

## Droughts, Aridity and Desertification in the Indian Sub-continent

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**Abstract:** An attempt has been made to gather the information on dry season, aridity, desertification and drought related problems in the Indian sub-continent. The spatial complexity and the temporal variability have been briefly reviewed. Distinction has been maintained between climatic droughts and man-induced magnification of water shortage through faulty land use.

**Key words:** Bioclimatology, arid zone, forest rainfall link, India.

The word drought in its most usual sense implies dryness. This dryness may be rigorous or mild in its intensity, long or short in its duration, seasonal or aperiodic in its occurrence and if seasonal, then hivernal, estival or biseasonal in tendency.

Arid zones in their broadest sense may be defined as the zones experiencing chronic water deficit. However, there are large areas in India with water shortage at one time or another. The monsoon regime leaves the major part of the country dry for a period varying from 2 to 11 months on an average, but the inter-yearly variations are quite important. Whereas, the normal dry season, when rains are not expected, goes unnoticed, the extension of the dry spell beyond the time of onset of the normal monsoon season poses a severe threat to water management and agricultural operations. This is also the case when couple of weeks pass without receiving any precipitation during the rainy season.

### Ecological definitions

The annual cycle of climate in many places of the world manifests a dry period.

This period of drought occurs within a certain limit of precipitation and temperature, and geographers, climatologists and ecologists have tried to express it in different ways based on the values of precipitation, precipitation and temperature, precipitation and evaporation and number of rainy days.

The word drought is related to the term aridity for it is the dryness that in its extremely intense form and long duration contributes to the aridity. The term aridity expresses a deficit of water arising from poor precipitation or resulting from excess of water loss as compared to the water received. Aridity of a region, in general, increases in inverse proportion to the precipitation and therefore different limits of rainfall have been suggested to define the aridity, the arid region, the arid season, the dry period and the dry month.

However, there is a diversity of opinion as far as the definition of dry period is concerned and the basic difficulty stems from defining a dry month. Estimates of what constitutes a dry month vary from 20 mm to 100 mm.

The definitions of droughts and dry month have been reviewed by Subrahman-yam (1967) and Meher-Homji (1963), respectively.

### Degree of aridity

Several degrees of aridity may be recognized. The extremely arid zones are the ones not experiencing any rain for more than a year at a stretch. Only a very small portion of the Thar Desert in the extreme western Rajasthan in India and Sind in Pakistan belongs to this category. In other cases, there may be a few sporadic showers, but of very low intensity and duration so that no month may be characterized as humid. Subsequent degrees of decreasing aridity may be recognized on the basis of the number of dry months. Defining a dry month in terms of rainfall poses several problems. According to the definition of Bagnouls and Gaussen (1957), a month is defined as dry when its precipitation (P) in mm is equal to or less than twice its mean temperature (T) in degree Celsius:  $P \leq 2T$ ; though empirical, this definition is shown to be of practical use (Legris, 1963; Meher-Homji, 1963). The length of the dry period in itself does not convey a true picture of the aridity and the amount of precipitation must also be taken into consideration. A station such as Bombay, receiving 2000 mm of rainfall annually experiences a dry season of 8 months but Mysore having a dry season of 4 months receives annual average rainfall of 800 mm.

Therefore, in his index of aridity-humidity, Meher-Homji (1962, 1965), proposed a combination of the value of the

"precipitation quantity" factor with that of the length of the dry period. The stations having the index values 8.5 to 10.5 characterize the semi-arid zones and correspond to the thorn forest. Index values of 11 to 12 correspond to desert vegetation typifying the arid zones. According to this classification, there are 2 main belts of semi-arid climate in India (Fig. 1), one in the north contiguous with the desert of Thar and the other in the south. The northern zone lies between 22° and 32° N and between 70° and 79° E, comprising parts of Rajasthan, Punjab, Uttar Pradesh, Madhya Pradesh and northwest Gujarat. The southern semi-arid zone situated between 15° and 21° N and 73.5° and 79.5° E, includes the Deccan plateau. Besides, there are two small patches of semi-arid climate in the south; one in the region of Coimbatore situated in the shadow of the Nilgiri and Palni hills, the other in the extreme south-east corner of India comprising parts of the Ramanathapuram-Tirunelveli districts of Tamil Nadu. The semi-arid regions of north and south are separated by a narrow humid strip comprising the hilly region of the Satpura mountains and the plains of the Tapti river.

The arid climate occurs in the extreme north-west corner of Rajasthan and in Pakistan. These limits of arid and semi-arid climates tally well with results given by Bagnouls and Gaussen's (1957) classification of biological climates (Meher-Homji, 1962).

Several climatic classifications defining arid and semi-arid climates have been ap-

plied to the stations of the sub-continent but these have not been found to be entirely satisfactory in explaining the vegetation types. Better suited is the bioclimatic classification of Bagnouls and Gaussen (1957) in which the climatic regions and sub-regions are formed according to:

- the duration of the dry period ( $P \leq 2T$ ),
- the duration of the frost period, constituted by the months,
- with mean temperature  $0^{\circ}\text{C}$ ,
- the characteristic values of the temperature, and

- the regime (i.e., the season of occurrence) of precipitation.

According to this classification, the hot desertic region, with 12 months dry, comprises the Thar as mentioned earlier.

A peculiarity of this desert climate is that it is of tropical tendency (whatever little rains that occur are during long days i.e., summer), wherever it prevails, except in the north-west corner where it is of irregular tendency (rains without seasonal rhythm).

