Trans. Inst. Indian Geographers
Vol. 3, No. 2, July 1981

EVOLUTION OF THE INDIAN CLIMATES AND WATER USE PLANNING

V. P. SUBRAHMANYAM and A. A. L. N. SARMA, Waltair.

ABSTRACT : It is well-established that India is a land of monsoons and that the country's economy is strongly geared to the monsoonal precipitation. The Asiatiatic monsoon of which the Indian monsoon is a sub-system is a complex circulation and meteorological models for it have been suggested by Flohn (1958) and Koteswaram (1958). The paper presents the schematic illustrations and major features of the southwest or summer monsson of the Indian region and discusses the influence of the geographical and physiographic features like the Tibetau platean, the Eastern and the Western Himalayas and the Western Ghats on the monsoonal circulation and the resulting spectrum of climatic types of the sub-contionent.

The paper then proceeds to consider the moisture regime of the Indian climates with particular reference to their water potentialities. The rational scheme of classification of climates proposed by Thornthwaite (1955) has been employed for the purpose. Typical water balance charts for ststions situated in the different climatic regions of the country are presented and their usefulness discussed in agricultural and hydrological planning. Shifts in the climatic regimes of the stations following changes in water balance in extremely dry and wet years are also considered and their possible occurrence due to circulatory changes speculated.

It is suggested that serious efforts be made to understand these climatic shifts thoroughly by concentrating on the synoptic patterns of atmospheric circulation over the country. This aspect of drought climatology is expected to be of great practical use not only in the assessment of desertification problems but also in drought area planning in the matter of prediction of the occurrence, intensity and duration of different categories of droughts which afflict all parts of world from time to time.

Introduction

Any model of the general atmospheric circulation for a uniform and homogeneous surface of the earth can never explain the large scale modification of surface winds. Among such terrestrial modifications are some which are planetary in magnitude, others are of sub-continental size, while still others are relatively local. These modifications result from a) the inclination ($23\frac{1}{2}^0$) and parallelism of the earth's axis causing a uniform latitudinal shifting of the belts of solar energy following the seasons, b) non-homogeneous surface composed of both land and water areas having contrasting temperature, pressure and wind characteristics and c) land areas, the surfaces of which are variable in configuration and altitude.

As the word monson is commonly used in climatological literature, it involves not only a wind reversal but also of thermal origin arising from the differential heating of extensive land and water surfaces.

The Asiatic Monsoon

Owing to the great size of the continent and consequently the greater seasonal extremes of temperature, eastern and southern Asia are considered to be the classical monsoon region. Here the monsoon system of winds with its seasonal reversal of direction is most perfectly developed. It is now generally agreed that the basic cause of the southwest or summer monsoon of the Indian region is the existence of the vast Asiatic continent in the northern hemisphere and the Indian Ocean in the southern hemisphere, both these contrasting geographical features being quite close to the equator. Actually, the Asiatic monsoon is not one but at least two monsoons – that of China and Japan being distinct from the tropical monsoons of South Asla. The system of high Himalayan mountains and plateaus separating India and Pakistan from China makes any transport of air between the two regions unlikely.

The tropical maritime air moving northward into India in summer is a deep current which has crossed several thousand miles of tropical sea and consequently highly charged with water vapour. It advances rapidly northward over India as a definite front, its arrival being designated as the 'burst of the monsoon'. With the burst, comes a complete change in the face of the weather, for heavy squally rains accompanied by thunder and lightening, ordinarily herald the arrival of the monsoon. In farther India, the northward advance of the monsoon is less abrupt and is accompanied by less severe weather disturbances. Weather is less turbulent during the height of the monsoon (although rainfall is greatear) than during the advance and retreat of the monsosn at the beginning and end of summer. The retreat of the monsoon is often accompanied by hurricane-type of storms. During the height of the monsoon, much of the rainfall is associated with weak cyclonic storms known as depressions which appear to originate in zones of convergence.

Three main currents or stream-lines of summer air-flow may be recognized in India and Pakistan : a) A main westerly current from the Arabian Sea meets Western Ghats at nearly right angles and flows across peninsular India. b) What appears to be a branch of this main current advances northward over the Bay of Bengal. c) A third current from the southeast advances up the Ganges valley to the south of the Himalayas. The main westerly current after recurvature in north India continues westward across farther India. Excessively heavy rainfall whenever these unstable monsoon currents are forced to asend relief barriers such as the Western Ghats, the mountains of the northeastern region of India and Pakistan and the mountains along the west coast of Burma.

