Chapter 2

RAINFALL AND DROUGHT

Monsoon drought is natural disaster known to India from time immemorial as the rain in some area of India underperforms. The Indian sub continent experiences large-scale drought in some part or the other, almost every year. Drought occurs in nearly all climatic zones of the world at one time or other, but this creeping phenomenon mostly affects tropics and adjoining regions. As a disaster, its experience feels only after it has occurred. Drought exerts profound influence over agriculture, hydrology, tourism, transport, water supply, hydroelectricity, etc. There is hardly any decade when the drought not occurred in India at least in two years. Hence, drought a normal feature of our climate and its recurrence is inevitable. It is part of climate variability. Unlike other weather related natural disasters drought creeps in slowly and passively. Naturally, the study of monsoon features and consequent drought has attracted the attention of Indian meteorologists' since long time.

2.1 Drought Definitions

Drought is an occasion when the rainfall for a week is half of the normal or less, when the normal weekly rainfall is 5 mm or more. Agricultural drought is a period of four such consecutive weeks in the period from middle of October or six consecutive weeks during rest of the year. Seasonal drought occurs when the actual seasonal rainfall is deficient by more than twice the mean deviation.[1] This is description of drought stated in the report of National commission of Agriculture of 1976. Subramaniaym and co- workers made use of aridity index of Thornthwaite and drought years were classified as moderate, large severe or disastrous according to the departure of the yearly aridity index from the climatic normal values. [2]

Drought is a period of drier-than-normal conditions that results in water-related problems. Definitions of drought varied widely with area of interest. Palmer (USA) defines drought as an interval of time, generally the order of months or year in duration, during which the actual moisture supply at given place consistently falls short of the climatically expected

[1] Government of India Ministry of agriculture and irrigation New Delhi Report of the National Commission on Agriculture part IV Climate and Agriculture 1976
pp.35-36

[2] ibid Loc.Cit p.36

moisture supply. The US weather bureau defines drought as period of dry weather of sufficient length and severity to cause at least partial crop failure. Thornthwaite defines drought as condition in which the amount of water needed for transpiration and direct evaporation exceeds the amount available in soil.[3] Warrick defined drought as a lack of rainfall so large and so long continued to adversely affect all established human activities of the region. Different countries have, however defined drought as per their rainfall pattern. The British rainfall organization in UK defines "absolute drought" when at least 15 consecutive days none of which receive at least 0.25 mm of rainfall and partial drought when at least 29 days during which mean rainfall does not exceed 0.25 mm per day.[4] In U.S.A. according to Conard (1944) a period of consecutive 20 days or more without 6.4 mm precipitation in 24 hours during season March to September is considered as drought situation. In Australia according to Gibbs and Maher (1967), the rainfall is the best single index of drought and use of rainfall declines demonstrate temporal and spatial distribution.[5] In USSR drought is defined as period of ten days with a total rainfall not exceeding 5mm.[6] According to Ramdas "drought is an occasion when the actual rainfall fell short of the normal by more than twice the mean deviation."[7] However, from practical standpoint, drought may be regarded as a period of abnormal dry weather sufficiently prolonged for lack of water to cause serious hydrological imbalance in the affected area. The Indian meteorological Department defines drought in any area when the rainfall deficiency in that area is more or equal to 26% of long term normal. It is further classified in to moderate and severe drought depending upon the rainfall. A period of drought is defined as a year or season in which the total rainfall is less than 75% of the normal. It may further be classified as a year or season of 'moderate drought' if rainfall deficit is between 26percent and 50 percent and a year or season of 'severe drought' when it is more than 50 percent. When during a long period of years,

[3] ibid pp.34-35

[4] Shewale M.P. and Shravan Kumar climatological features of drought incidences in India IMD Pune Meteorological monograph Climatology 21/2005 2005 p.3 Koteshwaram Cff, P.Koteswharam Drought in Asiatic monsoon region a symposium Indian National Science Academy New Delhi 1976 a Symposium on droughts Delhi held between 14 to 16 December 1972 editor K.R.Ramaswamy. Bulletin No. 54, Vol.42 1976 p.11 p.11

[5] ibid p.4

[6] Report of National commission on agriculture 1976 Opp.Cit p. 35

[7] Ramdas L.A., '1950: Rainfall and Agriculture,' Indian Journal for Meteorological Geophysics (IJMG) 1 (4), pp.262-74

drought as defined above, occur on at least 20 percent of the years over an area that may be classified as a 'drought prone area.' If the frequency is, 40 percent or more then area may be termed as 'chronically drought area.[8] For the country as whole, the area-weighted rainfall having normal of 88 cm, also called Indian summer monsoon rainfall (ISMR), is considered. When the rainfall deficiency exceeds 10% and when area under drought exceeds 20% of the total area of the plains in the country (which is 32, 87 787 sq. km) such situation is considered as drought for country as whole.[9]

The definition of drought remained inexact and based on inference for over 5000 years of human history until the means of quantifying it became available in the late 19th century when reliable observation of rainfall began.

Drought may be broadly classified into the following three types:

(1)Meteorological drought: It is a situation when there is significant (more than 25 per cent) decrease from normal precipitation over an area.

(2)Hydrological drought: meteorological drought, if prolonged, results in hydrological Drought marked depletion of surface water and consequent drying of reservoirs, lakes, Steams, and rivers, cessation of spring flows and fall in ground water levels. Hydrological drought may be reflected in depleted snowmelt due to poor snow-fall in an Earlier season and this may result in curtailment of power generation and affect industry As well as agriculture.

(3) Agricultural drought: It occurs when soil moisture and rainfall are inadequate during growing season to support healthy crop maturity and cause extreme crop growth to maturity and cause extreme crop stress and wilt.

(4) Economic drought: When deficit precipitation affects the normal economic growth of the country it results into economic drought. [10]

2.2 Scope of Drought Studies

[8] The climate of Maharashtra India Meteorology department publication Pune 2006 p.8

[9] See Shewale M.P. and Shravan Kumar climatological features of drought incidences in India IMD Pune Meteorological monograph Climatology 21/2005 2005 pp.3-4

[10] Sikka D.R. & Kulshreshta S.M., ' Indian droughts in the context of history and climate' A study for institute global environment and society Centre for Ocean-Land-Atmosphere studies and Centre for the application of Research on the environment Joint COLA/CARE report no.6, 2002 pp.7-8 Cff. Government of India ministry of agriculture and irrigation, Report of the national commission on agriculture 1976 part IV climate and agriculture 1976 pp.34-35

Considering all definitions of drought, it appears that drought concerned with deficiency of water for different purposes. Measures to quantify drought is part of drought studies. Water is indispensible part of human life and civilization. Therefore, drought poses serious concerns to human life. Averages of rainfall and other climatic conditions like temperature, wind velocity and rate of evaporation of very long period set normal water retaining and storing potential of particular geographical area. Any deficiency in such water storage and retaining capacity if affecting gross domestic product of country through any set of consequences have to be considered as drought condition of that particular country. Thus, water requirements are important attribute in defining drought. In future or as part of new innovations effective and economic use of water may reduce existing water requirements at such instance water requirements for different use may get reduced. At such instance threshold limit of water availability for defining drought condition have to be reduced further. Effects of droughts, drought proofing measures, use of drought resistance crop varieties, and augmentation of ground water along with economic measures are also considered within ambit of drought studies.

2.3 Some characteristics and Significance of droughts

Droughts occur in a chaotic way and there is no quasi-periodicity in their occurrence**.** Drought is identified with situation when a water loss, due to vapor- transpiration exceeds the effective rainfall. In India not only the tropical situation but also its entire dependence on the monsoon rainfall aggravates the situation of drought even more. Drought prone areas in India are generally associated with low level of development, and when drought strikes, the condition of toiling people becomes miserable. Drought affected people have to lead the life of destitute. Moreover, the scope of agricultural growth in these areas is limited by low and uncertain moisture conditions. Predominance of small holdings, large incidence of agricultural workers, non availability of suitable high yielding variety of crops and above all, lack of suitable infrastructure to stimulate economic growth are important attributes of typical drought prone areas. All these combine to aggravate unemployment and low income and create glaring disparities in living standard compared to the areas which have good irrigation facilities and fairly high rainfall. These are common features associated with drought-affected areas. Drought has been a constant visitor in India since time immemorial. In fact, whenever

drought occurs, chances of it being of severe nature are quiet high in Saurashtra & Kutch (with 48% probability), Gujarat Region (41% probability), west Rajasthan (36% probability) east Rajasthan(23% probability) Haryana and Punjab (18% probability) Himachal Pradesh (14%) probability. In rest of the sub-divisions, the chances of drought to be severe in intensity appear quite remote.[11] Shewale and Shravan Kumar further identified areas that are having drought probability of less than 10% belongs to least drought category, areas having drought probability between 10 to 20% belongs to frequently drought prone areas and more than 20% probability categorized as chronically drought prone areas. Shewale and Shravan Kumar also made two categories of drought one is moderate having rainfall deficiency between 26 to 50% and another of severe drought having rainfall deficiency more than 50%. [12]