The ombrothermic diagram (Bagnouls and Gaussen, 1953) of Jacobabad (Fig. 2)

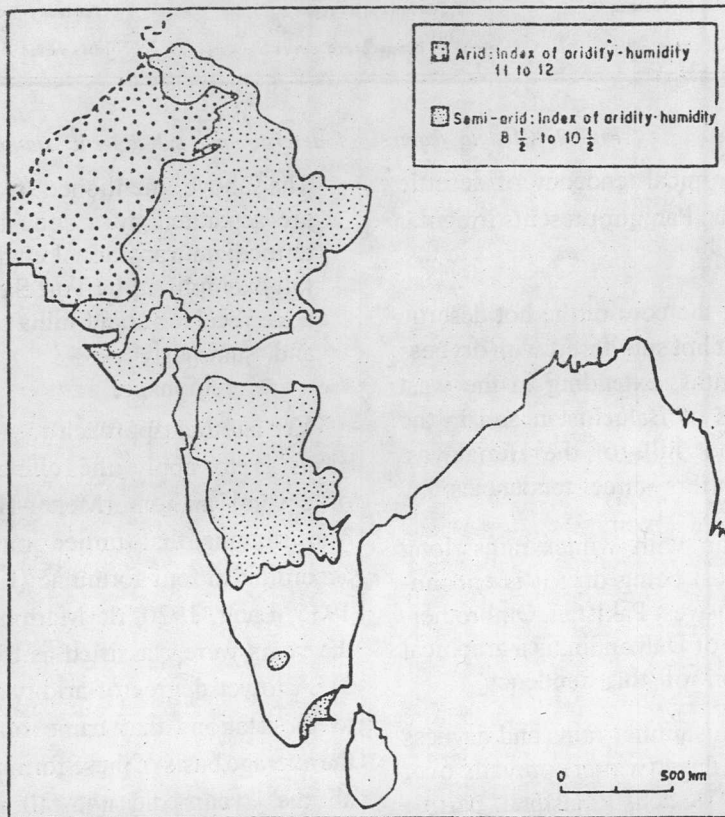


Fig. 1. Arid and semi-arid zones of the Indian sub-continent (source: Meher-Honji, 1962).

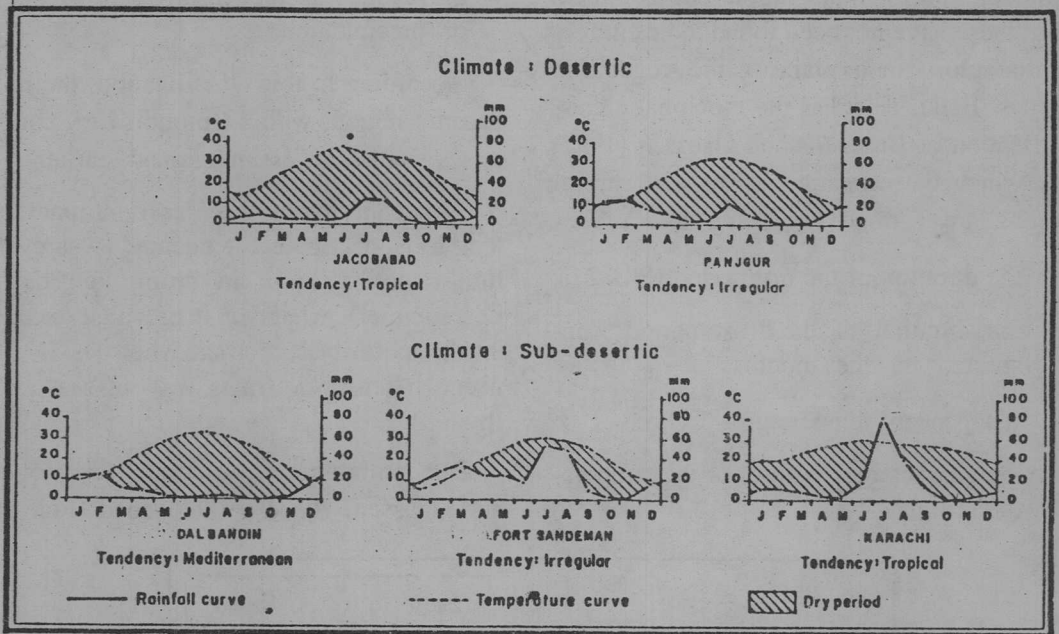


Fig. 2. Climate features of desertic and sub-desertic stations.

illustrates the tropical tendency of desertic climate, whereas, Panjgur presents irregular tendency.

Surrounding the core of the hot desertic area, is a zone of hot sub-desert with dryness of 9 to 11 months, extending in the west to the foot hills of Baluchistan and in the north to the foot hills of the Himalayas. This climate offers three tendencies:

- Mediterranean with winter rains, long days (summer) being dry; it is encountered in north-west Pakistan. Ombrothermic diagram of Dalbandin, is a graphical representation of this tendency.
- Tropical with summer rains and dryness during short days (winter) prevails over the whole of Kutch, Rajasthan, part of Sind and Punjab. Karachi serves as a climate diagram.

- The above mentioned two tendencies are separated by a zone having an intermediate transitional character of rainfall exemplified by Fort Sandeman. This zone receives some rains both in winter and summer.

Yet another approach to define arid regions is to apply the climatic formulae of several authors (Meher-Homji, 1972). The stations that turned out to be arid according to four formulae (Koppen, 1918, 1936; Lang, 1920; de Martonne, 1926) all the years were classified as truly arid (Fig. 3). A lower degree of aridity was assigned to the stations that came out as arid on the average basis of these formulae, although all the years did not fall into the arid category. Further degrees may be recognized on the basis of the number of formulae

