire Kanker district) and half of Dantewada. The second belt covers Chuikhadaan and Bodla (Rajnandgaon and Kawardha districts, respectively). All the blocks forming the northern border of the state (falling in Korea and Surguja) comprise the third cluster. The southern (Mainpur block) and northeastern (Bilaigarh and Kasdole) reaches of Raipur district and Pondi Block (the largest block in Korba) are the other areas of poor soil.

Clayey soils are not found in their pure and rich form to any large extent in the state. Instead, clayey and very fine loamy soils are found in the innermost part of the central plains, tapering as it runs from southwest to northeast. These are also the areas of maximum soil depth. This *kanhar* core is surrounded by *dorsa* and *dorsa matasi* soils. While the sandier soils extend along the western part of the state, the *matasi* and *dorsa* soils are distributed along the eastern part. The central belt stands out as the area of relatively deeper and heavier soils.

Table 3.23 below show the distribution of different soil types or selected districts.

Table 3.23: Block-wise Distribution of Soils

	Kanhar%	*Bhata%*	*Matasi%*	*Dorsa%*	*Kachhar%*
Bilaspur	37.42	27.48	6.56	28.54	-
Dhamtari	47.28	7.31	19.97	25.44	-
Durg	45.94	14.26	21.23	18.57	-
Janjgir_Champa	28.10	11.33	26.65	33.92	-
Jashpur	2.77	25.24	47.47	24.52	-
Kanker	28.50	38.27	31.85	1.38	-
Kawardha	37.02	10.16	20.44	31.14	1.24
Korba	9.61	44.72	31.97	13.70	-
Mahasamund	23.46	17.59	35.97	22.99	-
Raigarh	7.37	15.61	49.16	27.86	-
Raipur	30.94	8.84	33.94	22.48	3.80

There is wide variation even within districts in the type of soil found in terms of its taxonomy and quality. While rich and heavy black clayey soils are prevalent in the more central and plains areas of Dhamtari, Durg and Bilaspur, the northern hills (Jashpur, Raigarh) and adjoining north-eastern undulating/plains districts of Raipur and Mahasamund are covered largely by lighter loamy soil. The sandier light soils are more visible in the areas of Jashpur and Janjgir-Chapa. However, within each district there is a divergence across blocks with respect to the type of soil and its quality. While the rich *kanhar* soils of Bilaspur are more concentrated in Mungeli, Patharia and Lormi, Gaurella, Pendra and Marwahi have far lighter soils. The story of intra-block unevenness and heterogeneity does not always repeat itself in different districts. The distribution of the dominant *matasi* or sandy loamy soil in Mahasamund district is far more even. From the viewpoint of this single variable, there is not too much variation within this broad agro-ecological sub-zone at the district level. We must, however, hasten to remember that even for land-use planning, this is only one of several factors even at the district level. We must remember that soil quality and taxonomy, though important, are by no means the solitary determinant of land-use planning for drought proofing.

Often, the best quality soils rich in humus are closest to the forests, which in turn are concentrated in the more undulating and hilly areas, where the rainwater does not stay long enough to be retained by the soil. Similarly, the heavy and water retentive soils may become a curse in the poorly drained regions of the plains in particular, and lead to waterlogging.

Table 3.24: Particle Size

Class Interval	Code	Frequency
< 4.49	1	39
4.49 – 5.05	2	38
5.05 – 5.61	3	20
5.61 – 6.17	4	12
6.17 – 6.73	5	11
> 6.73	6	27

Maximum: 7.0923
Minimum: 3.93
Range: 3.16

It can be inferred from Table 3.24 that most of the blocks fall in the category of coarse loamy to skeletal loamy soils. Very few blocks, about 18.36 per cent, have predominantly heavy soils that are suitable for soil moisture retention.

3.4.4 Soil Depth

Similar exercises were carried out for the other thematic layers and then the parameters were aggregated to evolve a block level scenario. In case of indicators that were defined in terms of a class range, the mid-values were taken as the weights to be assigned. The product of the mid-value and the proportion of the area under each parameter were calculated to generate the cumulative composite table for the blocks.

Table 3.25: Soil Depth

Soil Depth	Depth Ranges (cm)	Codes	Weights Assigned
Extremely Shallow	< 10	0	5.0
Very Shallow	10 – 25	1	17.5
Shallow	25 – 50	2	37.5
Slightly Deep	50 – 75	3	62.5
Moderately Deep	75 – 100	4	87.5
Deep	> 100	5	112.5
Rocky Outcrop	-	X	1.0