The arid sub-divisions of west Rajasthan and Saurashtra and Kutch are the most drought prone areas of the country. Most areas of per-humid and humid northwest India, face the drought menace but infrequently. Occurrence of drought in consecutive monsoon seasons are common in northwest Indian sub-divisions, particularly west Rajasthan, Saurashtra and Kutch and Jammu and Kashmir and Rayalseema in the Peninsular India. Probability of drought over India is 20%. The period 1965-1974 was the worst period with drought occurred on 5 occasions. In the 130 years under study, only 20 cases of drought observed which gave probability of drought for India as 15%. This figure seems to be lower than obtained by other method.[13] Similar findings are put forth in the studies of Sikka and Kulshresthta that Northwest India and Central North-East India are more vulnerable to droughts.[14] Pai and Shridhar observed that "It is seen that majority of the districts in the northwest part of the country consisting of Rajasthan, Gujarat, Jammu & Kashmir, Punjab, Haryana have drought probabilities of ≥20%. The probabilities decrease as moving eastwards from northwest India to northeast India. Over northeast India, most of the districts have probabilities of less than 10%. Over the peninsula, many of the interior districts have probability of≥20%. Districts along the west coast show less than 10%

[11] Shewale M.P. & Kumar Shravankumar Opp. Cit. p.6

[12] ibid. pp.4-5

[13] ibid p.7

[14] Sikka D.R.and Kulshreshta & Kulshreshta S.M. 'Indian droughts in the context of history and climate' A study for institute of global environment and society October 2002 p.10

probability."[15]Though as per percentage departure criterion humid and sub-humid climatic regions of India faces meteorological droughts. Such mild droughts over these areas did not result into agricultural droughts. Twenty five percent deficit rainfalls over such area does not affect much on paddy production. Finding of all above mentioned renowned meteorologists are similar indicating usually some area receives low rainfall and more prone to droughts. Some area receives higher rainfall and has very low probability of drought. Therefore it is easy to identify rainfall pattern and adopt drought proofing measures over such drought prone areas.

2.4 Monthly Monsoon Rainfall and droughts

Mooley (1984) has examined the month by month departure of rainfall in the monsoon season (June to September) for 18 of 22 drought years shown. There is clear pattern in the monthly progression of rainfall. Several years even started with positive rainfall anomaly in June (1899, 1904, 1911, 1918, 1941 and 1968) but the rainfall got suppressed in the subsequent months. In 10 drought years, there was a positive anomaly in at least one month of the season. On the other hand, in 1987, the All India rainfall deficiency was above 10% in all four monsoon months. There are years such as 1951 and 1979 in which the deficiency of monthly rainfall increased with the progress of the season-suggesting an abnormally persistent dry season. In 1987 the negative monthly rainfall was higher than 20% in June and remained above the 10% limit for the remaining 3 months of the season. The two years 1920 and 1982 show small positive rainfall departure in July and August respectively, but it made little impact as these large negative departures in the other two months overwhelmed the contribution of two months positive rainfall departure. [16]

2.4 Measures towards quantification of droughts

Van Rooy of south Africa has developed a drought anomaly index on rainfall departure and the mean of lowest ten values of rainfall in a series. This index gives an idea of water income but not water availability. The water availability depends upon such factors as

[15] Pai D.S., Sirdhar Lata,Guhathakurta Pulak and Hatvar H.R. Districtwise climatology of the southwest monsoon season over India based on standardized precipitation Index National climate centre research report 2/2010 March 2010 of IMD calculated SPI index means standard precipitation index for different districts for different 36 meteorological subdivisions. NCC research report March 2010 RR No. 2/2010 p.8

[16] Sikka and Kulshetra Opp. Cit p.19

evapo-transpiration, soil moisture desiccations soil type etc. A drought index computed using all such parameters besides rainfall only would be helpful to quantify drought objectively. Such index can provide the basis for classification of drought according to their severity. According to the water balance approach by Thornthwaite drought is described as condition when the amount of water need in the form of evaporation and transpiration exceeds the moisture supply that is available as rainfall and soil moisture. This water deficiency when expressed as ratio of the water need (Potential evapo-transpiration) becomes a very useful parameter, aridity index, which can be used for comparison of drought in space and time. Palmer conceived a two layer model of the soil in deriving a metrological drought index. Palmer developed empirical equations for monthly index values that are applicable to actual drought conditions. Based on these equations and indices he has evolved limits for four classes of droughts namely mild, moderate, severe and extreme. Such computations have been done for the various sub-divisions of the country from 1901 onwards. The index being dependent on antecedent moisture conditions represents agricultural drought in dry areas and hydrological drought in humid areas. Foley in Australia, Subramanayam and co-workers in India and Yevejvich and others made similar attempts using Palmer's and Thornthwaite's methods to develop drought indices.[17] India meteorology department also developed drought indices to monitor droughts in India. [18] A drought index is typically a single number value used for indicating severity of drought and it is far more useful than raw data to understand the drought condition over an area. During the past few decades, several drought indices based on remote sensing data such as Normalized difference vegetation index (Jordan 1969, Tucker 1979), Enhanced vegetation index (Huete et al. 2002) Vegetation condition index & Temperature condition index (Kogan 1995 & 1997) etc. have also been developed. [19] The standardized precipitating index (SPI) is an index developed by Mckee et al (1993) based on the probability of rainfall for the scale of

[17] Kotesharam P., ' Drought in Asiatic monsoon area a paper in symposium on drought organized by Indian National Science Academy' 1976 (symposium was organized between 14-16 December 1972) Opp.Cit. pp.12-13

[18] Pai D.S., Sirdhar Lata,Guhathakurta Pulak and Hatvar H.R. Districtwise climatology of the southwest monsoon season over India based on standardized precipitation Index National climate centre research report 2/2010 March 2010 of IMD calculated SPI index means standard precipitation index for different districts for different 36 meteorological subdivisions. NCC research report March 2010 RR No. 2/2010

[19] Ibid p.3 Due to multidisciplinary importance of droughts several drought indices found in the literature. (Bates 1935, Palmer 1965&1969, Gibbs and Maher 1967, Frere and Popov 1979, Bhalme and Mooley 1980, Petrasovits 1990, Rao et al. 1981, Sastri 1993, Heddinghaus 1991, Tate et al. 2000)

interest and is relatively less complex to compute. The time scale reflects the impact of drought on the availability of the different water resources. Soil moisture conditions respond to rainfall anomalies on a relatively short scale. Groundwater, stream flow, and reservoir storage reflect the longer-term rainfall anomalies. For the calculation of SPI for any location, long time series of rainfall for the desired period (monsoon season for this study) is used. This long time series of rainfall is fitted to probability distribution which is then transformed into a standardized normal distribution so that the mean SPI for the location and desired period is zero. Positive SPI values indicate greater than median rainfall and negative values indicate less than median rainfall. The classification of the drought intensities based on the SPI value as follows; drought is moderately dry/moderate drought for SPI value from -1.0 to -1.49, severely dry/severe drought for SPI value from -1.5 to -1.99 and extremely dry/extreme drought for SPI value of -2 and less.[20] Drought climatology based on SPI is not biased by the aridity of the region and hence is a better index for drought monitoring.[21] As the all India rainfall is significantly normally distributed, the years of all India drought (moderate and above) identified both PN and SPI were nearly same. However, there were significant differences in the district-wise climatology based on these two drought indices. The district-wise drought climatology over India based on PN was found to be highly biased by the aridity region. Highest probability for droughts of moderate intensity was observed over many districts from northwest India and neighboring central India and interior parts of south peninsula. The lowest probability for droughts of moderate intensity was mainly observed over several districts along west coast of the north peninsula and eastern and northeastern parts of the country. The highest probability of the severe droughts was also observed over the northwestern part of the country. On the other hand district-wise climatology of the drought based on the SPI was not biased by aridity of the region. Therefore, SPI is a better index than PN for monitoring the district-wise drought indices over India. Further as the SPI is normalized index, it can be used to represent the excess rainfall or wet conditions in the same way as it is used to represent the drought/dry conditions and wet periods can also be monitored using the SPI. As seen in the previous paragraph, whereas

