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Some aspects of water balance in the tropical monsoon climates of India

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ABSTRACT India is a spectacular example of the monsoon climates of the Asian tropics. Monsoons are defined as the seasonal winds blowing in almost opposite directions in summer and winter; it is mainly the summer monsoon that is of economic importance because of its rainfall potential. The paper presents and discusses the climatic water balances of three representative stations situated in the path of the summer southwest monsoon. The results indicate that the water balances change from humid to arid as one proceeds from south to north over the country. The examples of the stations studied depict various features which appear to be useful in planning water use and agricultural economy of the region. An assessment is made of the water balance elements of the stations during years of both active and weak monsoons.

Certains aspects du bilan hydrologique sous les climats de mousson tropicale en Inde
RESUME L'Inde présente un exemple spectaculaire des climats de mousson en Asie tropicale. Quoique les moussons soient définies comme des vents saisonniers qui soufflent dans des directions presque opposées en été et en hiver, c'est principalement la mousson d'été qui présente une réelle importance économique par suite de ses potentialités en précipitations. La communication présente et analyse le bilan hydrologique climatique de trois stations d'étude représentatives situées sur le passage de la mousson d'été du sud ouest. Les résultats indiquent que la nature du bilan hydrologique change d'une régime hydrologique humide à un régime hydrologique aride en allant du sud vers le nord du pays. Les exemples des stations étudiées mettent en évidence des caractéristiques variées qui sont utiles à connaître pour la planification de l'utilisation de l'eau et l'économie agricole de la région. Une estimation est faite des éléments du bilan hydrologique des stations d'étude pendant les années où la mousson présente une forte ou une faible activité.

India is considered to be an outstanding example of a typical monsoonal country since the prevailing wind direction over the region reverses almost exactly by 180° from the summer to the winter seasons of the year. What is, however, important in this context is not so much the wind regime but the rainfall distribution associated with the monsoon circulation. In fact, India experiences two monsoons - the southwest or summer monsoon (June-September) and the northeast or winter monsoon (December-March) - of which the former is the most important on account of its rainfall potential. Agriculture in India heavily depends on the southwest monsoon rainfall, failure or even delayed onset of which seriously hampers agricultural operations and crop yields.

The southwest monsoon, according to accepted concepts, originates in the subtropical high pressure zones of the southern hemisphere, travels northwards, crosses the equator and strikes the southernmost portion of the south Indian region towards the end of May. Then branching into two streams - the Arabian Sea branch and the Bay of Bengal branch - the southwest monsoon air gradually spreads over the whole country up to the State of Punjab by the end of July. Excluding the northernmost State of Kashmir, the entire region receives about 79% of its annual rainfall during the southwest monsoon period; the monsoon withdraws from most parts of the country by October. Yet, the monsoonal airflow over the Indian region is neither continuous nor steady but displays marked pulsations - late onset, early withdrawal, breaks as well as sudden intensifications - all resulting in both regional and seasonal variations in the distribution of rainfall. Studies have revealed (Subrahmanyam & Karuna Kumar, 1976) that the climate of the country is determined almost exclusively by the characteristics of the monsoon, stations in different parts of the country along the path of the monsoonal circulation experiencing different moisture regimes. Monsoons, as a special climatic category, were first recognized by Köppen (1900) who used the magnitude of the driest month's rainfall in relation to the total annual rainfall for distinguishing the monsoonal from the non-monsoonal climates. The concepts and criteria of water balance developed by Thornthwaite (1948) and modified later by Thornthwaite & Mather (1955) have enabled a more rational classification of climates. Subrahmanyam (1956), Subrahmanyam, *et al.*, (1965) and Subrahmanyam & Ram Mohan (1980) have used these criteria for classifying the climates of the Indian region. It was later shown by Subrahmanyam & Sarma (1981) that the evolution of the moisture regime of the Indian climates is mainly the result of the interaction between the monsoonal circulation and the topography of the country. The climatic types generated by this interaction range from the perhumid on the wet side to the arid on the dry side and are shown in Fig.1.

It may be seen that the western portion of India is completely arid (E) and adjoining this zone is an almost continuous semiarid (D) belt extending from Punjab in the north to the southern tip of the peninsula, divided into a northern-southern zone by a narrow subhumid (C) strip running east-west along the Vindhyan mountain region. To the immediate east of Western Ghats in south India is a very narrow subhumid zone (C) merging gradually with the humid (B) and perhumid (A) zones westwards to the Arabian Sea coast. An island of a fairly humid (B) climate in the northern semiarid (D) zone is found in the Aravalli Hills. To the east and north of this extensive dry belt lies a vast subhumid region (C) joining the same climatic category of the Vindhyan range of mountains. Further east and northeast are the humid (B) and the perhumid (A) areas of eastern India and Assam. Humid climates also prevail in the elevated

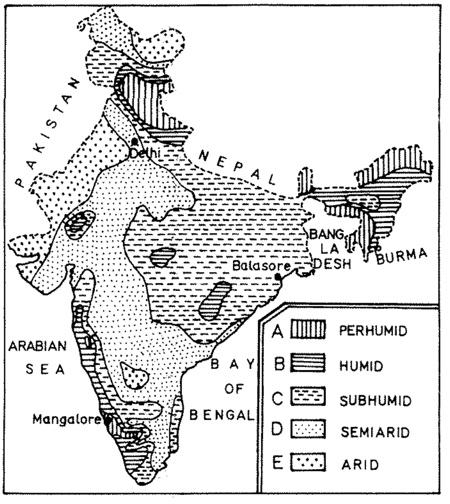

FIG.1 India - climatic types (after Thornthwaite).

zones of south India like the Eastern Ghats, Nilgiri, Annamalai and Palni Hills.