The depth of the soil has a major influence on the nature of the crops to be cultivated and the type of land use pattern that evolves in a region. A minimum soil depth of 25 cm can be used for producing certain short-term variety of crops with low yield. But for sustainable yield and improved variety of crops it is essential to have soil depth between 50 cm to 75 cm. For other tree crops soil depth greater than 75 cm is essential. Other than this, shallow soil can also be used as pasture and grazing grounds[33]. Soil depth is a function of several factors, including landform, underlying rock strata and parent material, slope, vegetation, fluvial action, etc. These can be divided into two broad categories—form or structure and process. Landform captures structural aspects. For instance, areas with rugged terrain have shallow soils. As can be seen from the maps (and as confirmed by a high significant negative correlation coefficient between soil depth and gradient), the plains and flat plateau regions have deeper soil, whereas the higher gradient areas have more shallow soils. Areas that deviate from this broad picture of correlation between soil depth and slope are: in the north Bhaiyathan and Surajpur blocks of Surguja district and the cluster in the northeastern part of Jashpur district comprising Bagicha, Kunkuri, Duldula, Jashpur and Manora. These blocks have high soil depth despite steep average gradient. In the plateau, a large part of the eastern and central Bastar district has relatively good soil depth, although lesser than that in the plains. The remaining portion of Kanker, Bastar and Dantewada has shallow soils. The central belt has, at its centre, the deepest soils to be found in the state, but the inter-block variations strongly conform to surface form and gradients (Table 3.26).

Table 3.26: Block Level Soil Depth

Class Interval	Code	Frequency
< 94.99	1	72
94.99 – 98.56	2	12
98.56 – 102.13	3	7
102.13 – 105.7	4	11
105.7 – 109.27	5	11
> 109.27	6	34

Maximum: 112.85
Minimum: 91.42
Range: 21.33

About 60.81 per cent of the uplands have shallow soil types. Over the remaining portion there is an even distribution between moderate to deep soils in the uplands. In the highlands of Chhattisgarh very often it is observed that the areas tend to have a fairly good soil category (Table 3.27).

[33] FAO (1979): Watershed Development with special reference to Soil and Water Conservation, FAO Soils Bulletin, 44, Soil Resources, Management and Conservation Service Land and Water Development Division, Rome.

Table 3.27: Percentage Area Under Land Location Categories

Land location Categories	Soil Depth Class category (figures in percentage)		
	Deep (5)**	Moderate (3, 4)**	Shallow (0, 1, 2)**
Upland (1, 2, 3, 4)*	21.20	17.57	60.81
Midland (7, 6, 5)*	59.84	35.42	4.72
Lowland (8, 9, 10)*	78.04	17.07	4.49

Notes: * Refer to the landforms table for the landform category codes.
** Refer to the soil Depth class table for the category codes.

The midland areas of Chhattisgarh have fairly deep to moderate soil type, which after some treatment can be brought under cultivation. Generally, the lowlands have heavy to deep soils, which have high water retention capacity due to high clay content. These soils have better nutrient value and are suitable for paddy cultivation. Such deep soil is concentrated in the central belt of the state, which constitutes the 'rice bowl' of the state. The highland areas with shallow and poor soil quality are the areas of immediate concern, as some of these areas that also have low vegetative cover are prone to high erosion. About 9.67 per cent of the total area of the state comes under this category.

3.4.5 Soil Drainage

Soil drainage or permeability is mainly dependent on the soil texture. Usually coarse textured soils have a higher degree of permeability, as the soil particle size is relatively large and the inter-particle compaction is also lower. Whereas, fine textured soils usually have a lower permeability. Thus, soils with high clay content tend to have poor soil drainage and can lead to water logging conditions. The standard permeability classes for soils are as shown in Table 3.28.

Table 3.28: Standard for Permeability Classes

Class	Cod	Percolation rate in *mm per hour* through sa undisturbed cores under 12.5 mm head of water
Very Slow	1	Less than 1.25
Slow	2	1.25 – 5.0
Moderately Slo	3	5.0 – 20.0
Moderate	4	20.0 – 62.5
Moderately Ra	5	62.5 – 125.0
Rapid	6	125.0 – 250.0
Very Rapid	7	Over 250.0

Source: FAO (1979): Watershed Development with special reference to Soil and Water Conservation, FAO Soils Bulletin, 44, Soil Resources, Management and Conservation Service Land and Water Development Division, Rome.

Based on this standard permeability index, we have assigned weights to the soil depth categories found in the Chhattisgarh region. The suitability for the existing agricultural practices (rain fed rice cultivation) was also taken into consideration while assigning the weights.

Table 3.29: Soil Drainage

Soil Drainage	Codes	Weights Assigned
Moderately Well	4	4
Well	5	5
Somewhat Excessive	6	3
Excessive	7	2
Rocky out crop	x	1

About 17.61 per cent of the state has very high soil drainage due to presence of coarse soil and highly undulating terrain with fairly high slope (Table 3.29 & 3.30). As these have a difficult terrain and are ecologically fragile areas, with fairly high concentration of tribal population, these are the main areas of concern from the point of view of drought proofing.