The climate of Indla, is therefore determined by the atmospheric circulations associated with the monsoons and the year is consequently divided into two main seasons, namely (a) the southwest monsoon (June to Suptember) (b) the northeast monsoon (December to March). The transition periods between them are known as the retreating southwest monsoon (October and November) and the Hot Weather season (April and May).

Rainfall from the northeast monsoon is so little and is restricted to such small areas, that its contribution to the overall water potential of the country is not significant thought it plays an important role in the water economy of the localized regions.

Rainfall during the hot weather season is due to violent convective thunderstorms which account for a significant portion of the annual rainfall of northeast India.

The southwest monsoon season which is the principal rainy period for almost the entire country is responsible for more than 80 % of the total annual rainfall. As already stated, it is during the retreating southwest monsoon season in the months of October

and November that several cyclonic storms of even hurricane intensity develop and produce copious precipitation over the coastal areas of Peninsular India, besides causing some times great economic loss through floods, winds and tidal waves.

Mechanism of The Indian Southwest Monsoonal Circulation

It has come to light in recent years that the easterly jet stream which occurs at an elevation of 14.1 Km has a close relation to the southwest monsoonal activity over the Indian region. This jet is supposed to reasult from the thermal effects of the elevated Tibetan plateau on the general circulation in Summer (Koteswaram, 1956). The plateau which is an ellipsoid, 3000 Km by 1500 Km, with an average elevation of over 4 Km, individual mountain ranges rising to 6 to 8km, receives an enormous amount of solar radiation during tbe summer season. The re-radiation of thermal energy from this elevated terrain goes directly to heat the middle troposphere and set up a strong solenoidal field in the upper troposphere for driving a clockwise circulation. The resulting upper air anticyclone, is, therefore, of thermal origin, and the monsoon trough south of the Himalayas helps in augmenting the circulation by liberation of condensation heat in the rising masses of monsoon air. The equatorward branch of the upper out-flow from this system gains easterly angular momentum and the poleward branch westerly angular momentum. Two jet streams thus originate, a westerly jet to the north of the anticyclone and an easterly jet to its south. Mass compensation is obtained through a reverse west wind circulation in the lower troposphere. The southwest monsoon according to Koteswaram (1960), is thus a return current in the lower layers of the meridional circulation system. It is convergent and picks up copious moisture from the warm sea areas over which it passes. During its ascent around the monsoon trough at the rim of the Tibetan plateau, latent heat is liberated through condensation and cloud formation and goes to augment tne 'heat source' over the plateau. The atmospheric circulation is thus completed, the 'engine, being maintained as long as the heat source and sink are available. When during the autumn, the inflow of cold polar air into the subtropics quenches the 'heat source' over the Tibetan plateau, the circulation ceases and the Southwest monsoon withdraws from the region.

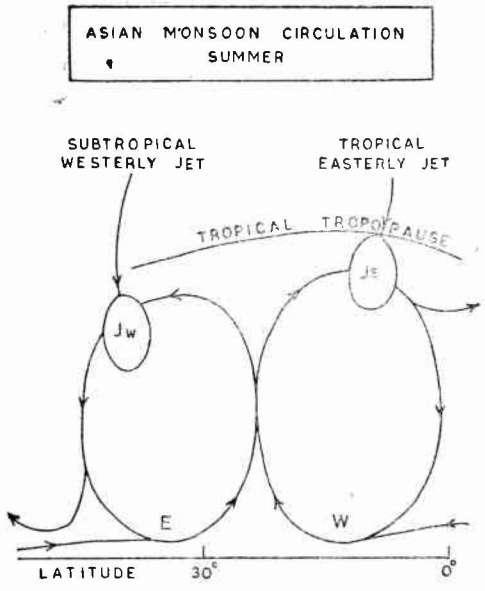


FIG. 1. SCHEMATIC MODEL OF VERTICAL CIRCULATION IN THE ASIAN SUMMER MONSOON.

Fig. 1 shows a schematic diagram of the above model for the southwest monsoon reproduced from Koteswaram's (1960) work. The tropical circulation cell (Hadley cell) of Palmen's well-known atmospheric model is replaced by two cells of opposite circulation with a common heat 'source' near the Tibetan plateau and 'sinks' over Siberia in the north and the equatorial regions in the south respectively.

