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Geographical distribution of physioclimatic regimes over India

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ABSTRACT. Utilising monthly normals of daily maximum and minimum temperature and their corresponding relative humidity for 223 stations distributed over India, Comfort Indices CS (Annual Cummulative Stress), PCS (Proportional Cumulative Stress), APR (Annual Physioclimatic Regime) have been computed and the geographical classification of physioclimatic regimes over India on the basis of the above comfort indices has been discussed. The practical utility of the classification has also been mentioned.

1. Introduction

Man exists in a climatic environment that directly affects his body and its functions. Healthy functioning of the human body and maintenance of the body temperature calls for a balance between heat loss and heat gain. Thermal load on the body is a function of number of interacting variables, mostly meteorological. To classify different climatic environments, a number of theoretical and empirical indices, incorporating weather parameters like temperature, humidity, wind, radiation etc have been developed (Terjung 1967, Gregroczy 1968, Steadman 1979, etc). These indices, by and large, reflect the responses of man and assess the physiological strain imposed by the meteorological parameters on the human body. In this paper geographical distribution of physiological effects of weather factors has been discussed. The present study confines itself to the effects of temperature and humidity and is based on the technique devised by Terjung (1967). It may be mentioned that a few studies on this subject have been made earlier in India with reference to selected locations (Swaminathan and Venkiteshwaran 1967, Garg 1974, Raman and Rangarajan 1974, etc).

2. Data material

In this study monthly normal data of 223 stations well distributed over the country have been utilised. The data have been collected from the *Climatological Tables of Observatories* (1931-60) published by the India Met. Dep. The basic elements used are mean daily maximum temperature (representing day time conditions), mean daily minimum temperature (representing night time conditions) and the corresponding relative humidity.

3. Effective temperature

Effective temperature is widely used to establish thermal responses to a human body by equating prevailing conditions with a standard set. The standard is generally obtained from the effect of still saturated air at given temperature. As a first approximation the effective temperature (E_t) can be derived from the formula:

$$E_t = 0.4\ (T_d + T_w) + 15$$

where T_d and T_w are respectively dry and wet bulb temperatures.

Munn (1970) prepared a nomogram for calculating effective temperature for sedantary, normally clothed individuals from dry and wet bulb temperatures and the wind speed. The isolines in the nomogram become too crowded for temperatures beyond 85 deg. F. And it is a well known fact that in a tropical country like India, temperatures round the year (except at the height of winter) are always above 85 deg. F. As such psychrometric chart prepared by ASHRAE (1961), as shown in Fig. 1 has been used.