Table 3. 30*: *Block Level Soil Drainage

Class Interval	Code	Frequency
< 3.75	1	3
3.75 – 4.0	2	16
4.0 – 4.25	3	37
4.25 – 4.50	4	28
4.50 – 4.75	5	35
> 4.75	6	28

Maximum: 5.0085
Minimum: 3.5047
Range: 1.50

3.4.6 Soil Erosion

Table 3.31: Soil Erosion

Soil Erosion	Codes	Weights Assigned
Slight	1	5
Moderate	2	4
Severe	3	3
Very Severe	4	2
Rocky out crop	x	1

The erosion rate is very high in the areas with high slopes and low forest cover, and there is little or no topsoil cover left. Other than the central belt, where the forest cover is low due to high percentage of cultivated land, the other areas have a higher percentage of degraded landforms with dissected terrain. About 29.75 per cent of the state is under the category of severe to very high rate of erosion (Table 3.31).

The problem of flooding is very nominal within the state, and only 3.89 per cent of the state faces slight to moderate flooding, which is concentrated in the valleys of the Godavari and the Mahanadi sub-basin regions (Table 3.32).

Table 3.32: Flooding Conditions

Flooding	Codes	Weights Assigned
No flooding	0	4
Slight	1	3
Moderate	2	2
Rocky out crop	x	1

3.5 GEO-HYDROLOGY, PARENT MATERIAL AND GROUNDWATER

In times of drought, groundwater can provide a reliable and often only buffer by emerging as the only source of water for drinking and other vital sustenance purposes. The best route to prevent human and livestock misery on account of rainfall unreliability and fluctuations is sustainable groundwater management in, both, the drought and the normal years, proper identification of recharge and extraction zones, and adequate attention to recharge. There is less evaporation and seepage with stored underground water. Increasing water resources by emphasis on the construction of percolation tanks must be an important element of drought proofing. Under favourable bedrock conditions, this stored ground water could be used for irrigation purposes in the next crop-growing season. This can help in providing supplemental and/or protective irrigation at critical crop growth stages and/or when crops start wilting. Such lifesaving irrigation is probably the only way to stabilize crop production in semi-arid and arid lands, especially under drought conditions.

The occurrence and movement of ground water is a direct manifestation of geological setting of the terrain. The occurrence of ground water is controlled by the local topography, drainage characteristics, lithology and disposition of the structural features, like fractures and joints. Ground water moves from higher to lower level through the interconnected pore space and fractures of saturated rocks, under the effect of fluid potential force within the flow system boundaries. The system boundaries contain both recharge and discharge areas. The landform highs coincide with the recharge zones and the lows with the discharge zones. Thus, the geo-morphological and geological features control the development and circulation of ground water.

The water bearing capacity of rocks largely depends also on their chemical and mineralogical constituents, their grain size and cementing material, compactness and also on available porosities within them. Therefore, the moisture holding capacity of the soil depends, to a large extent, on the porosity and Parent Material. As far as the inherent land capability and the cropping pattern it can support are concerned, the parent material is an important factor. On the other hand, permeability measures the ease with which water can move through earth materials. The permeability of granular materials is dependent on the particle size of the grains, shape, packing and uniformity of size of the grains. Thus it is essential to study the lithology (properties of primary rock materials), stratigraphy (chronological and, vertical and horizontal order of rock deposition) and their structural features (folds, faults, fractures and lineaments) in order to understand the hydro-geological response of a watershed. This is due to the higher soil moisture retaining capacity of less porous and permeable earth material. The opposite is true for groundwater. Hence, the study of ground water is always preceded by the study of the geologic framework. In any groundwater study it essential to know the mode of deposit and the nature of the grains composing it.

The earth formations are usually classified according to their origin, such as igneous, sedimentary or metamorphic. However, this classification is not of much help in the area of ground water occurrence studies. For such purposes two broad categories of the earth material are found more suitable, namely, unconsolidated material and indurated material. The unconsolidated materials are of recent geological deposit and have relatively higher porosities. They are usually composed of alluvial or stream transported sediments, or colluvial or gravity driven debris in this region. In general the coarse-grained sediments, whether unconsolidated or consolidated are found to be the best aquifers[34]. The indurated materials also play a major role in determining the occurrence of ground water. Sedimentary rock deposits get indurated through the chemical action of water and deposition of particles like clay, which can form a cementing matrix by reducing the original void spaces within the deposits. Thus, sedimentary rocks are usually much less permeable and porous than their unconsolidated counterparts. Limestones are an exception to this category. Igneous and metamorphic rocks have very low porosity as well as permeability. But in these rocks the fractures form the primary source of void spaces, which can contain or transmit water. Chemical and the mechanical weathering process may also affect the porosity and permeability of the rocks. The igneous and the metamorphic rocks are more susceptible to the process of chemical decomposition than the sedimentary rocks[35]. Stromatolitic limestone and dolomite limestone are hard, compact and massive and are devoid of primary porosity. The presence of closely spaced joints and cleavage planes enhance their water bearing properties. The movement of groundwater in them is mainly through joints, bedding planes and solution cavities. These rocks have secondary porosity and permeability due to solution effect along the joints, fractures and bedding planes. There is a thick capping of shale and yellow clay serving as the aquicludes[36].