It is thus clear from the above description of the climatic spectrum of India that though the rigorous Köppen definition of the monsoon climates is applicable only to a narrow strip on the west coast of south India, all five climatic types and zones discussed above do represent the monsoon climates of the Indian region and must be treated as such. It is in fact this aspect that has been stressed in this paper with a view to highlight the potential of the various sections of the country for agricultural and hydrological development. For this purpose, representative stations have been chosen from different sections of the country influenced by the southwest monsoon circulation. Three stations are cited as examples: Mangalore from the west coast of south India belonging to the perhumid (A) zone, Balasore from the upper east coast of peninsular India which has a moist subhumid climate (C_2) and Delhi from the semiarid (D) north Indian plain.

Mangalore which is under the direct influence of the Arabian Sea branch of the southwest monsoon may be taken to be a typical monsoonal station since it receives about 90% of its total annual rainfall within a period of about six months from May to October while it is extremely dry from December to March. While this is the climatic picture (Fig.2(a)) the moisture regime of this perhumid station in more active and less active monsoon years is equally interesting (Table 1). In the wet year of 1961 (Fig.2(B)) the rainy season here started in April and the water surplus of 464.2 cm was more than twice the normal of 216.3 cm, while in the dry year of 1934 (Fig.2(c)) when the very weak monsoon started in June and practically ended by September the water surplus of 111.2 cm was less than half of the normal. What is interesting, however, is that there was not much change in water deficit even during the dry year when it was just 12% higher. It may thus be seen that in perhumid climates of monsoonal origin water deficits do not show much variation even during dry years but the water surpluses, which themselves are fairly

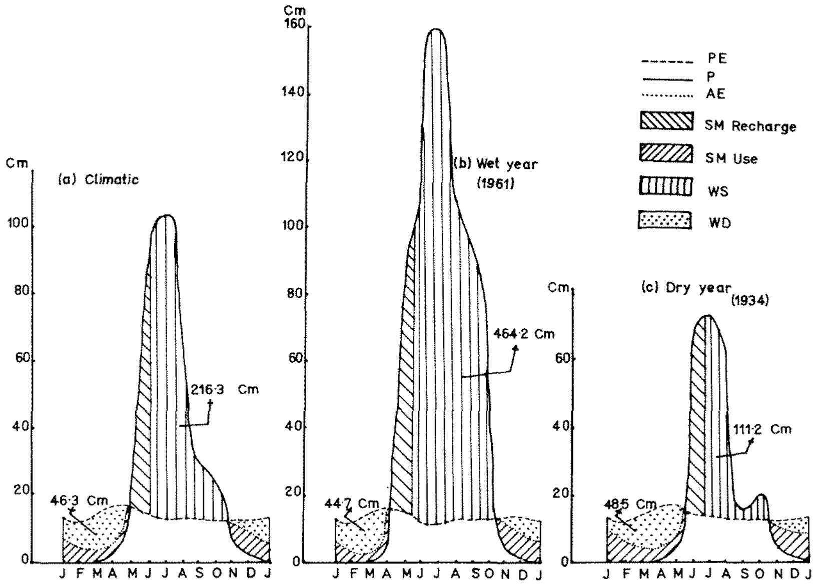

FIG.2 Water balances of Mangalore (perhumid, A).

high, register considerable diminution; it is significant to notice even an increase in water deficiency (44.7 cm) during the wet year of 1961 at Mangalore while the normal water deficit is only 43.3 cm.

TABLE 1 Comparative water balance data in monsoon climates of the Indian region

Year	Water need (cm)	Precipitation (cm)	Water surplus (cm)	Water deficit (cm)
MANGALORE				
Average	169.8	342.8	216.3	43.3
Wet year (1961)	166.7	583.8	464.2	44.7
Dry year (1934)	168.6	219.5	111.2	48.5
BALASORE				
Average	156.6	162.4	28.1	22.3
Wet year (1956)	154.1	295.3	155.8	8.3
Dry year (1954)	158.0	115.7	0.0	53.2
DELHI				
Average	147.6	65.2	0.0	82.4
Wet year (1933)	134.1	153.5	47.1	27.7
Dry year (1929)	153.2	30.1	0.0	123.1

This is only on account of the uneven distribution of rainfall causing large imbalances in the water budget.