Evolution of The Indian Climates

India is thus regarded as belonging to the Monsoonal Climate in terms of its precipitation march through the year, but analysis shows that it possesses almost all the major climatic types according to any system of climatic classification. For the study of Indian climates in relation to water use planning, Thornthwaite's scheme (1948) may be seen to be very useful since it seggregates the climate of any place into its thermal and moisture regimes. Being mostly in the tropical latitudes and also effectively shielded from the impact of the cold Siberian air-masses during the winter season, the thermal regime of most stations in India is almost Megathermal capable of supporting the luxuriant development of rainforest type of vegetation. Ecoclimatic considerations, however, show that the highly nonuniform seasonal distribution of annual precipitation responsible for the evolution of a variety of climatic types which constitute the full spectrum of the moisture regime of climate.

It was Waldimir Koppen (1900) who first gave serious thought to monsoonal climate as an important subtype of the tropical climates. According to him the tropical monsoon (Am) is intermediate between the Tropical Rainforest (Af) on one side in terms of the total annual amount of rainfall and the Tropical Savanna on the other (Aw) in so far as its seasonal distribution of rainfall is concerned. If the mean temperature of the coldest month in such a region is equal to or greater than 64.4° F (18°C), then it is tropical while when it falls below 18° C then it belongs to the subtropical regime. Thus, one comes across both Tropical and Subtropical Monsoons in World Climatology, while Flohn (1960) even talks of Subpolar Monsoons if we consider the seasonal wind shifts rather than the precipitation distribution, for the definition of the monsoons.

In the rational scheme for the classification of climates, Thornthwaite (1948) does not recognize monsoons as a separate category under the moisture regime. Employing the modified water balance procedure (Thornthwaite and Mather, 1955) and adopting the limiting values proposed by Carter and Mather (1966) for the moisture indices, a map of climatic types of India has been prepared which is shown in Fig.2. It is observed that two thirds of the region is covered by subhumid(C_2 and C_1) and higher order namely D and E of dry climates The area occupied by perhumid and humid climates is small, and they exist only as isolated pockets especially over the elevated portions. The dominance of the monsoon in determining the climate can, however, be seen along the Arabian Sea coastal region or the west coastal section of Burma where the southwest monsoon activity is very strong. The geographical similarity of these regions of the subcontinent coupled with the presence of long momntain chains parallel to the coast lines are conjointly responsible for the similar types of climate obtained. The low rainfall amounts in the Deccan plateau and the Irrawaddy valley in central Burma are clearly on account of the rain-shodow effect of the Wertern Ghats in south India and the Arakan and Yoma in Burma respectively.

The dryness of the northwestern part of India including Rajasthan is ascribed to the interference between the moist monsoon air and the hot dry continental air which subsides after its long passage over the hot, dry plateaus of Persia and Baluchistan. The continental air, projected into and above the oceanic monsoon air mass prevents the ascent of the moist air, thus inhibiting evolution of rainfall except for the occasional downpour when conditions of instability temporarily obtain. The inclined plane of the Inter-Tropical Convergence Zone (ITCZ) reaches the land surface south of Karachi and all oceanic air is excluded from the deserts of Baluchistan. Farther east, the amount of rainfall is roughly proportional to the height of the ITCZ above the ground