[20] Ibid p.7
[21] Ibid p.10

both PN and SPI are suitable for the seasonal drought monitoring on all India scale. SPI is more suitable for district-wise drought monitoring. This is mainly because of the higher C.V. of district-wise rainfall than all India rainfall. The C.V. also increased with decrease in the spatial and temporal scale for region of reference because of more frequent extreme events at these scales. Therefore, the SPI will also be a better index than PN in monitoring wet and dry incidences at intra-seasonal scales such as break and active events over India. SPI is also more suitable as it allows drought severity at two or more locations to be compared with each other regardless of climatic difference between them. As the variability of SPI is nearly same as that of the precipitation anomaly, prediction models can be developed for SPI and hence it is suitable for drought prediction. Dynamical model forecasts of rainfall can be altered to produce spatial maps of SPI for drought prediction. [22]

2.5 Enquiries into Historical Indian Droughts through different Studies

Many scholars have studied Indian droughts D.R.Sikka, Shewale and Shravan Kumar are prominent among them. Number of drought incidences over India its classification and types described in table No. AT-16 & AT-58 appended in Appendix-A. This classification is prepared by D.R.Sikka. This gives clear idea of Indian droughts. Monsoon droughts over India categorized as mild, moderate, severe and phenomenal, if the quantum of seasonal monsoon rains has been below 1.0 of standard deviation (SD), 1.25-1.49 of SD, 1.50-1.99 of SD, and equal or above 2.00 of the SD, respectively. The monsoon season of the years' 1877,1899, 1902, 1905, 1918, 1920, 1965, 1972, 1979, 1987 and 2002 witnessed severe droughts, of which 1877, 1899, and 1918 were phenomenal droughts and the recent 3 years 1972, 1987 and 2002 were very close to the phenomenal category in which the deficit of seasonal rainfall was 19%. Almost all the severe droughts except those of 1920 and 1979 are associated with warm El Nino phenomenon in the central and eastern equatorial Pacific Ocean and low Southern Oscillation Index (SOI). Walker (1924) discovered the relationship between the out-of-phase performance of monsoon over India and Southern Oscillation (SO).[23]As far as Indian droughts concern D.R.Sikka drawn following conclusions. Droughts occur in a

[22] ibid p.12

[23] Sikka D.R., and Ding Yuhi Wang Bin et al. 'The Asian Monsoon' Opp.Cit. p. 176

chaotic way and there is no quasi-periodicity in their occurrence. Almost all (20 of 22) drought years(See table AT.16 appended in Appendix-A) have occurred simultaneously in at least two homogenous regions of India except two years 1920 and 1941, which occurred in West Central India region only. The deficiency of rain reached the phenomenal category over West central India on both these occasions. Thus, all India droughts are expected to cover two or more homogeneous regions of India simultaneously. In the 22 All India droughts regional scale droughts occurred over west central India homogeneous region on 17 occasions (77%), over Northwest India homogeneous region on 16 (73%) occasions and over Central NE India homogeneous region on 14(64%) occasions. Simultaneously of all India drought and drought in South Peninsular India and NE India homogenous regions is only on 7 (32%) and (4%) occasions only. This implies first two homogenous regions are more drought prone and last two least drought prone areas of India. During 13 drought years, three or four homogenous regions were simultaneously gripped by droughts (1873, 1877, 1899, 1905, 1911, 1918, 1951, 1965, 198, 1972, 1974, 1979 and 1987) and on four occasions four homogenous regions simultaneously came under grip droughts (1918, 1972, 1979, 1987). Only, in the case of 1972 all the five homogeneous regions of India were simultaneously under the grip of a drought. The 1972 drought is unique in this respect. However, the areal extent covered by severe drought was not as large as 1918, 1877, 1899 and 1987. [24]

Shravan Kumar and Shewale studied Indian droughts. The range of drought years faced by different climatic regions of India is from 27 to 31 for period of 1875 - 2002.[25] As per percentage departure from normal criterion they identified 1877, 1899, 1918, 1972 as worst drought years ranked as per sequence enlisted herein.[26] 1918, 1899, 1877, 1987,

[24] Sikka & Kulshreshta Opp.Cit. pp.,9-10)

[25] Shewale M.P. Shravan Kumar p.4 Highest cases from West Rajastan, Saurashtra and Kutch with 31 cases, Gujratat region 27 cases, J&K 28 cases, other areas recording significantly large incidences of drought are Haryana, Delhi & Chandigarh, Punjab, Himachal Pradesh and Rajastan in northwest India and Rayalseema in southern peninsula. The lowest number of droughts have been observed in Northeast (Arunachal Pradesh, Assam, Meghalya, Orissa and Gangetic west Bengal and Jharkhand per humid areas of coastal Karnataka also experience significantly less frequency of droughts though similar climatic zone of Konkan and Kerala do experience drought on comparatively more occasions.

[26] Shravan Kumar and M.P.Shewale Opp.Cit. table 4 p.17,p.7 The worst drought the country faced was in 1877 with ISMR deficiency 33%, followed by 1899 with 29% deficiency, 1918 with 25% deficiency, 1972 with nearly 24% deficiency and 2002 with nearly 19% deficiency.

1985 and 1972 are worst drought years as per aerial spread criterion. They are ranked as per sequence enlisted herein.[27] (See also table appended T.2 in Appendix-A) Shewale and Shravan Kumar also identified 27 all India drought years as per the areal extent criteria. The probability of all India droughts as per areal extent criteria is 20%. It observed that 13 year period; from each span of following periods,. 1878 to 1890, 1926 to 1938, 1952 to 1964 and 1988 to 1999 the country was free from droughts with respect to areal extent criterion. (When drought area exceeds 20% of all India area then it is considered as all India droughts) As per criterion of departure from normal or average rainfall i.e. 88 cm of all India level 10% negative departure is considered as all India droughts. 20 such cases identified by Shewale and Shravnkumar. Thus, probability as per rainfall departure criterion is only 15% of drought all over India. [28]

It can also be observed that in some years like 1891, 1907, 1913, 1915, 1925, 1939, 1985 and 2000 all India droughts identified by criterion of areal extent did not match with the criterion of rainfall deficiency. Within span of 130 years there were only two years i.e. 1986 and 2004 when the ISMR was deficient by 12.7 and 13.0% but it affected only about 19% area of the country as whole.[29] Data analyzed for 130 years shows only two cases of consecutive droughts over India as one unit i.e. 1904-1905 and 1965-1966. These years satisfy both criteria and confirm consequent drought years. However when the analysis is extended to the meteorological sub-divisions, obviously, a different picture emerged. For a good number of sub-divisions we not only found two consecutive droughts but also sometimes even more occasions of consecutive droughts. Sub-divisions which experience such situation are shown in table appended in the appendix. Not surprisingly the humid areas of Arunachal Pradesh and Assam and Meghalaya, Gangetic West Bengal, Bihar, Jharkhand and costal Karnataka seem to be free from persistent drought in consecutive years. Even sub-divisions like west Uttar Pradesh and Tamil Nadu West Bengal and Nagaland, Manipur, Mizoram and Tripura through belonging to per humid climate have observed to experience drought on 2 or more consecutive years. In fact in NMMT (Nagaland, Manipur Mizoram Tripura) drought has

[27] Shravan Kumar and M.P.Shewale table 4 p.17,p.6 during 1918 the spread of drought area was 70%, 1877 the corresponding figure was 59%, 1987 it was 48% and during 1905 corresponding figure was 37%.
[28] ibid p.7
[29] ibid p.7

occurred in three consecutive years once viz. 1887-1889. This observation shows that on very few occasions drought over particular region and year coincide with all India droughts. This also implies that during regional drought year scarcity over particular region get relieved by good monsoon over other regions. Cases when areas where drought has occurred once in 2 or more consecutive years east Uttar Pradesh, Uttranchal, Madhya Pradesh (including Chatisgrah) Marthwada, Vidharbha, Coastal Andhara Pradesh and South Interior Karnataka. In parts of northwest India like Harayana, Himachal Pradesh, Jammu & Kashmir, Rajastan, Gujrat and Kerala in southern India, recurrent drought appears more common as is evident from table. Over Punjab, Jammu and Kashmir, West Rajasthan, Surashtra and Kutch such occasions even exceeds 5 in number. They attain frequency of 8 over west Rajastan. Over western Himalyas viz. Himachal Pradesh and Jammu and Kashmir, in 4 consecutive years droughts have occurred. In fact over Jammu and Kashmir there was one incidence during 1983 to 1987 the drought has occurred on 5 consecutive years. [30] Thus, West-Rajasthan, Saurashtra and Kuthc are chronic drought prone area of India.