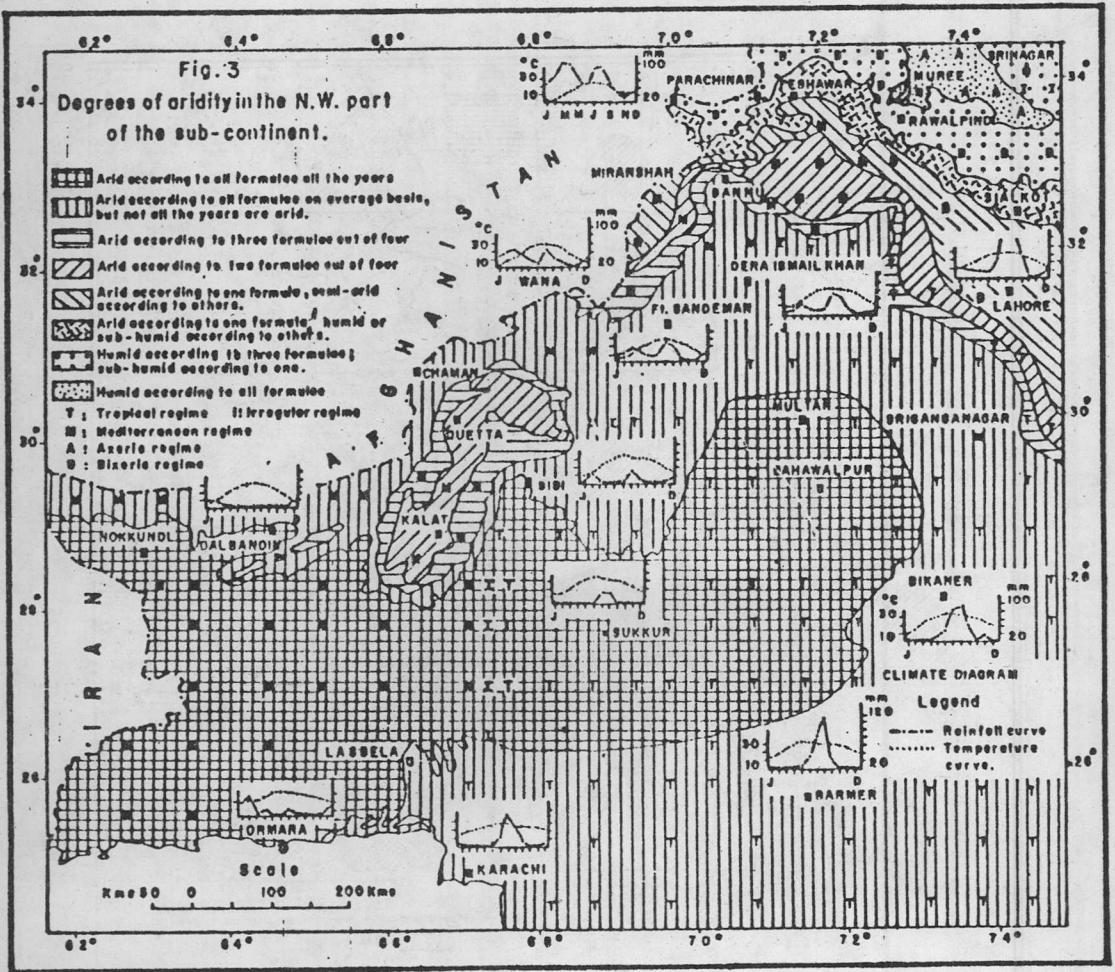


Fig. 3. Degree of aridity in the N.W. part of the sub-continent.

classifying the stations as arid, semi-arid or sub-humid. Finally, the climatic regimes<sup>1</sup> (the season of occurrence of rains) may vary for the stations having the same degree of aridity.

**The Desert as a Zone of Contact Between the Tropical and Mediterranean Climates**

In the north-west part of the subcontinent, winter rain from the north-west owing its origin to the western disturbances, becomes

<sup>1</sup> The regime based on the season of occurrence of rains is either of tropical, mediterranean, bixeric, axeric or irregular type. In the tropical regime, rains are concentrated in summer, and in winter-spring in the mediterranean regime. The bixeric type is characterised by 2 dry periods and 2 rainy seasons in a year. The regime without seasonal rhythm is termed irregular and one without any dry season, axeric.

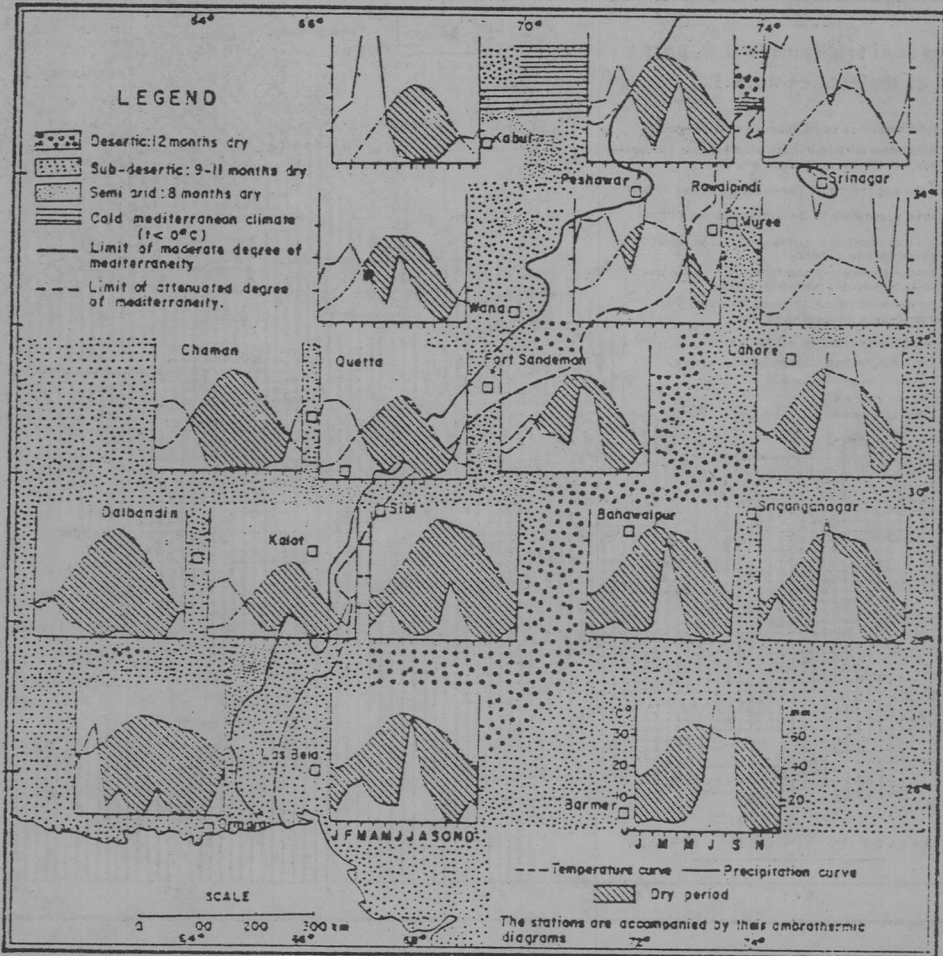


Fig. 4. Limits of mediterraneity in the Indo-Pakistan sub-continent.