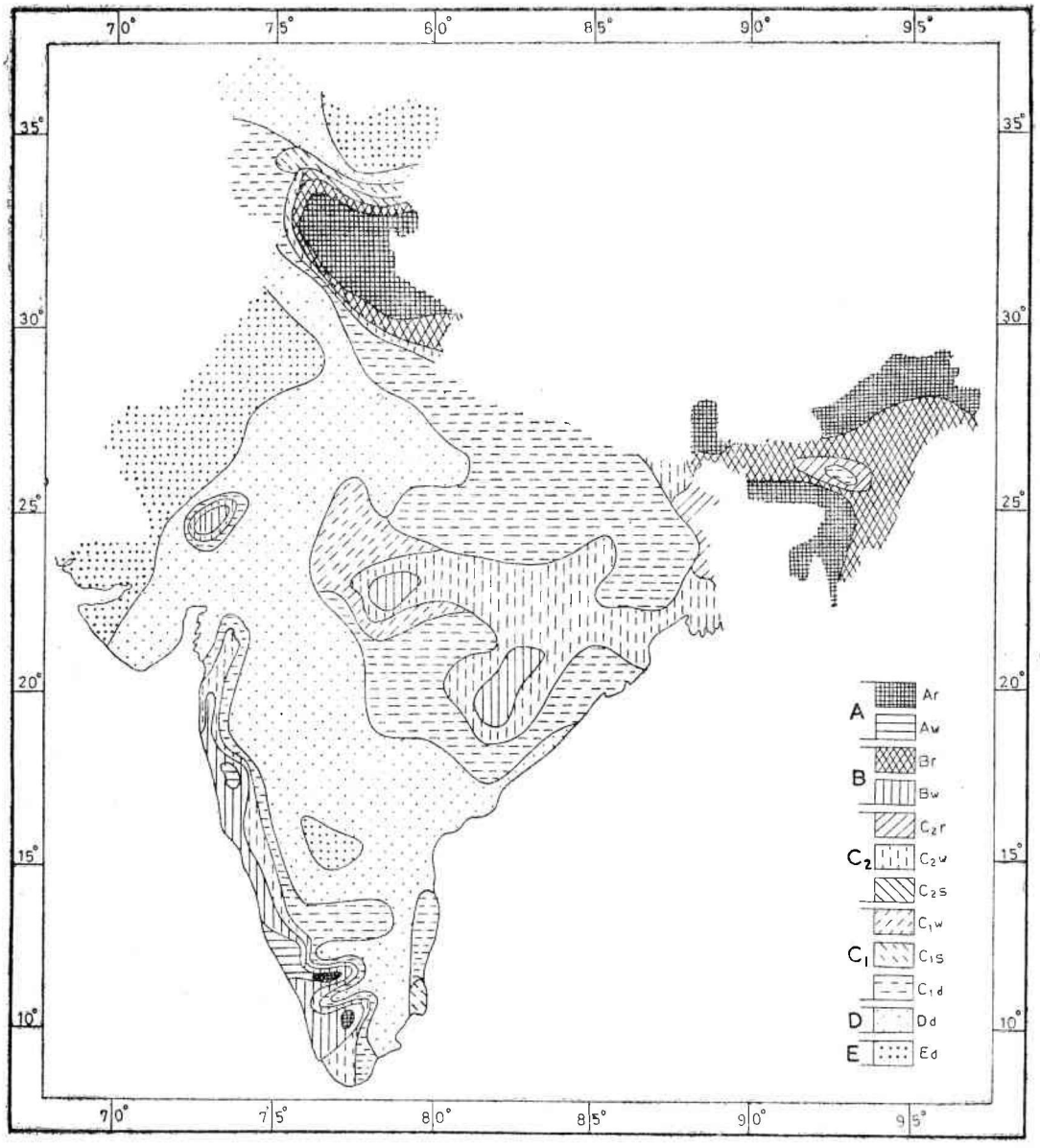


FIG. 2. CLIMATIC TYPES OF INDIA – MOISTURE REGIME (THORNTHWAITE, 1955 SCHEME).

since the higher the plane of discontinuity the higher the air can ascend and the greater the possibility of rain. Even so, rainfall is very slight and highly irregular, producing the arid conditions of Western Rajasthan and Sind.

Water Balance of The Indian Climates

The book-keeping procedure for water blance suggested by Thornthwaite (1948) and later modified by Thornthwaite and Mather (1955) enables the computation of the water budget of any region by comparing the water-supply by precipitation with water need through petential evapotranspiration. In this procedure rainfall is treated as income and potential lvapotranspiration as comitted expenditure, the soil playing the role of a capacitor capable of storing water during periods of excessive rainfall and releasing it for evapotranspirational purposes during periods of deficient or no rainfall. The waterneed obtained through measurement or computation may then be compared with the measured precipitation on a monthly basis using the measured or assumed values of soil field capacity and arrive at the derived elements of the water budget, namely, Actual Evapotranspiration (AE), Water Deficiency (WD) and water Surplus (WS). These elemente have immense application in water use planning both for agriculture and hydrology,

In Table I are shown the climatic types to which the representative stations in India belong according to their moisturc regime.

Plotted graphically, these data appear as water babance charts which yield enormous amount of information on the amount, duration and cessation of water deficiency and water surplus. Based on this knowledge, one can plan the conservation and utilisation of available water resources.