The lowest number of droughts have been observed for obvious reason in per-humid and humid areas in the northeast (viz. Arunachal Pradesh, Assam & Meghalaya, Orissa Gangetic west Bengal and Jharkhand.) per humid areas of costal Karnataka & Meghalaya, Orissa, Gangetic Bengal and Jharkand. Per humid areas of coastal Karnataka also experience significantly less frequency of droughts though similar climatic zone of Konkan and Kerala do experience drought on comparatively more occasions.[31]

"Area affected by drought seems to have shown steady increase between 1894 to 1908 and between 1964 to 1975. A progressive decline from 1908 and 1964 and from 1985 to 1998 are also seen. Drought area has more or less remained constant from 1976 to 1986. Surprisingly, in recent years there again seems to be a tendency for drought affected area to increase from 1988 onwards." This observation underlines the epochal or decadal behavior of monsoon. [32]

[30] Shewale & Shravan Kumar Opp.Cit. p.8
[31] ibid p.4.
[32] ibid. p.8

These findings of Shewale and Shravan Kumar are deals with meteorological droughts. However, these droughts at humid and sub-humid places like high-rainfall areas would not have resulted into agricultural drought but may lead to hydrological drought. The places where normal rainfall is above 150 cms. at such places 10% deficiency in normal rainfall could not affect paddy production. Even at places having 100 cms. annual rainfall could not affect agricultural production. Therefore rainfall departure at high rainfall areas is not sufficient to depict the exact picture of drought situation.

Pai, Sridhar and other meteorologists of IMD Pune developed new standardized precipitation index for all districts of India in 2010. However they also classified Indian drought with conventional departure from normal rainfall method. They observed that during the period 1901-2003, there were 22 deficit monsoon years (with percentage normal (PN)values less than 90%) and 28 years when the percentage area of the country under drought was more than 21%. Using PN criteria and areal extent criteria Pai and his colleagues identified 16 years as all India moderate droughts. These years are as follows 1901, 1904, 1905, 1907, 1913, 1920, 1941, 1951, 1965, 1966, 1968, 1974, 1979, 1982, 1986 & 2002. They identified as the all India moderate drought years with PN less than 90% and 21-40% of area of the country under drought. Further, they observed that 4 years 1911, 1918, 1972 & 1987 were all India severe drought years (with PN less than 90% and more than 40% of area of the country drought). [33]

Pai and his colleagues from calculating of standardized precipitation index derived another classification of Indian droughts. Drought classification of all India rainfall time series based on SPI criteria identified following 10 years 1901, 1904, 1907, 1913, 1920, 1941, 1966, 1968, 1974, 1986 as moderate drought years. Another 6 years as mentioned further 1905, 1911, 1951, 1965, 1982 & 2002 identified as severe droughts. They further identified following 4 years mentioned as follows 1918, 1972, 1979 &1987 as extreme drought category. On comparing the drought years based on both the drought indices, it

[33] Pai D.S., Sridhar Latta., Guhathakurta Pulak.m., Hatwar H.R., District-wise Drought Climatology of The South Monsoon Season over India Based on Standardized Precipitation Index (SPI) National Climate Centre NCC Research Report No.2/2010 IMD 2010 p.10; Using criteria given in the section 3.1 all India drought and all India severe drought years were identified. For this purpose the percentage of area of the country under drought was calculated using PN and geographical area data of all the 458 districts.

observed that in both the cases the list of 20 years is the same. Further, it can be seen that 15 of the 16 moderate/severe drought years based on SPI is same as 15 of 16 moderate drought based on PN criterion. The only exception is that in drought yeas based on PN 1979 comes under the moderate category and 1911 comes under severe category. On the other hand, in the case of SPI, 1979 comes under extreme drought category and 1911 comes under moderate/severe category. [34] The trend analysis of district-wise SPI series showed significant decreasing trends over many districts in Uttaranchal, Kerala and in the subdivision from east central India and such as east Madhya Pradesh, Vidarbha, Chattisgarh, Jharkhand, Bihar etc., and significant increasing trend was observed over several districts from Konkan region, Karnataka, West Madhya Pradesh, Andhra Pradesh, Punjab and West Uttar Pradesh. Some districts from Kerala and Chattisgarh showed decreasing trends in SPI series and relatively high probability for drought occurrences of moderate and above intensity. [35]

Thus D.R.Sikka identified 22 cases of all India droughts as per rainfall departure criterion for span of 112 years. Shewale and Shravan Kumar identified 20 cases of all India droughts for 130 year span on percentage departure criterion while on area extent criterion they identified 27 all India drought cases. Pai and his colleagues identified 28 all India droughts on area extent criteria and 22 all India drought by percentage departure criteria. Using SPI index Pai and his team identified 20 all India droughts. They further identified 16 all India droughts which satisfied both PN and SPI index criterion. Shewale and Shravan Kumar covered 130 year span, Sikka covered 112 year span up to 1987, Pai covered 102 years up to 2003 period in their studies. Thus we can add only one all India drought in Sikka's list that of 2002 drought. In Pai's list we can add droughts of 1875 onwards to 1901. Thus we can add only three droughts as per areal extent criterion and two droughts as per percentage normal or percentage departure criteria. The corresponding figures of Pai's list of area extent criteria and percentage normal criteria would be 30 and 22. Thus there were only 22 to 23 all India droughts as per departure from percentage normal rainfall criteria. However, in this list only 4- 6 droughts were of severe category.

[34] Ibid p.10-11
[35] ibid p.13

2.8 Physiographic information and Rainfall of Maharashtra

Maharashtra is situated between16.4 to 22.1 degree north latitude and 72.6 to 80.9 degree east longitudes. This state of Indian union has occupied western part of Indian peninsula.[36] It is bounded by Arabian Sea on its western side. The physical features of the state is characterized by western Ghats (Sahyadri) run north to south separating the coastal districts of Konkan from the rest of Maharashtra. As the ridge runs across at right angles to the monsoon stream, it forms an important climatic divide. The western slopes and the coastal districts get very heavy monsoon rains, while to the east of the Ghats rainfall drops to less than a tenth within a short distance from the Ghats. The state receives rainfall mainly during the southwest monsoon season (June to September).There is heavy rainfall in coastal region (about1000 mm) of the state. Fortunately, all the important rivers like Godavari, Bhima and Krishna which originate from the water shades of the Ghats flow east across the drier regions and contribute to their economic benefit. The influence of the smaller and less cohesive east west oriented ranges of Satpura an Ajaanta is not so marked.

There are four meteorological sub divisions viz. Konkan, Madhya Maharashtra, Marathwada and Vidharbha in the state. The state consists of 35 districts as on first January 2002.

2.9 Rainfall pattern over Maharashtra

Maharashtra state experiences extremes of rainfall ranging from 600cms over the Ghats to less than 60 cm in Madhya Maharashtra. The coastal strip and adjoining Western Ghats exposed to the southwest monsoon receive the heaviest rains exceeding 200cm. rainfall over the Ghats may exceed 500cms annually. Rainfall decreases very rapidly towards the eastern slopes and plateau area where it is a minimum. It again increases as we proceed further eastwards. The Madhya Maharashtra is the region of lowest rainfall. In this region, the annual rainfall is less than 60cms at most places. Within this strip lies the area of lowest rainfall less than 50cms running from Dhond- Baramati sector to Indapur-Mhaswad sector to south east of Pune district. July is generally the rainiest month except in the central region except in the central region of the state comprising of

[36] Subramanian committee for drought area determination report Government of Maharashtra 1987 pp.8-9

the districts of Ahemednagar, Beed, Osmanabad and Latur where September is the rainiest.

The state gets its rainfall chiefly in the southwest monsoon season (June to September) . Konkan receives 95 % and Vidharabha 88 % of annual total during the monsoon season. Madhya Maharashtra and Marathwada receive around 83% of the annul during the monsoon and about 11 % during Post monsoon months of October and November. The post monsoon showers are of considerable economic importance. The advent of monsoon is generally sudden the rainfall increases from 1 to 2 percent of the annual normal in May to 15 to 23% in June. The rainfall becomes heavy to very heavy on occasions in association with cyclonic storms and depressions. The monsoon advances from the south to north and reaches Mumbai by about 1oth June. The number of rainy days in a year varies from 70 to 100 in Konkan to 34 to75 in the interior to east of Western Ghats .Indian meteorology department prepared the charts of heavy rainfall days but none of the event is noted during Known drought year.[37]

2.10 Rainfall Variability over Maharashtra

Coefficient of variation of normal rainfall is more than 25% in southeastern eastern and extreme north western parts of the state. In western parts of the state, it ranges between 20 to25 percent. In the months of January and February, the coefficient of variation (C.V.) is extremely high and it ranges from 100 to 400. It increases from east to west. During the summer months i. e. March, April and May, it is the lowest in the southeastern parts of the state, adjacent to Karnatka state boundary and increases to its northern and western coastal sides even greater than 120% in the coastal region of Thane and Mumbai; it is more than 200% in the north eastern parts of the state. Lower values of the C.V. are noticed and range 80 to 100%. During the southwest monsoon season, C.V. is more than 30 percent in southeastern and extreme northwestern parts of the state. In extreme western parts, it is less than 20% and in other parts of the state, it ranges between 20 and 30%. During post monsoon season, central parts of the state comprising parts of Aurangabad, Jalana, Prabhani, Hingoli, Washim and Buldhana and northwestern and

[37] Climate of Maharashtra pp.5-6

some eastern parts of the state, C.V. is greater than 80%. In the southern parts of the state, C.V. is less than 60% in the remaining parts of the state, it ranges from 60 to 80%.