a decisive factor and combined with low temperature creates a climate similar to that of the Mediterranean countries. The geographers consider as essential characters of the mediterranean climate a mild winter which does not affect the vegetation, winter-spring-autumn rains, a dry period in summer which stops the growth of non-woody plants and slows down the growth

of woody species. The fact that the north-west part of Pakistan and Srinagar region of Kashmir (India) experience mediterranean type of climate was noted as early as in the first century A.D. by the historian, Pliny the elder.

The complexity of mediterranean climate in the Indian sub-continent has been brought out by Meher-Homji (1973, 1984); based

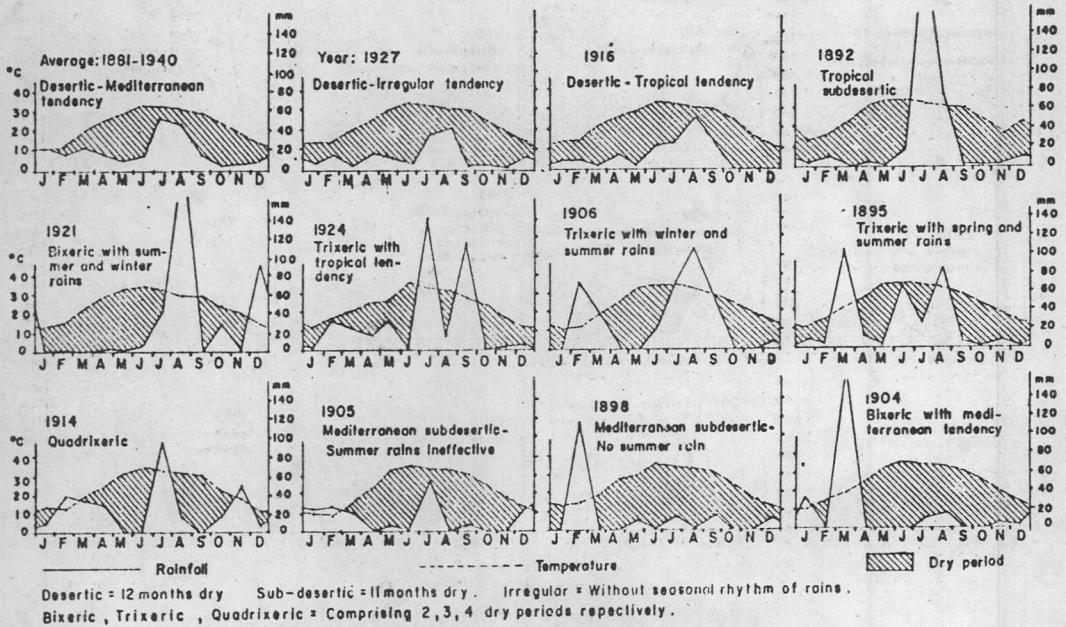


Fig. 5. Inter-yearly variations in regime of Dera Ismail Khan.

on percentages of rainfall and rainy days in summer and percentage number of Mediterranean years he recognized three degrees of mediterraneity: pure, moderate and attenuated. Fig. 4 shows the degree of aridity and mediterraneity in the north-west part of the sub-continent and the gradual change in the seasons of occurrence of precipitation from the dominance of winter-spring rains (Mediterranean regime) in the west to the prevalence of summer rains (Tropical regime) in the east.

Whereas, the stations towards the west like Dalbandin, Chaman and Quetta have over 88% mediterranean years and Kalat, 75%, the stations located further eastwards like Dera Ismail Khan, Fort Sandeman and Peshawar, though presenting a mediterranean regime on the average basis, conceal

a good deal of variations in the season(s) of occurrence of rains and dry period(s) from year to year. The ombrothermic diagrams of Dera Ismail Khan and Peshawar for few selected years (Figs. 5, 6) reveal the full gamut of regimes ranging from typically mediterranean to bixeric (with 2 dry periods in a year), bixeric with Mediterranean tendency, trixeric, quadrixeric (3 and 4 dry periods, respectively), desertic (12 months) and even tropical with summer rains, a situation diametrically opposite to the mediterranean regime.

Besides the arid and the semi-arid zones, the sub-humid and even the humid zones are subject to periodic droughts, i.e., occurrence of rainless spells during the rainy seasons proper.