In perhumid climates (Fig, 3a) water deficiencies may be totally absent or negligibly small but water surpluses will be enormous. Depending upon the magnitudes

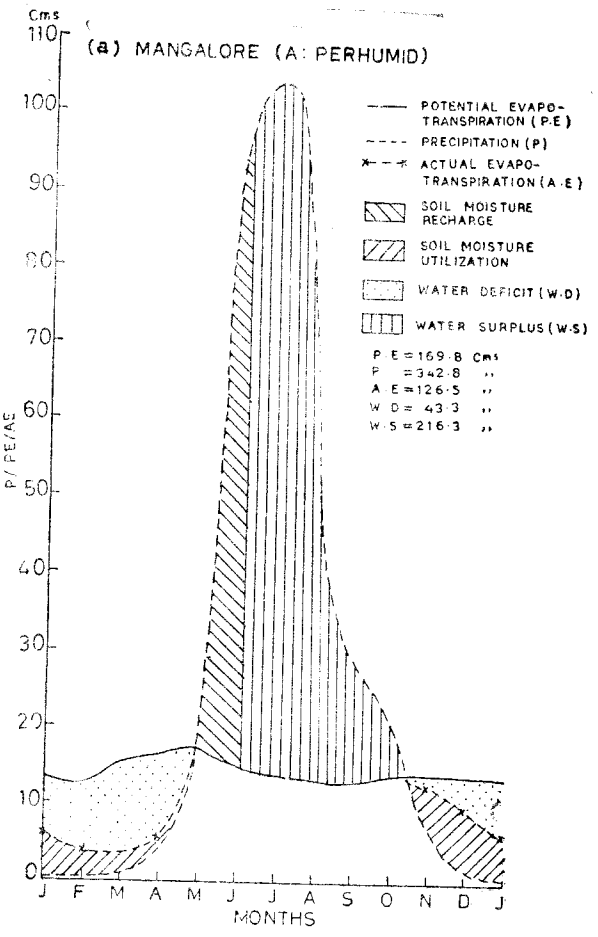


FIG. 3. CLIMATIC WATER-BUDGET OF INDIAN STATIONS.

and seasonal distribution of water deficiency in relation to water need the vegetation distribution is accordingly adjusted. Dense broadleaf forests are characteristic of these climates where both water availability and thermal deficiency are more than adequate throughout the year. The monsoon climates, however, support ever-green rainforests which may not be so dense and luxuriant on account of the uneven distribution of rainfall which is quite abundant in quantity but is received in a brief season of three to four months.

In humid climates (Fig. 3b) water deficits remain more or less the same as in the perhumid type but the water surpluses show a

TABLE I

Climatic Types of Indian Stations

Station	Climatic type according to	
	Thornthwaite's Scheme	Koppen's Scheme
Mangalore	Aw (Perhumid)	Am (Tropical Monsoon)
Dhubri	B_4r (Humid)	Aw (Tropical Savanna)
Belgaum	C_2w (Moist Subhumid)	Cw (Subtropical)
Nagpur	C_1d (Drysubhumid)	Cw (Subtropical)
Hyderabad	Dd (Semiarid)	Bs (Steppe)
Jodhpur	Ed (Arid)	Bw (Arid or Desert)

sharp decline due to a general diminution of rainfall. After full soil storage only a small quantity of water from precipitation is left on a seasonal basis for occurrence of outflow or for contribution to underground reservoirs. In either case full water availability throughout the year is not assured as in perhumid climates; forests do develop but are more open without much undergrowth. Where the seasonal rainfall contrasts are marked, vegetation exhibits deciduousness as a seasonal rhythm.

Moist subhumid climates(Fig. 3b) exhibit a further reduction in water surplus combined with an increase in the overall magnitude ond duration of water deficiencies. The ecological consequence is that the natural vegetation here is open jungle type interspersed with shrubs and tall grasses. The drier counterpart of these subhumid climates are the Dry Subhumid (Fig. 3d) whose water budgets are rather critical swinging hazardously between deficit and surplus situations year after year. Water surpluses in these transitional climates are not uncommon but when they at all occur, they are so small in amount and are confined to such brief periods that vegetation of only a drought-resistant type can thrive successfully in these climatic regions.

In the semiarid zones (Fig. 30) a state of decidiousness or dormacy in vsegetation is clearly observed on account of the prolonged and pronounced water deficiency. Where water deficits are severe, no broad-leaved species thrive and the landscape can support only tiny and thick-leave hardy trees and scrubby types of low vegetation.

The arid climates (Fig. 3 f) of which numerous examples are available are those in which there are only water deficiencies throughout the year and water surpluses of any nature are practically unknown. Meagre and erratic precipitation in these climates together with high rates of evaporation and an associated low ground-water table result in a relatively scanty vegetation cover which is composed of many forms of scrubs.