The above discussion gives the picture of rainfall variability in different seasons as well as year as whole.[38]

2.11 Drought over Maharashtra different studies and observations

The state gets its rainfall primarily in the southwest monsoon season (June to September) Konkan receives 95 percent and Vidharba 88 percent of the annual total during the monsoon season. Madhya Maharashtra and Marathwada receive around 83 percent of the annual rain during monsoon and about 11 percent during post monsoon months of October and November. The post monsoon showers are of considerable economic importance.[39]

Incidence of widespread drought over the state in any particular drought year is usual phenomenon. In the years 1941, 1952, 1972, 1984 and 1986 widespread drought affected the state. In the years 1952, 1972 and 1984, the number of districts affected by drought were 22, 32 and 18 respectively. In the years 1941 and 1986; 12 and 17 districts were under the grip of drought respectively. During the years 1918, 1920, 1972, 1985 more than 2 lakhs sq. km. area has been affected by drought.[40]There, were no drought anywhere in the state in 16 years.[41]

P.G.Gore and Sinhha Ray also identified following years as drought years over Maharashtra. 1904,1905,1911,1918,1920,1925,1941,1965,1972,1974,1982,1985&1987 are large scale droughts over Maharashtra.[42]

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[38] Climate of Maharashtra pp.7-8 Coefficient of variation (C.V.) which is expressed as percentage is defined as
CV=Standard deviation÷Normal×100

[39] ibid p.6

[40] Gore P.G.,& Sinha Ray K.C., letter to editor Masusam,53,4 (October 2002) IMD publication 2002 pp.535-537

[41] Climate of Maharashtra Opp.Cit.p.10 namely 1948, 19531954, 1955, 1956, 1957, 1958, 1959, 1961, 1963, 1967, 1969, 1977, 1980, 1983 and 1988

[42] Gore& Sinhha Opp.Cit. P.537 Least number of droughts is in decades 1931-40. 1951-60 and 1961-70. There are three worst drought years in decades 1911-1920 and 1981-1990 on an average one worst drought is noticed in each decade. Successive years of either large scale or worst drought are 1904-05,1911-12, 1924-25, 1971-72, 1984-85, 1986-87.[42] Rainfall of less than 50% of the annual normal representing severe drought conditions occurred in various districts may be summarized as follows.

Ahemednagar, Aurangabad, Beed,Jalana, Latur,Nanded, Osmanabad,and Solapur were the districts which faced severe drought condition during the year 1972. The area under this severe drought of 1972; for each of these districts are 38, 46, 40, 41, 34, 41, 36, 37 percent respectively.[43]

Gore and Sinha Ray studied the rainfall of all 26 districts of Maharashtra. Then identified drought years with moderate and severe category and reached following findings. There are 26 large-scale meteorological droughts identified over Maharashtra during 1901-1998 and out of them 11 years are worst drought years when more than 50% area of the state was affected by drought.

A trend for total area affected by drought over Maharashtra did not show a significant trend and epochal behavior of occurrence of drought is depicted. The severe drought probability is 1to 7 percent for most of the districts. The severe droughts not experienced in some of the districts of Vidharabha and Konkan for last 98 years.[44] The probability for large scale drought years for Maharashtra is 59% during the drought over country and is about 55% during EL Nino years.[45]

The frequencies of drought have reduced a little during the decade 1991-98 except Marathwada. Successive years of either large scale or worst droughts are 1904-05, 1911-12, 1924-25, 1971-72, 1984-85 and 1986-87 were the severe drought years. [46]

Severity of drought not only depends upon the order of rainfall deficiency in single year but also upon continued occurrence of deficient rain in successive years even though the

[43] Climate of Maharashtra Opp.Cit.p.10

[44] The decadal frequency of drought for most of the districts has been reduced during the years 1931-70. Most of the districts from Vidhrabha experienced no drought during years 1931-40. A single occasion of drought incidence during 1931-40 was shown only over Wardha district. In addition, most of the district Bombay showed two incidences of drought during this period.

[45]Gore Sinha Opp.Cit. p.538 Most of the districts show 2 to 4 incidences of drought during first 3 decades from 1901 to 1930. The decadal frequencies of drought have been increased little after 1970 to 1990 except Konkan. The districts in Madhya Maharashtrsa and Vidhrbha experienced about 2 to 5 incidences of drought during 1981-90. While districts in Maharashtra also experienced 2 to 5 incidences of drought during this period.

[46] Gore P.G. & Sinha, Ray K.C. India Meteorological Department Mausam 53,4 October 2002 p.535(By using seasonal rainfall departure for southwest monsoon, season for period 1901-98, the years with deficit rainfall more than 25% for different districts in Maharashtra identified as drought years for districts. Maharashtra, have been identified as drought years for districts These are further classified as moderate when the percentage deficit is 26 to 50 percent and severe if deficit is more than 50%. The probabilities of moderate and severe droughts have been computed for various districts for period 1901-1908. if in a year 25% or more of the area of state is affected by drought , then that year is considered as one in which the state suffered from large scale drought , then that year considered as in which the state suffered from large scale drought. The worst drought affected years were demarcated (marked with star) out of large scale drought years, when the area affected by drought is exceeded by 20% of country's area.)

deficiency in such successive years may not be as high in a single year. Successive droughts were never faced by Ratnagiri, Kolaba , Raigad and Sindhudurg districts of Konkan subdivision. Beed, Hingoli,Nandurbar, Osmanabad,Pune are the districts which faced most of the time successive droughts. These districts faced in four successive years droughts. Eleven districts faced successive droughts during 1971-72 which is so far highest. Further, rainfall of less than 50 percent of the annual normal representing severe drought conditions occurred in various districts as indicated below. India meteorology department has identified such 13 instances for affected districts. 1972 was the severe drought condition for eight districts. Ahemednagar, Aurangabad, Beed, Jalana, Latur,Nanded,Solapur are these districts where severe drought condition was prevailing during this drought.[47]

Years of severe/extreme drought conditions occurred during (June-September) are also examined at different locations. Severe and extreme condition prevailed on 28 out of 44 years during 1934-77 at some location or other. At half of the locations, severe/extreme drought conditions prevailed during June to September in 1972-73 alone. At few stations like Yeotmal drought situation (1951-77) never touched the extreme conditions during the period. The severe/ extreme drought conditions also prevailed in the region for two to three consecutive years. Because of spatial and temporal variability of rainfall, the data of beginning and ending of different classes of droughts are differing from location to location.[48]

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[47] Climate of Maharashtra pp.8-10 Ahemednagar faced 1985-86 the successive drought years. Akola faced 1984-85 successive drought years. Aurangabad faced 1984-85-86 years in succession droughts. Beed faced 1945-46, 1984-85-86 years in succession drought. Buldhana faced 1971-72, 1984-85 years as drought years. Gadchiroli faced 1971-72, 1984-85 as the drought years in succession. For Gondia 1984-85 were the successive drought years. Hingoli faced 1943-44-45, 1984-85 the droughts in succession. Jalgaon faced 1971-72, 1984-85 the drought years which come in succession. For Jalana 1984-85-86 as successive drought years. Kolhapur faced 1971-72 years as drought years in succession. Latur faced 1971-72 as drought years. For Mumbai city 1972-73 were the years successive droughts. 1971-72, 1984-85 were the years of droughts for Nanded. Nandurbar faced 1951-52, 1985-86-87 as the successive droughts.Osmanabad faced 1971-72, 1984-85-86 as the years of droughts. Prabhani faced droughts in the years 1951-52, 1971-72 droughts in succession. Pune faced the droughts in the years of 1981-82, 1985-86-87 in succession. Sangli faced droughts in the years 1985-86 droughts in succession. 1986-87 were the years of droughts. For Thane as successive drought years.1984-85 were the years of successive droughts for Wardha. Washim faced droughts in succession in the years of 1971-72.