Relative weights have been assigned to the parent material based on the porosity of the geologic material. These are shown in Table 3.33.

Table 3.33: Parent Material

Parent Material	Codes	Weights Assigned
Alluvium	a	9
Basalt	b	5
Colluvium	c	8
Sandstone	d	7
Granite	g	4
Granite gneiss	gn	3
Gneiss	n	2
Laterite	r	6
Rocky out crop	x	1

Note: Weights have been assigned on the basis of readings from the following articles: Waltz J P (1969): Ground Water, ed. Richard J Chorley, Introduction to Physical Hydrology, Methuen & Com. Ltd., London, pp- 123, Table 6.1.1.

34 An aquifer is a layer of rock that acts as a hydrologic unit and is sufficiently permeable to yield water in a usable quantity to a well or spring.
35 Waltz J P (1969): Ground Water, ed. Richard J Chorley, Introduction to Physical Hydrology, Methuen & Com. Ltd., London, pp- 123-125.
36 An aquiclude is a layer of rock that has such a low permeability that it will not yield water in a usable quantity and will not transmit water readily. An aquiclude may, however, contain considerable water in storage.

3.5.1 Geological Features Of Chhattisgarh

The geological setting of Chhattisgarh region shown in Table 3.34**:**

Table 3.34 Broad Geological Profile of Chhattisgarh

Deccan trap	Basaltic formation
Gondwana	Sand stones, shale coal bearing SSt. Conglomerate.
Vindhyan	Lime stone, shale Sand Stones, Quartzite and meta Sediments
Bijawars	Shale, Limestone, Dolomite, Sand stones
Archeans	Iron ore bearing Schist, Phyllite
Basement Rocks	Gneisses, Granulites

The main water bearing formations are the sandstones of the Gondwana formation. The alluvium formations of the river basins of Mahanadi, Shivnath, Arpa, Indravati etc. are also potential. The cavities and weathered portions of limestons and dolometic formation are also very good for ground water storage in the Chhattisgarh region.

Table 3.35: Percentage of Area Under Parent Material Categories

Geologic formations	Percentage area	Geologic formations	Percentage area
Alluvium	32.44	Granite Gneiss	15.79
Basalt	3.51	Gneiss	0.70
Colluvium	0.45	Laterite	5.51
Sandstone	26.03	Granite	15.49

As per our calculations presented above, alluvial deposits cover the largest part of the state, with 32.44 per cent in the central Chhattisgarh basin region, in scattered parts of the Indravati basin in the south and the Sabari Basin; it is also found in small pockets in the north (Table 3.35. About 26.03 per cent of the state is covered by earth material whose parent rock is sandstone. These sandstone areas are largely concentrated in the northwestern part of the state mainly covering Korea and parts of the Surguja district. There are several patches of sandstone formation along the rim of the Chhattisgarh basin. Sandstone is also found in small-scattered pockets in the south. Granites are mainly found in the northeastern part of the state.

Table 3.36: Block level Parent Material

Class Interval	Code	Frequency
< 4.46	1	11
4.46 – 5.37	2	26
5.37 – 6.28	3	13
5.53 – 6.69	4	12
6.69 – 7.85	5	32
> 7.85	6	53

Maximum: 3.5519
Minimum: 9.0279
Range: 5.4760

About 65.98 per cent of the blocks comprise parent material that has high potential with respect to the porosity and permeability characteristics for ground water recharge (Table 3.36). In 29.93 per cent of the blocks, covering southern Chhattisgarh in the districts of Bastar, Dantewara, Kanker, due to presence of the hard rock of granite and gneissic origin the potential of recharge is very limited and localized to the areas where fractures and lineaments are present in the north in the north eastern parts of Surguja district. Almost half the state is covered by hard rocks like granite and granite-gneissic. The Bastar division is predominantly hard rock too, with some areas of laterites and basalt. The alluvium areas are confined to the eastern reaches of Bastar, comprising Jagdalpur, Bastar, Bakaband and Tokepal, narrowing as one moves southwards into Chhindgaon block in Dantewara. Sandstone occurs in the narrow eastern belt in Asur and Bhopalpatnam blocks of Dantewara. In the Central belt the alluvium tract extends from the central part of Durg in the southwest to merge into the sandstone areas of Korba, Korea and Surguja towards the north. Most of Jashpur and the eastern reaches of Surguja are lateritic and granitic. The northwest too has lateritic areas. In the west, granite and granite-gneissic rocks border the Central alluvium belt.