For its size and geographical position, India possesses all the ecoclimatic types discussed on account of its physical relief and peculiarities of monsoonal circulation; the gradation of the climatic spectrum, perhumid to arid, is, as already stated, from east to west in north India and west to east in the south. Though striking similarities are apparent in their patterns, closer examination reveals marked differences in their

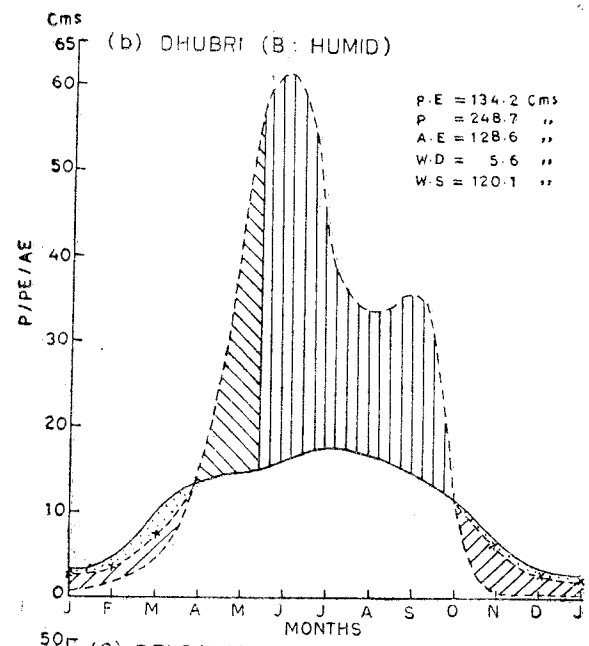
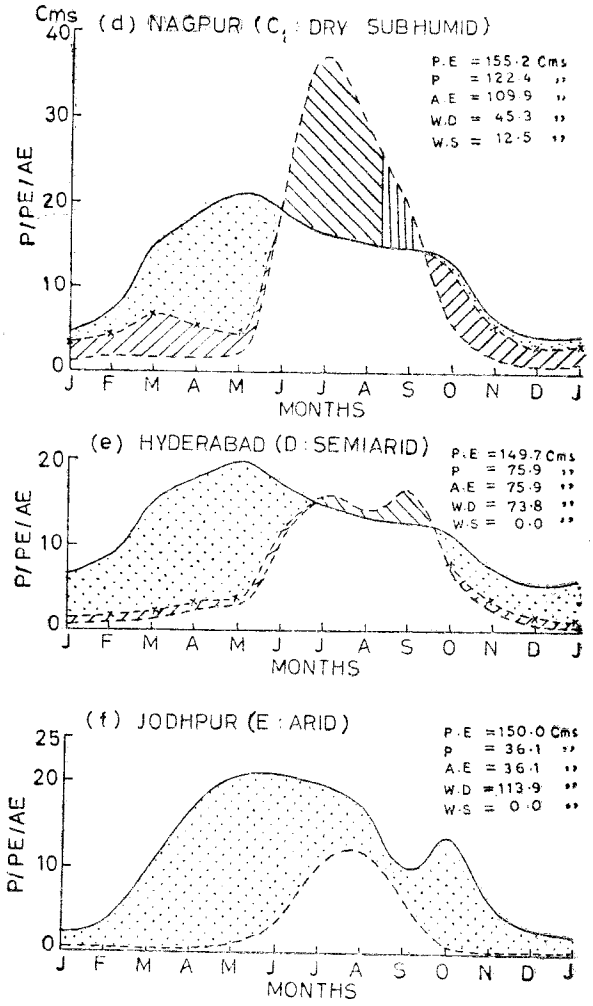


FIG.3 CONTINUED



FIG·3 CONTINUED

nature and individual characteristics.

Depending upon the terrain properties like texture, structure, geological formations and surface cover, the water surplus takes its course either through surface run-off or deep percolation to underground regions and becomes available for exploitation as ground water. Though contributions to ground water directly from the dry climates are normally absent, nevertheless in certain years, due to strong monsoonal activity or frequent occurrence of depressions and storms, the precipitation may be much greater than normal; local water surpluses do occur, for brief periods producing not only enormous surface flow resulting in