[48] Rao Sambashiv Mausam (1986), 37,3,377-384 India Meteorology Department p.382-383

2.12 Rainfall analysis of 1971 & 1972 drought years

A prolonged spell of scanty rainfall in July and the first fortnight of August led to drought condition in the interior parts of Maharashtra state, Andhra Pradesh and some parts of north interior Mysore, Southwest monsoon withdrew by 9 October 1971.[49] Rainfall over Konkan, Madhya Maharashtra, Marathwada and Vidharabha fail short by 4,20, 31 and 33% respectively of normal rainfall during monsoon season of 1971.[50]

C.J.Jorge a meteorologist of India Meteorology Department developed a index to quantify agricultural drought. Jorge's drought index inferred that the main agricultural drought belt of 1971 monsoon season revealed by the index was over the peninsula covering areas of Tamil Nadu, Interior Mysore, Rayalseema, costal Andra Pradesh, Telegana, Marthwaa and Madhya Maharashtra. this drought belt persisted almost during the whole season from 23rd week (4-10 June) to 38th week (17-23 September) with a break of only one week namely 34th (20-26th August). The prevalence of persistent drought conditions in the areas mentioned above had been very well corroborated by newspaper and crop reports of the period. [51]

The 1972 monsoon was characterized by its late onset over most of the country outside northwest India, an unusually long three weeks of break in its activity from about the middle of July up to the first week of August and its rather early withdrawal from north Peninsula. As a result the rainfall of the season was deficient over most of the country outside Jammu and Kashmir where it was in excess and over Bay islands, Arunachal Pradesh, Assam & Meghalaya, Gangetic West Bengal, Orissa, Bihar Plateau, hills of west Uttar Pradesh, Haryana, Punjab, east Madhya Pradesh, Rayalseema, Tamilnadu, South

[49] Indian journal of Meteorology and Geophysics Vol.23 No.3 July 1972 p.103

[50] Harihar P.S., S. Ayyar, Abbi S.D.S.& Raj Hem Indian journal of Meteorology and Geophysics Vol.23 No.3 July 1972 p.294

[51] Georje C.J. Vol.42 pp,262-266; An index computed on a weekly basis of a network of 100 stations in the country during 1971 monsoon is used to demarcate agricultural drought areas. In 1971 monsoon season, there was a belt of agricultural drought covering several weeks over the peninsula stretching from Tamilnadu to Marathwada. This is corroborated by News paper and crop reports of the area. The paper provides agricultural drought index based on the water balance computations by taking into account factors like rainfall evapotranspiration soil moisture and climate of the place and is therefore a suitable one to indicate agricultural drought possibility. Index computation :- water balance computation are done on a weekly basis (standard weeks) of representative network of 100 stations in India for the monsoon season of 1971. Aridity value of the station for week is calculated from weekly moisture deficit. Normal aridity value of the station of the week is also calculated from climatic water balance computation. The difference between actual and climtatological aridity values, when positive is taken as agricultural drought index. The value are plotted on a map for each week. The areas where index has some value, are hatched to indicate agricultural drought.

interior Mysore, Kerala and the Arabian Sea Islands where it was normal. Rainfall over Konkan, Madhya Maharashtra, Marathwada and Vidharabha fail short by 32, 44, 55 and 37% respectively of normal rainfall during monsoon season of 1972.[52]

The extreme drought condition prevailed during 1971-73 over Maharashtra 23 locations are studied in by Sambashiva Rao and A.R.Subramanian by modified Palmer's approach. In their study the following were the locations where the extreme condition prevailed during respective years.[53]

Ahemednagar 1972-73, Baramati 1970-72, Jalgaon1971-73, Jeur 1971-73 Kolhapur 1972, Malegaon 1970-74, Miraj not noticed so far, Nandurbar 1971-72, Ponna 1970-72, Sholapur 1972, Aurangabad 1971-73, Nanded 1971-74, Prabhani 1971-72 ,Akola 1971-72, Amravati 1971-72 , Barhampuri 1972-73, Buldhana 1972-73, Chandrapur1971-72 Gondia 1972-73, Nagpur 1972-73, Pusad 1971-73, Sironcha not noted so far, Yeotmal not noted so far.[54]

The frequency of extreme droughts was zero at Kolhapur in Madhya Maharashtra and Sironcha in Vidhrabha. Yeotmal in west Vidhrabha has 4 % of severe drought in February March, the stations Jalgaon, Ahemednagar, Amravati have experienced severe droughts for 13.8 and 6 % of total period. The maximum number of extreme droughts in the region was in January-April.[55]

2.13 History of droughts over climatic regions of Maharashtra

Rainfall tendency and rainfall patterns along with drought probability of each and every climatic regions of Maharashtra are discussed in foregoing passages.

KONKAN

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[52] Indian journal of Meteorology and Geophysics Vol.24 No.3 July 1973 p.215 & p.221

[53] A. Sambasiva Rao and A.R. Subramaniam Dept of Met. And oceanography, Andhra university Mausam, (1986) 37, 3, 632.116.6333pp.377-384p.382

[54] Ibid Loc.Cit.

[55] Sambashiva Rai p,383

P.G.Gore studied rainfall patterns of Maharashtra and made foregoing observations about the Konka subdivision. The probabilities for wet weeks are mostly high and rainfall is persistent in nature with moderate to high probabilities for 2 and 3 consecutive wet weeks in large area except Bombay.[56] IMD made foregoing observations about the number of drought years during 1941 to 1990 over districts of Konkan. Sinhudurg (5), Thane (5), Raigad (5), Ratnagiri (5), Mumbai city (6), Mumbai suburban (6), Ratnagiri (5), the districts mentioned above had faced number of droughts as indicated in brackets. [57]

Konkan falls under high rainfall climatic zone, therefore probability of drought over this region is very low. The probability of occurrence of less than 75 percent of annual or monsoon normal rain is about 11 percent .Occurrence of severe drought was very rare.[58]Decadal frequencies over Konkan of Maharashtra after 1970 did not found any increase.[59] The severe droughts not experienced in some of the districts Konkan for last 98 years.[60]SPI values of 4 districts of this region show positive trend means rainfall is increasing over these 4 districts of this region.[61]

MADHYA MAHARASHTRA

P.G.Gore observed through studies that the spatial variation in rainfall probability is noticed. The probabilities of wet weeks are low to moderate, those for districts Kolhapur, Pune and Satara are moderate to high. The rainfall is persistent and probabilities of 2 consecutive wet weeks are low to moderate for some areas. The persistency in dry weeks is noticed for Sangli up to 2 consecutive weeks and for Sholapur for 3 consecutive

[56] P.G. Gore, 'Dry and wet spells for meteorological sub division of India'., Meteorological monograph No. 12/2000 drought research unit office of additional director general of meteorology 2001 Pune pp.48-51

[57] Climate of Maharashtra p.8

[58] Indian Meteorology Department Publication 'The Climate of Maharashtra' 2007p.10 From finding of Gore and Sinha Ray following points are inferred. Each district had 5-6 years of drought during 50 year period under severe drought condition was experienced only once at Mumbai district in the year 1941. Also the districts except Bomaby in Konkan experienced no drought during 1931-40. The district Bombay showed 2 incidences of drought during this period. In addition, most of the district Bombay showed two incidences of drought during this period.

[59] Gore 535

[60] Gore p.538

[61] Pai and others Opp.Cit.p.17

weeks.[62] Sambashiva Rao studied contemporary drought by Palmer's approach over Maharashtra during 1932-71 and made following generalization. The divisional analysis shows that the drought spells have occurred for only 10 times during 1934-71 in Madhya Maharashtra, whereas the location analysis in the area at Poona and Malegaon identified 28 and 25 drought spells during the same period.[63]IMD observed number of droughts occurred over different districts of Madhya Maharashtra. The number of droughts occurred in districts as follows the number in brackets indicates number of droughts Ahmednagar (6), Dhule (3), Jalgaon (8), Kolhapur (2), Nandurbar (8), Nashik (6), Pune (10), Sangli (6), Satara (6), Sindhudurg (5), Solapur (6),. [64] The probability of occurrence of annual rainfall less than 75 percent of normal over this subdivision is about 14 percent, while probability occurrence of rainfall less than 50 percent of the normal is 1 percent. [65] Sambashiv Rao by using modified Palmer's approach showed that The pattern of drought prone areas for Rabi season was similar to that of Kharif season. The north Madhya Maharashratra experienced 40 months of drought in the Rabi season, whereas the south of Madhya Maharashtra 5-10 months during 1934-77.[66]He further showed that the percentage occurrence of mild drought (index value _1.00 to -1.99) was highest in the northern parts and lowest in southern parts of Madhya Maharashtra. Mild drought prevailed on 7% occasion at Kolhapur.[67]The number of drought months during Kharif seasons ranged from 30 in the extreme north to zero in extreme south of Madhya Maharashtra when the index value reaches -2.00 or lower during 1952-76.[68] The southern parts of Madhya Maharashtra was almost free from extreme drought (index value-4.00 and below).[69] The percentage occurrence of moderate droughts (index values from -2.00 to -2.99) was low compared to mild droughts in all locations except in the North Madhya

[62] Gore P.G., 'Dry and wet spells for meteorological sub division of India'., Meteorological monograph No. 12/2000 drought research unit office of additional director general of meteorology 2001 Pune pp.48-51

[63] Rao Sambashiv Opp.Cit. p.381

[64] Climate of Maharashtra Opp.Cit. p.8

[65] Climate of Maharashtra p.11 Pune district experienced drought in 10 years out of 50 years. As such Pune is drought prone area. The remaining districts except Kolhapur and Dhule had 6-8 such years. The Pune district experienced severe drought in 1985. Ahmednagar and Solapur districts had severe drought in the year 1972 and Satara had severe drought in 1968.