Balasore is a moist subhumid (C_2) station on the upper east coast of south India exposed to the Bay of Bengal branch of the southwest monsoon whose potential precipitation is not only much less than that of the Arabian Sea branch but Balasore is almost in the lee of the Eastern Ghats as far as the prevailing monsoonal circulation is concerned. Consequently, its normal annual rainfall (162.4 cm) is less than half that for Mangalore and water surplus is only 28.1 cm, while the water deficit is 22.3 cm (Fig.3(a)). In the very active monsoon year of 1956 Balasore received 295.3 cm of rainfall which produced an enormous water surplus of 155.8 cm - six times the normal - and reduced the water deficit to 8.3 cm - almost to one-third the

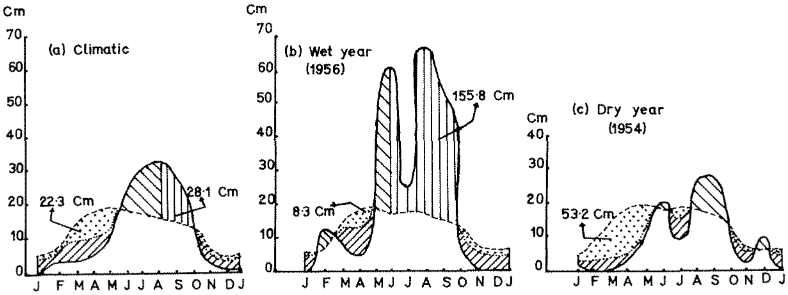

FIG.3 Water balances of Balasore (moist subhumid C_2).

normal (Table 1). But in the dry year of 1954 when the southwest monsoon was very weak and was delayed until August, the rainfall was only 115.7 cm - about 70% of the normal value. The water surplus, therefore, came down to zero while the water deficit (53.2 cm) rose to about two-and-a-half times the normal.

This is but a characteristic feature of the subhumid climates which are intermediate between the wet and the dry climates on either side and, therefore, they possess very critical water balances that fluctuate between large water surplus and large water deficiency year after year. The vagaries of the monsoons are very strongly felt in these buffer climates where the water resources are meagre and uncertain and augmentation and conservation measures are a dire necessity for successful implementation of agricultural and hydrological programmes.

On the other hand, Delhi is almost at the northernmost limit of the southwest monsoon over the Indian region and has an annual rainfall of 65.2 cm which is less than half its water need of 147.6 cm. Hence, it has a semiarid (D) climate (Fig.4(a)) which becomes much worse in the dry year (1929) when the water deficit (123.1 cm) rose to one-and-a-half times its normal value of 82.4 cm. (Fig.4(c)). But when the monsoon was particularly active as in 1933 (Fig.4(b)) Delhi received so much rainfall (153.5 cm) that its water deficit (27.7 cm) had not only come down almost to one-third its normal value but a water surplus of 47.1 cm was registered, while in normal years it has none (Table 1). Such wet monsoon years are, however, very rare in the semiarid climates of either the north Indian or the south

Indian region but when they do occur they cause much concern because of the resulting river flooding and vast inundations.

The behaviour of individual stations in the paths of the two branches of the southwest monsoon in summer as well as of the northeast monsoon during winter is thus a very interesting study particularly from the point of view of water balance and its fluctuations from year to year. The monsoon climates cannot, therefore, be defined purely in terms of the total annual rainfall and

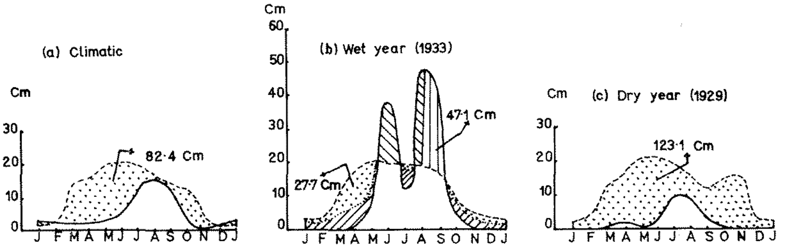

FIG.4 Water balances of Delhi (semiarid, D).

rainfall of the driest month as Köppen did. It would appear that monsoons can generate a whole spectrum of climates from the perhumid to the arid depending upon the geographical location of the region and topography of the area (Table 1). Under these circumstances the natural vegetation cannot be forest but varies depending on the water surplus and water deficit in relation to water need. The humidity and aridity indices thus obtained as percentages serve a very useful purpose in the ecoclimatic planning of the region for development purposes. Considering these points monsoons must be understood only as seasonal wind circulations with their rainfall potential determined by several regional factors.

One of the significant conclusions that has emerged from this study is that the concept of monsoons as regions or periods of heavy downpour of rainfall supporting forest vegetation is not in fact quite correct. They must be viewed as only one aspect of the general circulation of the atmosphere in the tropics and rainfall associated with this circulation is neither the same nor constant everywhere; it is the complex interaction between this circulation and the geography and the physiography of the region that generates a range of climates varying between the perhumid and the arid depending upon the nature and the extent of the interaction. The Indian region being an outstanding example of the Asiatic tropical monsoon affords strong evidence supporting this concept, perhaps necessitating a revision of the definition of monsoon climates from an ecological angle.

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