TABLE II

Elements of Water Budget In Different Climates

Station	Water need mm	Rainfall mm	Water Surplus mm	Water deficit mm	Sub-climatic type
			a) Perhumid (A)		
Darjeeling	651	3211	2562	2	r
Jalpaiguri	1359	3266	1981	74	r
Shillong	803	2150	1349	2	r
Mahabaleshwar	924	6636	5936	224	w
Mangalore	1698	3428	2163	433	w
Kodaikanal	675	1678	1003	0	r
			b) Humid (B)		
Dehradun	1175	2161	1022	106	r
Pachmarhi	1078	2021	1184	241	w
Tezpur	1838	1844	546	40	r
Ratnagiri	1640	2591	1547	596	w
Cochin	1718	3096	1605	227	w
Coonoor	783	1513	730	0	r
			c) Moist-Subhumid (C_2)		
Gauhati	1349	1612	321	58	r
Malda	1455	1541	234	148	w
Sambalpur	1549	1669	548	428	w
Pendra	1259	1374	346	231	w
Belgaum	1200	1417	518	301	w
Trivandrum	1662	1841	383	204	w
			d) Dry-Subhumid (C_1)		
Roorkee	1324	1048	0	276	d
Varanasi	1477	1039	0	438	d
Angul	1574	1292	79	361	d
Bangalore	1221	912	0	309	d
Hassan	1182	888	0	294	d
Madras	1771	1243	109	637	d
			e) Semiarid (D)		
Ludhiana	1394	691	0	703	d
Agra	1393	680	0	713	d
Ahmedabad	1708	742	0	966	d
Aurangabad	1450	719	0	731	d
Hyderabad	1522	748	0	774	d
Tiruchirapalli	1853	866	0	987	d
			f) Arid (E)		
Ganganagar	1391	260	0	1131	d
Jodhpur	1500	361	0	1139	d
Dwarka	1513	350	0	1163	d
Bellary	1700	533	0	1167	d

Where 'r' donotes no water deficiency during any part of the year
's' donotes water deficiency during summer
'w' denotes water deficiency during winter
'd' denotes no water surplus duiring any pert of the year.

severe floods but also significantly contribute to the gound water resources. Tables 2(a to f) give the water balance data for a few selected stations from different climatic zones in the Indian region. It is precisely these very aspects of water balance that play a vital role in agricultural and hydrological planning of the region. Over the hilly stations (like Mahabaleshwar and Kodaikanal) copious rainfall is the primary factor; over the nonhilly stations (e. g. Nagpur and Raipur) it is the waterneed that has a greater weight. But stations on the windward side of the mountains (Cochin, Mangalore, etc.) though not at high elevations receive high amounts of rainfall. Hence though water needs too are higher, enormous water-surpluses are produced and thus originate the perhumid (Mangalore, Kodaikanal) and humid (Calicut and Cochin) climates. As stated earlier, the lower rainfall in south India east of Western Ghats is a rain-shadow effect due to the obstruction of the southwest monsoon winds by the Western Ghats. But rainfall increases again towards the Bay of Bengal coast on the east on account of the depressions and cyclonic storms that form in the Bay and move westward or north westward. Consequently there is a development of a wide semiarid climatic zone in south India extending from the Western Ghats to the eastern coastal zone. It is only in the Coromandel region in the southeastern portion and in the northeastern section of the Peninsuta that subhumid and humid climates are found. This is because the Coromandel coastal region is influenced by the cyclones that form in the central or southern Bay of Bengal during the fall and winter seasons and move towards the west, sometimes crossing the mainland and entering the Arabian Sea to be regenerated there again. The north-eastern section of south India is influenced by the depressions that form in the head Bay and move westward or north-westward during the southwest monsoon.

In north India, on the other hand, the progress of the monsoon is from east to west and consequently it becomes weaker and weaker in its journey towards the northwest and the north. Thus climates which are initially perhumid and humid on the east gradually decrease in their molsture status to semiarid and arid as one proceeds westward. The orographic influence of the Himalayan slopes is, however, responsible for the occurrence of wet climates there.

Extreme northern sections of Kashmir again experience some precipitation during the winter season through western disturances though the southwest monsoon is practically ineffective here as a rain-producer.

Thus in the Indian region one comes across the entire spectrum of climatic types according to the moisture regime which plays a vital role in the water potentialities of the various sections of the country. Examples of these already given, show the climatic patterns on which depends the agricultural and hydrological prosperity of the nation. The cropping seasons, practices and patterns too are geared strictly to the above distribution of climatic types but the water balance approach discussed herein has led to a rational and objective planning of the agricultural practices and operations in respect of crop distribution as well as irrigation scheduling.