[66] Rao Sambhashiv. P.183

[67] ibid p,383

[68] ibid Opp.Cit. p.383

[69] ibid p,383

Maharashtra where it was high. Kolhapur in south Madhya Maharashtra was free from moderate droughts during May to November as suggested by data of the study period. The percentage occurrence of droughts is maximum at Malegaon (32%) and minimum at Kolahapur (2%)[70] The percentage occurrence of severe droughts (index valu-3.00 to-3.99 was highest in northern parts of Madhya Maharashtra compared to other parts of state. However, the percentage occurrence of severe droughts was less than that of moderate droughts.[71]Severe droughts occurred for about, 24%at Malegaon. The areas were free from droughts throughout the year over Kolhapur.[72] SPI index prepared by Pai, Sridhar and others shows that 4 districts of this region has positive trend means rainfall is increasing over these districts.[73] The longest spells of drought occurred at Miraj at beginning in January 1939 and ending in April 1944 with duration of 64 months. The station is situated in a low rainfall area.[74]

MARATHWADA

P.G. Gore observed that the probabilities of wet weeks and consecutive 2 and 3 wet weeks are very low. The district Nanded shows moderate probability for wet weeks and persistency in rainfall. The probabilities of dry weeks are low to moderate and persistency in dry weeks is noticed for most of the districts.[75] During 1941-1990 the number of droughts occurred over different districts of Marathwada indicated in the brackets observed by IMD; Aurangabad (6), Beed (10) , Bhandara (4), Buldhana (8), Hingoli(10), Jalgaon (8), Jalna (8), Latur (5),), Nanded (8), Osmanabad (8), Prabhani (10).[76] Sambashiv Rao jolted down drought months of each year for period of 1952 to 1977 by Palmer's approach. This study showed that Marathwada region experienced drought for about 10 months during 1952-76 the period.[77] Marathwada faced 15-20

[70] Rao Sambhashiva p,383
[71] ibid p,383
[72] ibid p,383
[73] Pai and others Opp.Cit.p.17
[74] Rao Sambhashiv Opp.Cit. p.382
[75] P.G. Gore, 'Dry and wet spells for meteorological sub division of India'., Meteorological monograph No. 12/2000 drought research unit office of additional director general of meteorology 2001 Pune pp.48-51

[76] Climate of Maharashtra p.8
[77] Rao Sambhashiv p.383

months of droughts during Rabi season inferred by Sambashiv Rao.[78]The southern parts of Marathwada was almost free from extreme drought (index value-4.00 and below).[79] Beed Hingoli and Prabhani districts experienced drought in 10 years during study period of Rao. Therefore these districts come under drought prone area. Other districts in the subdivision experienced 5-8 years of drought. Severe drought was experienced in the year 1972 by most of the districts. Severe drought was experienced by Hingoli in 1941 and 1950. The probability of occurrence of drought is about 16 percent and for severe drought, it is about 2 percent. The corresponding probability values for the southwest monsoon season also about the same. Shravan Kumar and Shwlae in their study found 1984-85 two consequent drought.[80] Sambashiv Rao by applying Palmer's method found that the divisional analysis of Marathwada could identify only 11 out of 26 drought spells at Prabhani and 22 at Aurangabad.[81] The percentage occurrence of mild drought Mild drought prevailed on 30% of the occasions at Aurangabad, 21% at Prabhani.[82]

VIDHARBHA

The divisional analysis by Palmer's Method for Vidharabha could identify only 15 drought spells out of 32 at Chandrapur and 27 at Akola during 1935-77. Thus the location wise analysis could identify properly the various intensities of droughts occurred in Maharashtra.[83] Official Publication of IMD the 'Climate of Maharashtra' mentions number of droughts each districts faced over Vidharbha during 1941-1990 as indicated in numbers enlisted in brackets as follows; Akola (7), Amravati (7), Bhandara (4)Chandrapur (8),Gadchiroli (8), Gondia (6), Wardha (5), Washim(5), Yavatmal (8).[84]The probabilities for wet weeks are low to moderate in western and central parts and moderate to high in eastern parts. The rainfall is persistent in only eastern parts with moderate probabilities for two consecutive wet weeks. [85]

[78] Rao. Sambhashiv Opp.CIt p.183
[79] ibid p,383
[80] Shewale Shravan Kumar p.19 table no.5
[81] Rao Sambhashiv Opp.Cit. p.381
[82] ibid p,383
[83] ibid p.381
[84] Climate of Maharashtra
[85] P.G. Gore, 'Dry and wet spells for meteorological sub division of India'., Meteorological monograph No. 12/2000 drought research unit office of additional director general of meteorology 2001 Pune pp.48-51

The percentage occurrence of moderate droughts (index values from -2.00 to -2.99) was low compared to mild droughts in all locations over Vidharbha. Yeotmal was free from moderate droughts from June to September.[86]The percentage occurrence of severe droughts (index valu-3.00 to-3.9) was highest in, northwestern parts of Vidhrabha compared to other parts of state. But the percentage occurrence of severe droughts was less than that of moderate droughts.[87]Severe droughts occurred for about 2% at Yeotmal, 3% at Sironcha, and 16% at Nagpur. The areas were free from droughts during August to October at Chandrapur, June to December at Yeotmal, September to October at Akola.[88]The north western parts of Vidharabha experienced drought for 10-20 months during 1952-76. Vidhraba faced 10-30 months of drought during Rabi Season.[89] The dry sub–humid climatic location of Nagpur has experienced drought conditions for 32 consecutive months during December 1951 to July 1954, while Chandrapur has 26 months of drought period during September 1946 to October 1948. This shows that drought conditions prevail for longer periods in semi-arid regions compared to the dry sub-humid regions.[90] The southern parts of Vidhrabha was almost free from extreme drought (index value-4.00 and below).[91]Each district experienced 4-8 years of drought Washim had experienced severe drought in the year 1965. The probability of occurrence of drought is 13 percent and occurrence of severe drought was rare.[92] Shrvan Kumar and Shewale found 1971-72 these two years as consequent drought years over some parts of Vidharbha.[93] Most of the districts from Vidhrabha experienced no drought during years 1931-40. A single occasion of drought incidence during 1931-40 was shown only over Wardha district.[94] The severe droughts not experienced in some of the

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Analysis of probability of dry and wet spells

[86] Rao Sambhashiv p,383
[87] ibid p,383
[88] ibid p,383
[89] ibid p.382
[90] ibid p.383
[91] ibid p,383
[92] Indian Meteorology Department Publication 'The Climate of Maharashtra' 2007
[93] Shewale Shravan Kumar p.19 table 5
[94] Gore p. 535

districts of Vidharabha and Konkan for last 98 years.[95] Sahasrabudhe made following observations about the droughts of western Vidharabh. During active monsoon period scarce weeks (46%) dominate over excess (15%).[96] The grain filling and maturity period has more percentage of scarce weeks. Thus it is necessary to evolve and use shallow soils drought resistant and early maturing Kharif crop verities and follow suitable agronomic practices to enable as much of the scanty rains received during this last period to get soaked in the soil. Second and third week of July appear to have more of droughts than excess; on the contrary in 2nd and 3rd week of August the opposite situation prevails/ assuming the usually every year, the major area of cotton and groundnut is sown during 25th to 27th meteorological Weeks (between 8thJune to 18th July), these newly germinated crops have thus greater probability of facing a droughty fortnight or droughty three weeks period in their early establishment stages. It is therefore, necessary to give a small fertilizer dose at sowing in order to make the young seedlings more vigorous and use varieties which have rapid and deeper rooting habit during its seedling stage a narrow root: shoot ratio in its early growth.[97] SPI index analysis shows that one district shows positive trend and one negative indicating rainfall increasing and decreasing trends over these districts.[98]

2.14 Ascertaining drought prone area state government's efforts

V.Subramanin committee identified 94 talukas as drought prone talukas in Maharashtra.[99]

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[95] Gore p.538

[96]K.R. Sahsrabudhe, the paper was presented at the symposium on 'Drought in Asiatic Monsoon area' (et al. Ramnatathan 1976) pp.267-270., held during 14-16 December 1972 (Convener: Dr. K.R.Ramnathan, FNA) Vol.42 B. No. 1 bulletin of Indian National Science Academy New Delhi.