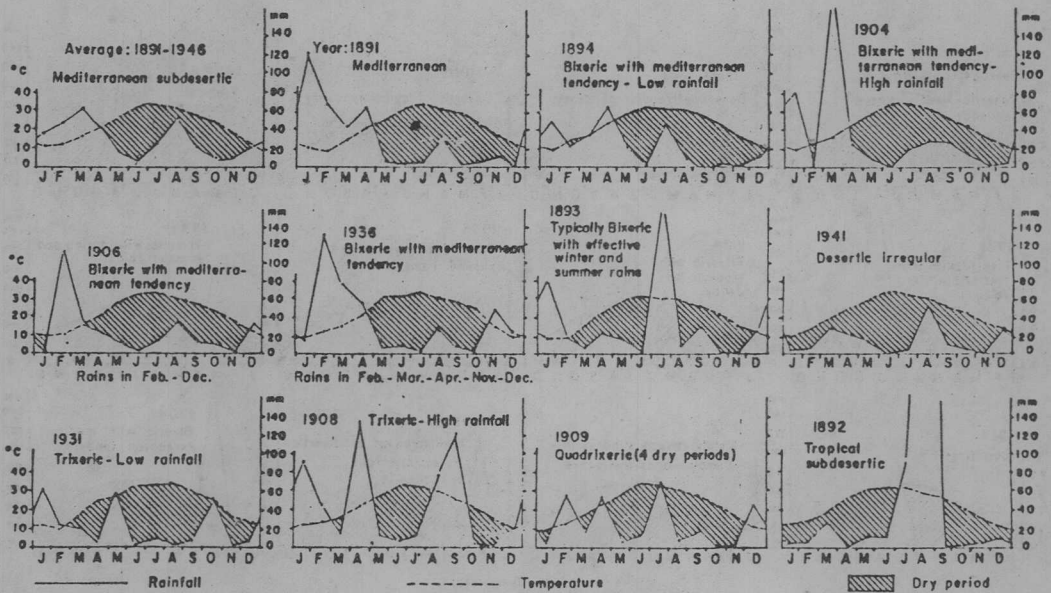


Fig. 6. Inter-yearly variations in regime of Peshawar.

Subrahmanyam and Subramnian (1965) have presented interesting data on the frequency of drought occurrence for the stations of humid and sub-humid zones. Using Thornthwaite and Mather's (1955) systems, drought intensity has been classified into the following four categories, based on the departure of aridity index from the normal.

Departure of aridity index from normal	Drought intensity
$< 1/2 \delta$	Moderate
$1/2 \delta$ to $\delta$	Large
$\delta$ to $2 \delta$	Severe
$> 2 \delta$	Disastrous

In Fig. 7 are shown the decade-wise frequency of occurrence of droughts for a humid zone station like Hassan and sub-humid Satna and Tiruchirapalli.

### Variability - A hallmark of the Indian climates

The climates of the Indian sub-continent present a good deal of variety, variability and complexity. At one extreme, in the south-west part of Sri Lanka, prevails equatorial climate with rains almost throughout the year. At the other extreme, in western Rajasthan and Sind, the climate is hot desertic. Between these extremes, we have a diversity of climate types ranging from average dry season of 2 months in the southern part of Kerala to dryness for 11 months at the periphery of the Thar.

Within the broad definition of dry month ( $P \leq 2T$ ), a further appreciation of the duration and intensity of dryness is expressed by the xerothermic index of Bag-nouls and Gausson (1953) which is a

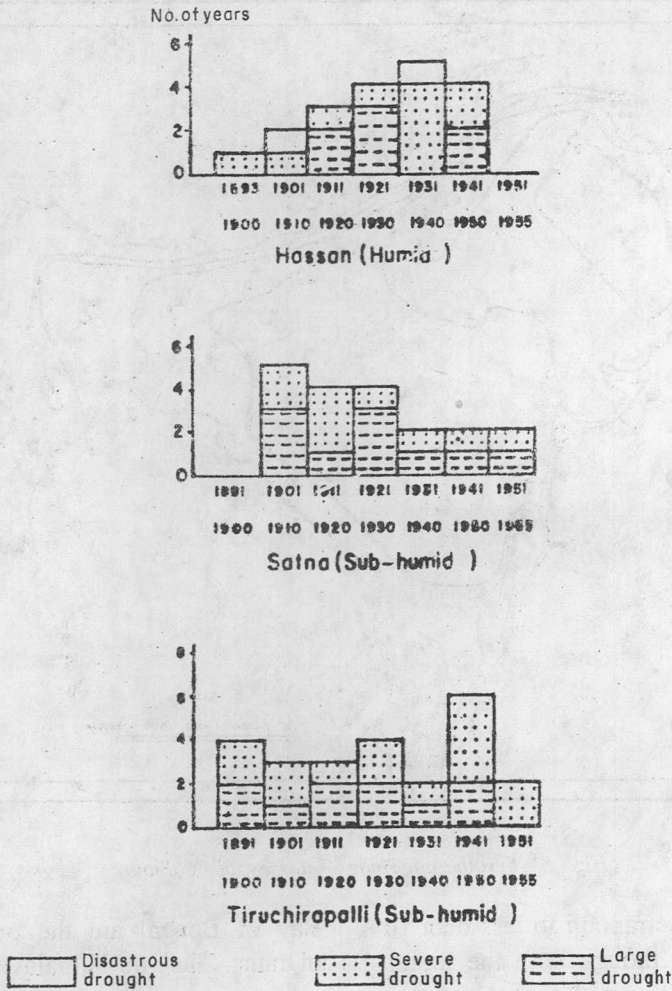


Fig. 7. Frequency of droughts at humid and sub-humid stations (Source: Subrahmanyam and Subramanian, 1965).

measure of the number of biologically dry days in the year<sup>2</sup>.

The rainfall also varies from the world record of over 10 m per annum in the

<sup>2</sup> It is calculated by subtracting from the total number of days in a dry month, the number of rainy days and half the number of days with fog and dew. This figure is multiplied by 0.7 if the relative humidity (H) is > 80%, 0.8 if H is between 60 and 80% and 0.9 if it is 40-60%. The total arrived at for the dry months gives the final value of the xerothermic index for which six classes are recognised as follows and mapped (Fig. 8). X1: 1 to 40 days are biologically dry; X2: 41 to 100; X3: 101 to 150; X4: 151 to 200; X5: 201 to 300; and X6: > 300.