3.5.2 District-Wise Characterisation[37]

Durg District

The Durg district region is mainly composed of crystalline rock formations. The groundwater occurs under unconfined conditions in all lithological conditions as also in deep fractured zones of granite rocks. Solution cavities in limestone, fractured and jointed portion of basalt, gneiss, meta-sediments and other igneous rocks are some of other zones for groundwater occurrence. The Archaean granites occurring in the southern part of the district are massive and hard, and lack in primary porosity, hence groundwater is found along the weathered mantle overlying the hard rocks and in cracks, joints and fissures. In the Chandrapur sandstones the occurrence is along the bedding planes. The contact between the Chandrapur and Archaean formation forms a good aquifer zone due to the presence of a conglomerated bed. The depth of water table varies between 7 and 15 mbgl[38]. The topmost unit of the Chandrapur formation is composed of shale, which is not productive. The middle unit is composed of flaggy limestone, having vertical joints perpendicular to the bedding plane. The chances of groundwater occurrence are greater in this region due to presence of both vertical and horizontal solution cavities. The lower unit composed of limestone is cavernous and groundwater is found here. The contact zone between the Charmuriya and Chandrapur horizon is also productive. In the Gunderdehi shale groundwater occurs under the water table as well as in confined conditions. The depth of water level ranges from 5 to 15 mbgl. The joints and the bedding planes of shale and sand stone constitute the phreatic aquifer, which is tapped by open wells in the area.

Kawardha District

Shale and sandstones, the weathered zones joints, cleavages and bedding plains constitute the water table aquifer in the area. These features generally lack uniform development, thereby giving rise to variation in ground water occurrence. Alluvial deposits of Sukhri *nala* consist of lenticular layers of fine to coarse material. The pore spaces form the main avenues for the movement of ground water.

Schists and Phyllites

These rocks are very hard, compact and devoid of any weak planes. Hence the chances of occurrence of ground water is very little. The dug wells of this area show poor yield, as water

[37] This is based on CGWB surveys and reports and is for those districts where it was available.
[38] mbgl: -meter below ground level

occurs only in the weathered zones. Feldspathic materials of schists and phyllites have been changed into clay due to weathering. Even though water gets stored in suitable locations, but due to clay that acts as an aquiclude, the yields are nominal. The sandstones are ferrugenous, hard, compact and devoid of any openings. At places these rocks show current bedding and thin bedding planes. Water occurs only in joints and bedding planes. Weathering is also limited in these rocks. These rocks appear to act as aquifuge. The grey limestone and pink limestones in this area are hard, compact and without any primary openings. So dug wells of the area show poor yield. At deeper levels these rocks have developed solution channels. Ground water occurs under confined conditions, in the secondary openings, solution channels and caverns. The solution cavities are presumed to be inter-connected and form solution channels, which allow for movement of ground water.

Surguja and Korea District

In the Archaean group of rocks occurring in the southern part of the district and in small patches in the south central parts, ground water occurs under phreatic conditions in the weathered, jointed and fractured zones. Archaeans exposed in the parts of Ambikapur, Ramanulganj and Semri blocks are hard, compact and impervious. Gneiss and granodiorites are susceptible to weathering and have fractures and joints. The phyllites and schists are moderately permeable and ground water occurrence depends on the intensity of weathering. The impervious bands of siliceous phyllites form the sub surface barriers for ground water. Ground water in dolomitic limestone occurs in joints, fissures and cavernous zones.

Gondwana rocks comprise thick beds of sandstone, shales, clays and coal seams. Sand stones with felsdpathic composition and medium to coarse grains are porous and permeable, but sand stone with siliceous matrix are impervious hard rock. Shale are fine grained, compact and porous but lack in permeability and do not form good aquifers.

In Gondwanas, the Barakar and Suprabarakar sand stones are good water bearing rocks. This formation occupies nearly one third of the district in the western part of the central, northern and southern part of the district. These sand stones are medium to coarse grained feldspathic and highly porous and permeable. Talchir sandstone is fine- grained and has a lower ground water yield. The depth of water table ranges between 4 to 16 mbgl. The intertrappean Lamenta formations occur over a small area in scattered patches. These rocks are hard and compact but are well jointed and fractured and, hence form good aquifers. The Deccan trap basalts occur in the northern and southern parts; ground water here occurs in the weathered, jointed and fractured, and vesicular zones, under both phreatic and semi-confined conditions. The shallow aquifers are found at 1.5 to 21 m bgl.

The alluvial occurs in the riverbed of the major and minor streams. The porous and permeable laterite caps on the Deccan trap basalt and Archaeans are seen in the plateau areas. Laterites form good high yielding aquifers in the low-lying areas. The depth of wells varies from 0.5 to 21 mbgl.

Bilaspur, Korba and Janjgir Champa Districts

In parts of Bilaspur district the unconsolidated material is composed of alluvial sand and sandy clay, weathered rocks and granular sedimentary material, overlaid by consolidated rocks. The residual material resulting from *in-situ* weathering of consolidated rocks such as granite, sandstone etc., are also unconsolidated formations. The semi-consolidated and consolidated formation consists of unweathered sand stone, limestone, quartzite, granite, gneiss, basalt and other unclassified metamorphics. The Gondwana sandstone, shale and siltstone have both primary and secondary porosity, and the depth of wells ranges between 2.25 to 15.20 mbgl. The sedimentary rocks of the Chhattisgarh group, comprising of limestone, dolomite, sandstone and gypsiferous shale have both, primary and secondary porosity, as well as voids big enough for good aquifers. The depth of wells varies between 5.20 to 16.80 m bgl. The basement of granite and gneiss has been subjected to prolonged weathering and stress, and hence has well-developed fractures and form good aquifers. The depth of wells varies between 3.70 to 12.21 mbgl. In general the opening of fractures in the hard rocks disappears with depth and does not yield significant water at higher depth.