Droughts occurring in four western Vidhrabha during the past 25 year's period (i.e. from 1947 to 1971) are studied. As per Sahasrabudhe's studies The districts which grow mainly Kharif crops to extent of about 90% are more vulnerable to droughty condition than flood condition over 40% of the weeks during each of important growth phase of Kharif crops (viz. seedling establishment and early growth. Flowering and grain filling phase) experience droughts. Moreover, during the 25 years period there were 27 occasions when drought conditions persisted for 3 or more consecutive weeks and 28 other occasions when such condition occurred consecutively for 2 weeks. As against this, 3 and 2 consecutive scarce weeks excess weeks came only on 3 and 9 occasions respectively. For first 3 periods scarce and normal rains have more or less the same chance of occurrence. In the years of meager rainfall in July and August only if there are good rains by end of August or early September, can be the situation is partly saved by taking recourse to some suitable late Kari early Rabi crops. In medium to deep soil where adequate soil moisture can be stored in September, crop like Jowar, sunflower or linseed can also be planted by late September and early October respectively.

[97] K.R. Sahsrabudhe, the paper was presented at the symposium on 'Drought in Asiatic Monsoon area' (et al. Ramnatathan 1976) pp.267-270., held during 14-16 December 1972 (Convener: Dr. K.R.Ramnathan, FNA) Vol.42 B. No. 1 bulletin of Indian National Science Academy New Delhi.

[98] Pai, Sridhar and others Opp.Cit. pp.17-18

[99] Subramanina V A report of drought prone are determination committee p.8

Considering Pardasani Committee and Sukhtankar Committee's suggestions state government have determined 87 Talukas of 12 districts as drought prone area in 1973. However number of talukas increased up to 89 Talukas of 14 districts due to newly created districts and Talukas. Over seven thousand villages and 1.51 croer population is covered under this drought prone area. The population thus covered under drought prone area was 37% of state population then. Average rainfall of this area then was between 460 to 800 mm. Insufficient and irregular rainfall is main characteristic of this area. Agricultural land of this area does not at all receive assured rainfall. Frequent droughts did not fetch any income from agriculture. It resulted into scarcity of fodder and drinking water. Union government under drought prone area programme is spending 15 lakh of rupees annually on each talukas of 74 drought prone Talukas of state that had identified by union government as drought prone Talukas of Maharashtra. Thus 13 Talukas which state government identified as drought prone Talukas not covered by union government committee remained unfinanced by union government. However, on these remaining 13 talukas state government is spending Rs. six Lakhs annually. [100] Following criterion were considered by various committees while considering drought prone areas. Report of National commission of agriculture mentions the characteristics of drought prone area in paragraph 59.4.4-5 of part 13 on page number 122. Insufficient and irregular rains, very short period of rainy seasons, no replenishment of ground water, very high percentage of utilization of agricultural land, very low percentage of land under forest, vagaries of rains and prevalence of long duration of dry air these are characteristics of drought prone areas of India. [101]Pardasani Committee (1960) set three criterions while determining the drought prone areas of Maharashtra rainfall. Ana valuation i.e. assessment of crop production, and past incidences of drought were these three criterion set by Pardasani Committee. Rainfall, area under irrigation, surrounding situation, employment, these are other criterion suggested by central secretaries committee in 1971. Second such committee set criterion of irrigation and rainfall, remittance in revenue, irrigation facilities etc. Rainfall, irregularity of rainfall

[100] Subramain V. Report of drought prone area determination committee 1987 Mumbai p.2
[101] Subramanin V. Report of drought prone area determination committee 1987 p..20

with respect to crops and soil texture were criterion set by Sukhatankar Committee to decide drought prone areas over Maharashtra in 1973. Sukhtankar committee set another set of criterion based upon the effects of droughts such as Anna valuation, past droughts, production, migration, prices, food grain supply etc. Finally, this committee highlighted rainfall at the time of requirements of crop and water retaining capacity of land. This committee fixed all regions that have rainfall below 750 mm. and the regions or areas between 750 to 800 mm rainfall having shallow lands in drought prone area.[102] During critical crop growth time deficit or insufficient rainfall results into drought condition. According to meteorologist Ramdas if the normal rainfall of week is between 5mm. or more at such instance whenever, the rainfall of week is half or less than half then drought condition persists.[103] Sukthankar Committee had ascertained that during June to October if rainfall over the area is less than normal for 11 weeks out of 22 weeks then drought condition prevails over such area.

Subramanian committee of 1987 relied in Thornthwaite and Mather method of 1955 while determining and ascertaining prevailing drought conditions. This method or definition relied on the effective need of moisture of particular crop. If the moisture evaporation and evapotranspiration from crop or plant is more than the moisture requirement of plant then drought prevails is the simple proposition that these scientist put forth. Mather and Thornthwaite developed method of calculating moisture index depending upon the evapotrnaspiration and evaporation. He then classified the climatic regions such as per humid , moist sub humid, arid, semiarid etc.[104] Subramanian acknowledged the work of Venkatramn and Khambote of Indian Meteorology department of Pune quoting their research article of Mausum 1984 vol. 35(4) pp.475-478. On the basis of their work Subramanian also agreed to identify 8 Talukas as chronic drought prone, 25 Talukas as acute drought prone. Towards eastward side and adjoining to these 25 talukas 13 talukas identified as occasionally succumb to droughts.

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[102] Ibid pp.*20-25*

[103] Ibid P.25

[104] Ibid P.34

Subramanin Committee has used Thornthwaite and Mather Principal in determining drought condition and drought prone area. Committee also applied scientist Pennman's method while calculating potential evapotranspiration and Thisense polygon method in determining values of the potential evapotranspiration over all Talukas of Maharashtra state. Subramanin Committee also used crop drought index of Khambote Venkatraman while calculating and ascertaining drought condition. By employing all these scientific methods and computer analysis threshold limit of rainfall that results into drought calculated for each Talukas. Then committee calculated the drought years of each Talukas. The Talukas having 20 to more than 20% drought years are considered as drought prone areas. Thus, Subramanin committee of 1987 fixed 95 Talukas of state as drought prone talukas. There are Seventeen talukas which were not previously in the list state government's list added by Subramanian Committee of 1987. Committee also deleted nine Talukas from its list which were included previous list of state government. Thus, the method employed by Subramanin committee is based on scientific principles. This method depends on three main criterion, rainfall, moisture requirement of plant and potential evapotranspiration along with water retaining capacity of soil.

2.15 Concluding Remarks

As monsoon studies are primarily related with unraveling mysteries of monsoon and to develop improved techniques in forecasting of monsoon, drought studies deals with optimum and effective use of available water resources. This study led to development of water-shade development program, better agronomic practices, use of improved seed to improve the production. Most of the studies revealed that there were 22-23 all India droughts over 130 years of rainfall data based on departure of rainfall from normal criteria. Meteorologist also identified 4-6 severe droughts over India. Whereas over Maharashtra some studies shows that there are 26 large-scale meteorological droughts identified over Maharashtra during 1901-1998 and out of them 11 years are worst drought years when more than 50% area of the state was affected by drought. During all India drought year the probability of drought over Maharashtra is 59% inferred by meteorologist. Frequency of severe drought is low over state. Konkan and eastern Vidharbha district faces least drought. These regions falls in high rainfall region drought of moderate intensity cannot exert much more influence on agricultural production of this

region. Epochal behavior of monsoon over Indian subcontinent is easily identified over Maharashtra by meteorologist. Droughts of different intensities noticed and studied by meteorologists. Probability of mild droughts found highest over northern parts of Madhya Maharashtra. Northern parts of Madhya Maharahtra and Northwestern parts are more prone to all intensities of droughts. Frequency of mild drought is highest followed by moderate and severe droughts. Sambashiv Rao's study reveal that Ahemednagar, Malegaon, Akola and Nagpur stations under study showed most number of severe droughts. All studies reviewed showed that 1971 and 1972 were droughts years and these years were of severe droughts.

The state has a large variety of agro climatic patterns, rainfall and vegetation. Konkan and east Vidhrabha have adequate assured rainfall for major crop like paddy. The droughts over the mid-western portion of Dhule, Nashik, Ahmednagar, Pune, Satara, Sangali and northeast Kolhapur may affect the crops like Bajra, Jowar and groundnuts. Droughts over the interior parts having low rainfall (of about 50-75 cm.) which includes regions of eastern portions of Dhule, Nashik, Ahemednagar, Pune, Satara and Sangali, Solapur, western portion of Aurangabad, Bhir Osmanabad and Jalgaon, affects on production of millet.[105]

Aftermath of 1972 drought had far reaching consequences on state policy. Foregoing chapters of this thesis reveals the facts that there were number of policies that changed the outlook of state towards drought proofing measures. Tremendous change could be seen water and soil conservation sector over state after 1970-73 drought of Maharashtra.

[105] Gore and Sinha p. 538