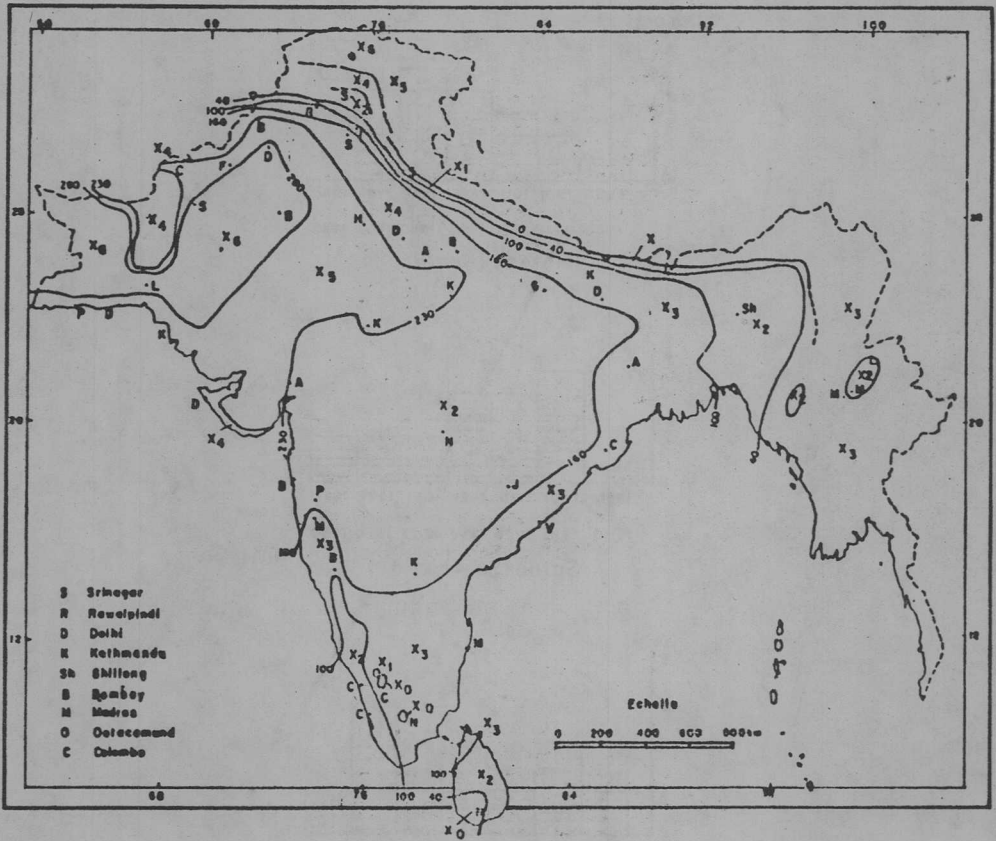


Fig. 8. Xerothermic index, classes of X (Source: Legris, 1963).

region around Cherrapunji to less than 100 mm in the Thar, though both the regions are located on almost the same latitude.

The seasons of occurrence of rains introduce yet another dimension of diversity. Though the major part of the subcontinent is subject to tropical regime with the dominance of the S.W. monsoon, the north-west part in Afghanistan-Pakistan remains under mediterranean regime as stated earlier. The Coromandel-Circar coastal tract receives bulk of the rains in October-November from the so-called N.E. monsoon, wherein the depressions and cyclones formed in the

Bay of Bengal are the principal sources of rains. The sub-Himalayan tract has two rainy seasons, one in winter-spring due to the Western disturbances and another in summer due to the S.W. monsoon, with two dry periods separating the two rainy seasons. Hence bixeric regime.

The inter-yearly variability on account of the vagaries of the monsoon disrupts the above-mentioned average picture of the climate.

The variations in the total yearly rainfall quantum may be so pronounced at certain stations so as to render the very defini-

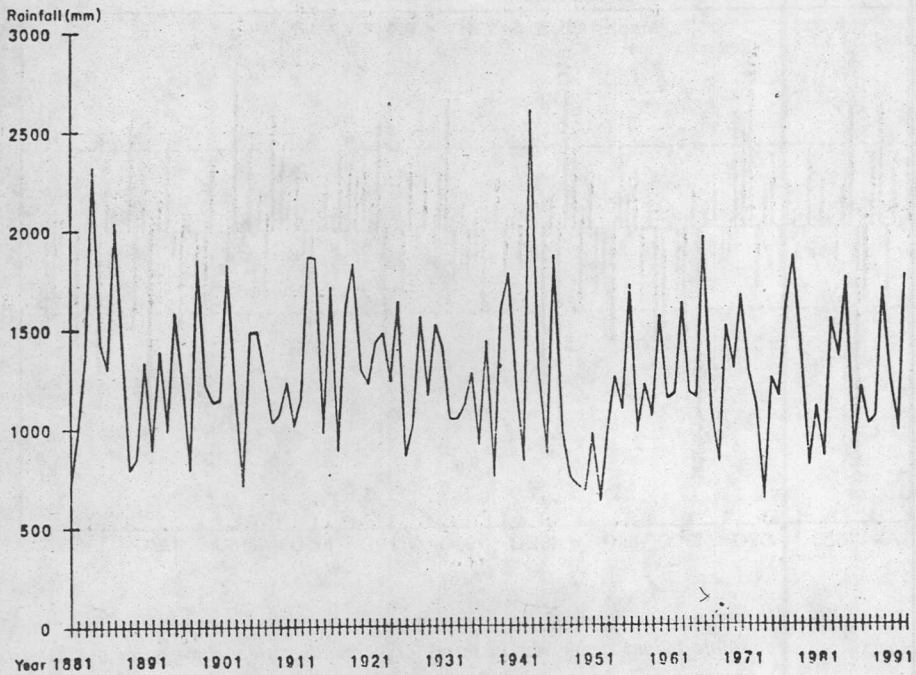


Fig. 9. Variations in rainfall at Pondicherry.

tion of average climate not very meaningful. At Pondicherry the annual amount may be as low as 600 mm in some years, three to four times higher in some other years (Fig. 9). Krishnan (1977) has brought out the variations in the rainfall quantum for the arid zone stations for the period 1891-1975.

The Indian sub-continent is characterized by large fluctuations in the total rainfall (400 million ha-m per year) from place to place and from year to year (Fig. 10). Particularly drought-prone areas (broadly defined as those receiving < 400 mm) are subject to such fluctuations.