Raipur, Dhamtari and Mahasamund Districts

Raipur district, which forms the southern part of the well-known Chhattisgarh basin, is covered by sedimentaries in the northwestern. The remaining southeastern portion is occupied by unclassified crystallines and meta-sediments intruded by rhyolites, dolerites etc. Unclassified crystallines and Dharwarian metamorphics are compact rocks with low porosities. These rocks are structurally less disturbed, that too, close to intrusive. Shallow, isolated, aquifers may be formed along large joints, fractures and highly weathered zones. The most common types of joints and fractures are vertical and cross each other at various angles, formed due to contraction during the cooling of magma. Horizontal joints also characterize granites and gneisses. Joints are concentrated near the surface and decrease with depth. Intensity of fracturing is also less in igneous and metamorphic rocks. Weathering in those rocks is effective along these porosities only in shallow depth, more so along valleys or in low grounds.

Lower Vindhyans are compact sedimentary rocks. Sandstones, mostly being quartzitic, show little permeability along vertical joints. They extend only in shallow depth and isolated aquifers are formed only in such places. Limestone and shale are compact and impervious rocks with little primary porosities. Small aquifers are formed in these rocks along joints or fractures mostly in upper weathered zones. Caverns and cavities develop in limestones, where slightly acidic water passes through these rocks, by dissolving the rock material along joints, fractures and other weak zones. Well connected such solution cavities present at some places, indicate isolated aquifers yielding copious amounts of water. Laterite, derived from sandstone, shale and limestone, forms a porous and permeable zone because of which quick charging and discharging exists in it.

Loamy soil, produced from weathering of shale and limestone, is impervious and does not provide any percolation of water due to its texture. Sand and sandy soil derived from sandstones, Dharwars and crystallines are porous and permeable, but excepting in low lands and valleys, their thickness may not exceed 1m.

Bastar, Kanker and Dantewara Districts

In the Bastar region groundwater and its movement is controlled by the thickness of the weathered zone, arrangement of the fracture zone in crystalline rocks and the solution cavities and tunnels in the limestone and basalt. Ground water occurs under unconfined to semi-confined conditions. The pre-monsoon ground water table varies from 2.69 to 15.10 m bgl, while during the post monsoon season it varies from 2.01 to 7.98 m bgl. The average annual water level fluctuation in phreatic zones varies from 2.01 to 7.66 m bgl.

3.5.3 Estimation Of Groundwater Potential – Method Of Central Groundwater Board

Irrigated agriculture dependent on ground water for irrigation may be less vulnerable to drought or the time lag may be more extended and tenuous between the drought period and the irrigation water supply changes. The connection between natural rainfall and ground water irrigation water supply is site-specific. Shallow aquifers dependent on annual recharge can be very responsive to drought. On the other hand, deep aquifers with minimal annual recharge can be mined for irrigation with little regard to the cyclic nature of rainfall. Groundwater potential therefore, must be determined for each area on the basis of local geo-hydrological conditions. This is the task of various government departments like the Central Groundwater Board, the Public Health and Engineering Department, the Irrigation Department, etc. The tables 3.37 and 3.38 summarize the findings of CGWB, for different blocks. *Ceteris paribus* a higher potential for irrigation from utilizable groundwater sources is better since it offers better protection against drought.

The method of ground water potential estimation prior to the 'Report of the Groundwater Estimation Committee' in 1984 was very primitive and only involved assessing the hydro-geological conditions based on the *rainfall infiltration* method. This estimation was based on the assumption that a certain fixed proportion of rainfall would infiltrate into the subsurface strata, depending on the geological characteristics. The ground water recharge was calculated as the product of total annual rainfall, the area on which it fell and the value of the infiltration coefficient of the area. The new estimation method is popularly known as *ground water level fluctuation and specific yield* method. In this method the rainfall fluctuation was recorded from observation wells (pre-monsoon and post monsoon water levels) and the specific yield of the wells and the area of recharge were used to calculate the volume of recharge from the rainfall. Various parameters were added to this index, such as recharge due to seepage from unlined canals, return seepage from irrigated fields, seepage from ponds and percolation tanks, seepage from influents rivers, recharge from submerged lands and lakes, waterlogged and shallow water table areas and flood plains. Though all possible sources of groundwater recharge were taken into consideration, however, the entire analysis was based on the few observation wells covering a huge area[39].

The total utilizable ground water available for irrigation was estimated after a deduction of 15 per cent for domestic and industrial consumption and a further 10 per cent allowance to ensure sustainability of the resource. Earlier, in ground water estimation the figure for domestic and industrial consumption was taken as 30 per cent[40]. As this figure was expressed in volumes, in order to obtain ground water potential in area terms, it was divided by the depth of irrigation. Further, the depth of irrigation is directly dependent on the cropping pattern of the area, and different combinations of crops will yield a different

[39] In Durg district, for example there are only 24 observation wells covering an area of 8708 sq km thus the representative observations are very low.