Water balance studies have also provided a rational understanding and realistic assessment of water resources, both surficial and underground (Subrahmanyam, Subba Rao and Murty, 1970). For example, water balance investigations for the entire peninsular region show that ground water potential of the semiarid region of south India is not certainly on account of water surpluses occuring directly over the territory itself, but from the eastern flanks of the Western Ghats where water surpluses exist. They belong to the perhumid and humid climates in these sections where enormous water surpluses accumulate both seasonlly as well as annually and are mainly responsible for

TABLE III
Water Surpluses in the Peninsular Region

Station	Water surplus (mm)
Mahabaleshwar	5936
Mercara	2370
Belehonnur	1675
Kodaikanal	1001

the maintenance of the ground water reserves of the semiarid region of Deccan. It is for this reason that the head-waters of the major river systems of Peninsular India, namely the Godavari, the Krishna and the Kaveri are situated on the Western Ghats alone, although they have long courses through the semiarid region of the central Deccan. For the same reason the main tributaries of these rivers too have their origin in the water surplus zones of the Western Ghats while the others that join the main rivers enroute, are highly seasonal and practically go dry in the non-rainy season, The declining water surpluses from the Western Ghats eastward can be seen from the following Table III.

Climates capable of yielding significant water surpluses exist also in the north and the northeast as well as in the Vindhyan region. The tributaries of the Mahanadi river system and the Narmada and Tapati systems respectively originate from the above surplus regions,

In connection with the development of water resources it is very essential to know the susceptibility of individual regions to the occurrence of droughts of different intensities and durations. In this respect again water balance concepts have provided new indices and rational approaches. Drought climatology, as this emerging field is called, concerns itself with such diverse aspects as identification, intensity and frequencies of occurrence of droughts of various categories, climatic shifts following wide fluctuations in the moisture regime of climate, water balances in years of extreme climatic shifts and the so called spread or shrinkage of droughts which is assuming vital importance in the content of desertification and drought area planning.

It may thus be seen that India, inspite of its geographical location in the tropical and sub-tropical latitudes experiencing monsoonal regime of climate has all the climatic types and sub-types of the moisture regime. Though this latter aspect is neither unusual nor unique, still the wide spectrum of climatic types originating due to the culmination of a variety of geographical and meteorological causes requires special techniques of conservation and utilisation of available water resources. In the perhumid climates where enormous water surpluses produce frequent floods and waterlogging of the soil, finding efficient means of drainage is a problem. On the other hand, in the arid climates where there is meagre and occasional rainfall, efficient growth and development of crops need adequate amounts of water for supplemental irrigation. In the sub-humid climates whose water balances are critical because of rapid and wide fluctuations in precipitation, agricultural and hydrological planning is fraught with several risks. It is only a scientific approach to the estimation of the magnitude and durations of water deficits and water surpluses that enables us to plan water use efficiently and rationally.

Tne water balance approach presented in this paper can thus be seen to serve as a powerful tool for water-use planning not

only in wet climates but also in dry climates. Since this is a computational procedure involving only rainfall and temperature, it may be regarded as a very convenient and useful method for direct application to practical problems in all fields in which water balance plays any role.

References

Carter, D. B. and *Mather, J. R.* (1966) : Climatic Classification For Environmental Biology, *Publications in Climatology, 19 (4) : 342.*

Flohn, H., (1960) : Monsoon Winds and Ceneral Circulation, Proc. *Internat. Symp. on Monsoon of the World, (IUGG and WMO)*, February 1958, New Delhi : 65–74.

Koppen, W., (1900) : Versuch eimer Klassifikation der Klimate, vorzugsweise nah ihren Bezichungen Zur pflanzenwelt, *Geogr. Zeitschr., 6, :* 593-611 and 657-679.

Koteswaram, P., (1156) : Easterly Jet Stream in the Tropics, *Res. Report Met. Dept. Univ. Chicago : 1–23.*

Koteswaram, P., (1960) : The Asian Summer Monsoon and the General Circulation over the Tropics, *Proc. Internat. Symp. on Monsoons of the World (IUGG and WMO)* February 1958, New Delhi.

Subrahmanyam, V. P, Subbarao, B. and *Murty, Ch. V. S. N.* (1970) : Water Balance of the Godavary River Basin, *Jour. Instn. Engrs (India)* 50 (1) 108-114.

Thornthwaite C. W. (1948) : An approach towards a Rational Classification of Climate, *Geogr. Rev. 38 (1) :* 55-94.

Thornthwaite, C. W. and *Mather, J. R*, (1955) : The water Balance *Publications in Clim.* (Lab. of Clim. Centerton NJ), 8 (I) 1-104.

Address of the authors

Prof. V. P. Subrahmanyam, Dept. of Meteorology and Oceanography, Andhra University, Waltair, A. p., India.

Dr. A. A. L. N. Sarma, Dept. of Meteorology and Oceanography, Andhra University, Waltair, A. P., India.