Less than 10% of the total hours of the rainy season experience rainfall during the south-west monsoon season. This would

amount to 300 hours. According to Pisharoty (1987) the precipitation occurs for mere 20 to 30 hours at any given place. A major proportion of this water (85%) goes waste by way of run off and < 15% percolates into the sub-soil to recharge the aquifer (Valdiya, 1987). Moreover, normal rainfall does not necessarily mean even distribution. In 1987, the state of Andhra Pradesh received normal rainfall but 18 out of 23 districts were declared drought affected.

Around 260 million ha or 79% of the total geographic area of India receives less than 75% of the normal rainfall and suffer from drought.

As per the estimate of Kaul and Das (1982), disastrous droughts have taken toll of over 20 million ha of land; severe droughts

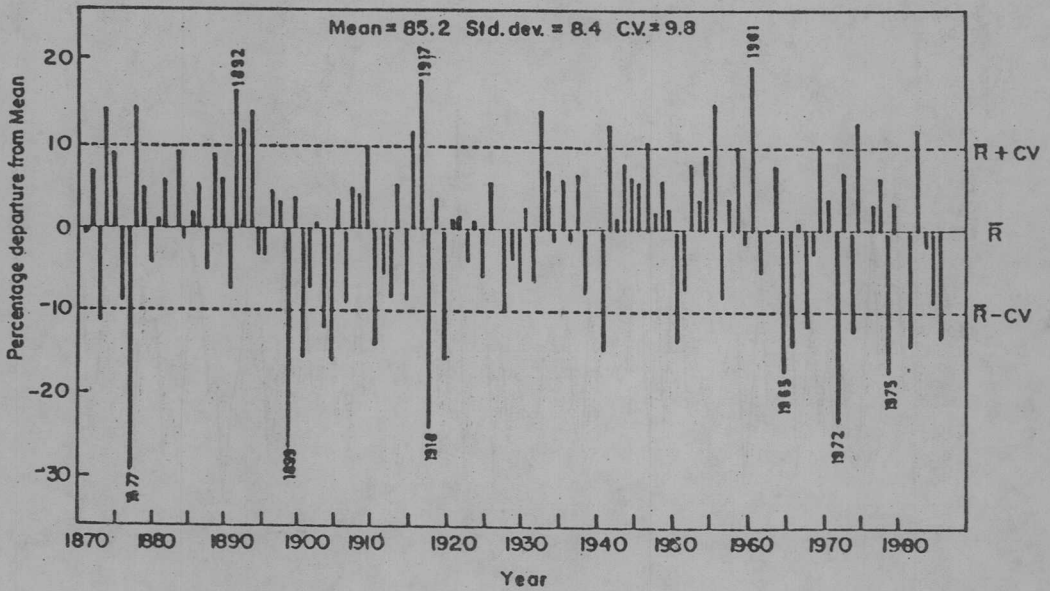


Fig. 10. Erratic variation in the summer monsoon rains since 1870. The rainfall data are given in terms of percentage departure from the average of about a hundred-year period (Pisharoty, 1987).

have ravaged 117 million and milder droughts have affected 76 million ha. States like Rajasthan, North Gujarat and Tamil Nadu experience severe drought once in 2 to 5 years, whereas, in the drier parts of India droughts occur every 10 to 20 years.

There are glaring examples of variations in the length of the dry season too. At Kodaikanal, the majority of individual years experience dryness of 1 to 4 months. Yet, on the basis of average, the dry period does not come out because spells of droughts occur in different months in different years. New Delhi, with a range of 5 to 11 months dryness presents average of 9.

In still other cases, the fluctuations involve the regime. For some stations of

Kashmir and Pakistan, the average regime turns out to be of mediterranean type but in fact the regime varies from year to year as exemplified by the stations of Dera Ismail Khan and Peshawar (Figs. 5, 6). No individual year matches with the average pattern nor do the individual years agree with each other so much, as far as the regime is concerned.

### Deforestation Linked Precipitation Change

Linked to the variability and instability of the climate is the problem of ascertaining whether the rain in India is on the wane. This has been a debated subject. Publications appearing till 1972 argued in favor of no climatic change. However, Winstanley (1973) tried to show that since the late

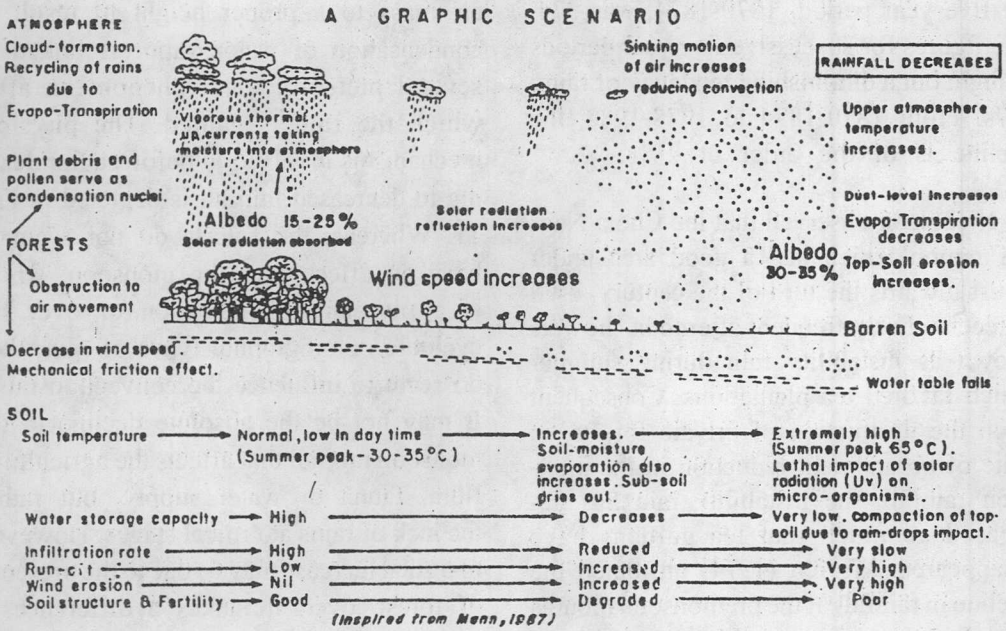


Fig. 11. Repercussions of deforestation on atmospheric and soil processes.