[40] Dhawan, B.D. (1986): Economics of Ground Water Irrigation in Hard Rock Regions with Special reference to Maharashtra State, New Delhi: Agricole Publishing Academy.

weighted average depth of irrigation. Though this figure is used for ground water potential estimation, the actual level of ground water development is much higher than the CGWB estimates as their computing of ground water extraction is flawed[41].

The total amount of ground water extracted from the ground water reservoirs in a year is known as annual ground water draft. The CGWB estimate totals the number of wells and tube wells in the area and multiplies the sum by the standard norms for the area irrigated by them. This figure is then multiplied by the norms for the depth of irrigation or the weighted average delta to compute the volume of ground water extraction. The computation of the weighted average delta has been reworked in Shah *et al* (1998) by considering the actual irrigated area figures, as the wells and the tube wells may not operate on the standard norms, and a weighted average of the depth of irrigation of each individual crop. The estimates for the net irrigation requirement for different crops were taken from the Indian Council for Agricultural Research (ICAR). This was multiplied by the area irrigated to derive the volume of water required for each crop. Then this figure is multiplied with the percentage of the area irrigated from ground water. The CGWB estimates are generalized, as a single value represents the state without any consideration for the intra-district variations. The assumption by CGWB, that 30 per cent of the gross draft goes back to the ground water regime as return seepage, is ambiguous as in dry regions the irrigation water is used discreetly. But this problem is sorted in this calculation as the depth of irrigation already refers to the net irrigation requirement of the crop for proper growth and yield in its growing period. Based on this method the weighted average delta for the individual districts were taken, and we have used the Shah *et al* calculation of the delta for different districts.

Finally, the level of ground water development was arrived at by annual draft as a percentage of utilizable potential for irrigation of each blocks. But CGWB has used available potential instead of the utilisable potential and, as a result, it has understated the level of ground water development by considerable margins. The table 3.38 provides the complete computation of the CGWB calculations and our revised estimation on the basis of the Shah *et al* methodology of ground water development. The frequency distribution of the level of the ground water development clearly depicts gross underestimation by the CGWB, in the range of 15 to 20 per cent. From this table, it is evident that most blocks display a high underutilization of the groundwater potential. Besides the problem discussed above, several other lacunae have been pointed out in their methodology, which can be summarized as below:

1. Arbitrary and low values for domestic and industrial consumption
2. Arbitrary and high values for recharge
3. Assumption of recharge as and where the rain falls, and contiguous to extraction zones
4. Inattention to dips and direction of flow of aquifers
5. Neglect of actual withdrawal as per existing cropping pattern
6. Neglect of actual irrigation practices
7. Calculation of potential on the basis of total rather than available balances

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[41] Shah M, D Banerjee, P S Vijayshankar and P Ambasra (1998): India's Drylands, Tribal Societies and Development through Environmental Regeneration, Oxford University Press, Delhi, pp 62- 69.

We utilized the same reports and data to reinterpret the results, to rework the numbers and see if the attention to local crop and irrigation practices alters the data. The CGWB estimates have been reworked for all the blocks and the results are as shown in Table 3.37 and 3.38.

Table 3.37: Frequency Distribution Of Blocks By Level Of Ground Water Development

Level of ground water development in percentages	Revised Estimates	Estimates by CGWB
< 5	71	76
5 – 10	37	40
10 – 15	22	15
15 – 20	10	12
20 – 25	3	1
> 25	4	3

Table 3.38: Frequency Distribution of Blocks by Districts and the Level of Ground Water Development

Name of District		Level of ground water development in percentages					
		< 5	5 - 10	10 - 15	15 - 20	20 - 25	> 25
Bastar	CGWB	14					
	Estimated	14					
Bilaspur	CGWB		3	3	3		1
	Estimated		3	3	2	1	1
Dantewara	CGWB	12					
	Estimated	12					
Dhamtari	CGWB		2	1	1		
	Estimated		1	2	1		
Durg	CGWB		2	6	2		2
	Estimated		4	3	2	2	1
Janjgir Champa	CGWB		2	4	2	1	
	Estimated		2	4	1	1	1
Jashpur	CGWB	7	1				
	Estimated	6	2				
Kanker	CGWB	6		1			
	Estimated	4	2	1			
Kawardha	CGWB	2	2				
	Estimated	2	2				
Korba	CGWB	1	4				
	Estimated	1	2	2			
Korea	CGWB	2	2		1		
	Estimated	2	2		1		
Mahasamund	CGWB	3	2				
	Estimated	3	2				
Raigarh	CGWB	4	4		1		
	Estimated	3	4	1	1		
Raipur	CGWB	7	7		1		
	Estimated	7	4	3	1		
Rajnandgaon	CGWB	7	2				
	Estimated	7	2				
Surguja	CGWB	11	5	2	1		
	Estimated	10	5	3	1		

Table 3.39:Ground Water Conditions

Ground Water	Depth Ranges (m)	Codes	Weights Assigned
Moderately Deep	2 – 5	3	3.5
Deep	< 5	4	2.5
Rocky out crop	-	x	1.0

The ground water level in the state varies from moderately deep-to-deep and in most of the blocks the water table is fairly high and found at a depth of less than 2.52 m.