1920s, the summer rainfall in the Sahel Zone and in the north-western India has been showing a declining trend. Several later studies ruled out this possibility (Agarwal, 1976; Chowdhury and Abhyankar, 1976; Legris and Meher-Homji, 1976; Mukherjee and Singh, 1978; Singh, 1978). However, trends are generally studied for the urbanized centers that have lost their forests long back. Therefore, it was felt that it would be interesting to compare the trends for two groups of stations, located in the vicinity of forests; the surroundings of one group would be undergoing large scale deforestation and destruction of woodlands, and those of the other group would be free of such devastation. Such an approach would eliminate the problem of periodic

cycles of lean years. Within the frame work of such a study, Meher-Homji (1980a, 1980b) selected two groups of stations in the forested tract of the Western Ghats, the first group having suffered extensive deforestation within recent years and the other group having witnessed only slight or no reduction in their forest mantle. The trends of both rainfall and rainy days were assessed by applying six statistical criteria. It was observed that as a rule, the larger the area of deforestation, more was the number of criteria showing declining tendency of rainfall and rainy days. Voeckler in his report entitled "Improvement of Indian Agriculture" noted that the number of rainy days (excluding those of the months June, July and August, when the rains are

of monsoonic origin and not local) during the five year period, 1870-1874, was 374. The figures for successive five year periods brought out a diminishing tendency of rainy days. From 1870-1874 to 1978-1982, the decline is of the order of 28%.

Nicholson observed that the Chota Nagpur region which had a good area under forest towards the turn of the century, used to receive fairly frequent afternoon showers known as instability rain during summer which favored tea plantations. Consequent upon the destruction of private forests, in spite of no apparent reduction in the monsoon rainfall, the instability rain has decreased so much that tea gardens have disappeared. Warren (1974) attributed the decline in rainfall of the premonsoon months over Ranchi plateau to the degradation of forests to scrubs over an extensive area.

During the prevalence of long droughts in the (summer) monsoon season of weak monsoon years, conditions resemble those of the premonsoon months. Whereas, the wooded areas are likely to benefit from such convective rains which may be low in amount but sufficient to maintain the crops and water supply for the local economy, the regions devoid of forests may not derive any benefit of thunderstorm showers.

Several factors play a role in the hydrological cycle, among them the rain bearing mechanism, geographic location, topography, sea-surface temperature, land temperature, El-Nino phenomenon and indeed the vegetation cover (Meher-Homji, 1989).

The ascension of the moisture bearing air mass to a proper height to result in condensation of water vapor is linked to several meteorological phenomena after which the rain is named. The physical mechanisms involved in deforestation leading to decreased rainfall is depicted in Fig. 11. Whereas, the forests do not seem to have an effect over the monsoon, which is a planetary phenomenon or over the cyclonic or orographic types of rain, they do seem to influence the convection rains. It may not be the absolute decline in the monsoon rainfall that affects the agriculture, flora, fauna or water supply, but rather the lack of rains at critical stages. However, marginal increase may be due to the presence of forest-cover, it makes a difference in sustaining the crops and maintaining the ecosystem.

### Conclusion

Literature is replete with definitions of drought. Also available are several classifications aiming to define and delimit arid and semi-arid zones. More commonly used are those of Koppen (1918, 1936) and Thornthwaite (1948, 1955). Some of the classifications are not very practical as they require data that are not readily available while others do not agree with the distribution of vegetation. The bioclimatic classification of Bagnouls and Gaussen (1957), though empirical, is found to be both practical and convenient for defining dryness, deriving arid zones and explaining the vegetation pattern (Legris, 1963; Meher-Homji, 1962). Droughts are a characteristic feature of monsoonal climates where rainy season

is restricted to some months. Phenomena like El-Nino are linked to weak monsoons and prolonged droughts.

Besides climatic droughts, water shortage is also magnified by anthropogenic influences such as over-crowding in metropolis, over-stocking of cattle and goats, irrational land-use, wide spread practice of monoculture of water-consuming crops like rice and sugarcane in drought prone areas and excessive irrigation. Deforestation too has a telling effect on the precipitation cycle.

As against these wasteful practices, maintenance of green mantle of drought-resistant indigenous trees and suitable fast-growing exotics, with proper bunding, helps the recharge of the aquifers and conservation of moisture. The cropping pattern has to be geared to minimum water use through cultivation of water saving varieties of cereals, pulses, vegetable, fruits, fodder, fuel trees, economic and medicinal species of dry zone like jojoba and *Commiphora mukul*.

Meteorological forecasting which has been good enough to predict the general behavior of monsoon has to be precise at sub-divisional or regional level. The forest-cover has to be integrated as one of the parameters in forecasting as recent researches in hydrology and atmospheric sciences provide a link between forests and precipitation, not necessarily of monsoonic origin but convectional, and more as receptor of rains than generator; creation of green belts could go a long way in conserving water resources.

Desertification may be defined as the process leading to desert formation and is characterized by gradual decline in productivity. It could be either a natural phenomenon linked to tectonic and climate changes or it may be due to abusive land-use.

Vinod Shankar (1977) suggested analysis of certain vegetational criteria for assessment of degrees of desertification. A biological parameter proposed here to assess the accentuation of aridity at a place is to ascertain the shifts in population of plant species towards xeromorphic traits. Certain species exhibit a number of populations, for example, the grass *Oropetium thomaeum* (Tandon, 1977). It may be possible to arrange these populations along a gradient of humidity-aridity. An evidence of desertification may be obtained if the present-day population of a given site in western Rajasthan or Sind reveals greater xeromorphic tendencies than the population of the same locality collected say 70 years earlier and now preserved in a herbarium.

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