Table 3.40: Groundwater Depth

Class Interval	Code	Frequency
< 2.52	1	116
2.52 – 2.63	2	14
2.63 – 2.74	3	9
2.74 – 2.85	4	4
2.85 – 2.96	5	1
>2.96	6	3

Maximum: 3.0482
Minimum: 2.4089
Range: 0.6393

3.6 FOREST COVER

One of the most critical determinants of high run off rates and soil erosion in physiographically broken and rugged areas is the forest cover. The role of forests in reducing rapid runoffs is particularly important for areas that are marked by thin light soils, high slopes, rugged terrain, and concentrated and heavy downpours after a long dry spell. Forests provide natural protection for the catchment areas of large and small basins, and increase the water harvesting capacity of the watersheds. Forests are important for another reason. They provide livelihood, fodder, fuel and food supplements, through non-timber minor forest produce, as well as food like tubers that is gathered as a food supplement by forest dwellers. Furthermore, forests protect the habitats of animals and birds that are hunted by the forest dwellers. This is very important in areas where the dependence on agriculture and forest is high, such as in forest areas in the backward regions of the country, which also are inhabited by tribal populations.

For drought proofing, it is not enough to know how much forest there is, but also its location in terms of the gradient, the soil and the drainage network. We attempted to map the forests as per their location, to see whether it covered and protected the catchment areas.

Information on forest cover was obtained from the following sources:

1. Forest department maps, which show land under the jurisdiction of the forest department, and not the standing forest cover.
2. Survey of India toposheets, which indicate standing forest cover but are outdated.
3. Revenue department data.
4. 1991 Census data.
5. NRSA district level land use data.

We used the Survey of India sheets because of their uniformity of coverage and greater reliability, and made adjustments by assigning weights after an analysis of all four sources.

The spatial data was generated from Survey of India toposheets and the forested area was digitized. The forested and non-forested areas were coded and polygons were created. This forest layer was then overlaid on the block map and polygon-on-polygon analysis technique applied, to calculate the percentage of area under forest cover in each block. The majority of the central plains area have a low proportion of forest cover due to well-established agricultural practices and industrial development, whereas the ecologically rugged and harsh areas have relatively high forest cover. Incidentally, these are also the regions inhabited by large tribal populations.

In the 1991 census 63.94 per cent of the blocks had less than 24 per cent of their area under forest cover, whereas in the 1971 toposheets 42.85 per cent of blocks were in this category. Further, blocks with high forest cover have also decreased substantially. In 1971 there were about 38 blocks with a forest cover greater than 61 per cent, whereas in 1991 there were only 6 blocks in this category (Table 3.41).

Table 3.41: Forest Cover (As Per Toposheets)

Class Interval	Code	Frequency
< 3.0	1	39
3.00 – 22.77	2	24
22.77 – 42.54	3	25
42.54 – 62.31	4	21
62.31 – 82.08	5	24
> 82.08	6	14

Maximum: 98.9006
Minimum: .0274
Range: 98.872

The Census of India (1991), percentage area under forest cover attribute data was attached to the block maps (Table 3.42).

Table 3.42: Forest Cover (as per Census of India, 1991)

Class Interval	Code	Frequency
< 12.21	1	69
12.21 – 24.41	2	25
24.41 – 36.61	3	18
36.61 – 48.81	4	20
48.81 – 60.01	5	9
> 61.01	6	6

Maximum: 73.19
Minimum: 0.01
Range: 73.18/6

The selected blocks clearly show that those in the southern part of the state face rapid depletion of forest cover.

Analysis of the data ranges in the two data sets clearly shows that not only have the districts with high forest cover reduced. The range between the highest and the lowest value has also reduced.

In 1971, there were about 6 districts with a forest cover higher than 82.08 per cent, whereas in 1991 the highest class value were 61.01 per cent and the block with highest forest cover had about 73.19 per cent of forest cover.

In this chapter, we analysed the ecological features of Chhattisgarh. These were subject to a detailed and rigorous analysis, and the interconnections between different aspects of ecology (rain, soil, slope, forest cover, geo-hydrology) were brought out. The analysis of each feature was done on the basis of how its qualities impact drought vulnerability. Weights were assigned on the basis of greater or lesser ability to withstand drought. Thus, they were related to agriculture. These were then averaged at the block level, and the conversion of attributes of ecological units to administrative boundaries was accomplished through painstaking iterative exercises. The database was now ready for ecological sub-regionalisation of the state, which is presented in the following chapter.