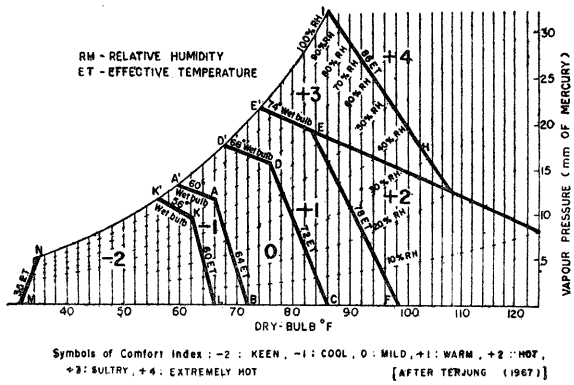

Fig. 1. Psychrometric chart

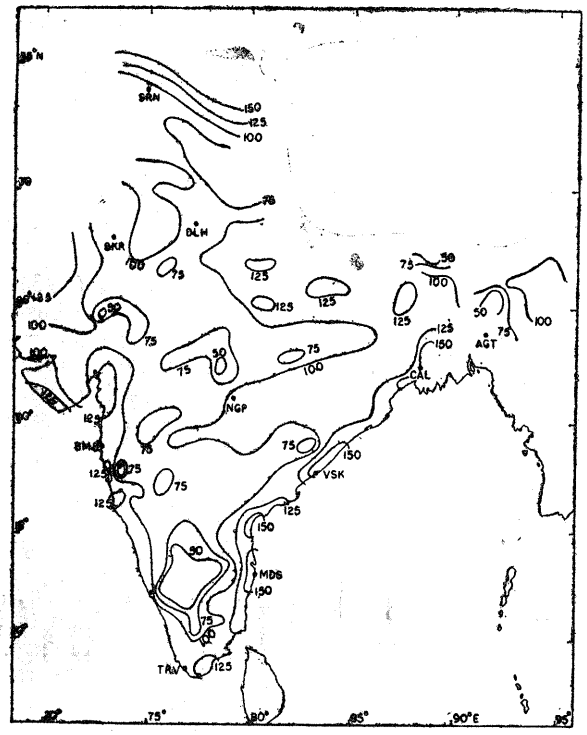

Fig. 2. Annual Cumulative Stress (CS)

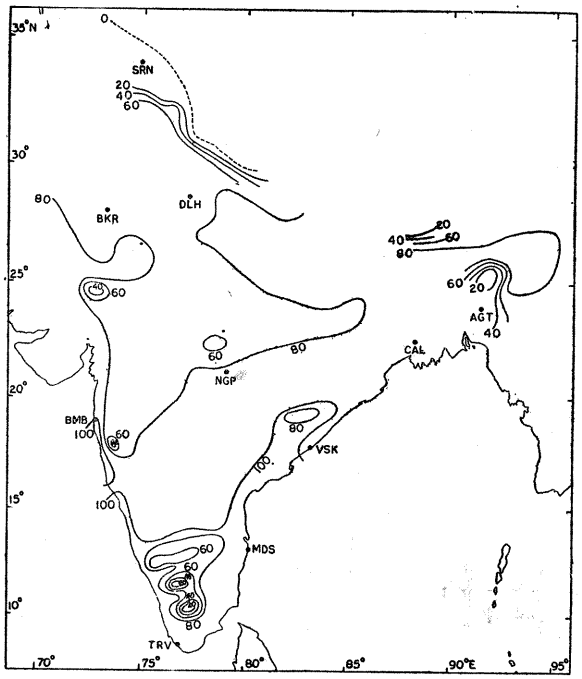

Fig. 3. Proportional Cumulative Stress (PCS)

4. Comfort index

A system of categories of comfort based on dry and wet bulb temperature and relative humidity is given in Fig. 1. The division is, of course, subjective and has been obtained after a series of researches in the field of human comfort. The positive zones denote different degrees of discomfort due to warmth and the negative due to cold. Comfort zone 0 refers to a sort of thermal neutrality. Since the temperatures in the pre-monsoon months normally exceed 110 deg. F over India, comfort zones beyond 110 deg. F have been obtained by extrapolation.

As has been stated earlier, to derive a monthly comfort index mean daily maximum/minimum temperatures in place of dry/wet bulb temperatures and the corresponding relative humidity have been used. For instance for any month, the day-time comfort index is determined as we go vertically up along the maximum temperature line and the point at which the maximum temperature line intersects the corresponding relative humidity curve is noted. The comfort zone in which this point falls is noted. This is the day-time comfort index for the month. Similarly the night-time index can also be determined. Day and night indices are combined to give a single comfort index. Classification for the comfort index is shown in Table 1. It may be mentioned that in none of the cases examined, did the day-time and night-time indices exceed beyond +4

TABLE 1

Day and night combination of comfort index

Extremely hot	Sultry	Hot	Warm	Mild	Cool	Keen
$+4/+3=EH_1$	$+3/+3=S_1$	$+2/+2=H_1$	$+1/+1=W_1$	$0/0=M_1$	$-1/-1=C_1$	$-2/-2=K_1$
$+4/+2=EH_2$	$+3/+2=S_2$	$+2/+1=H_2$	$+1/0=W_2$	$0/-1=M_2$	$-1/-2=C_2$	$-2/-3=K_2$
$+4/+1=EH_3$	$+3/+1=S_3$	$+2/0=H_3$	$+1/-1=W_3$	$0/-2=M_3$	$-1/-3=C_3$	$-2/-4=K_3$
etc	etc	etc	etc	etc	etc	etc

Source : Terjung, Physiologic Climates of the Conterminous United States.

Note : Capital letter(s) indicates day condition; subscript indicates diurnal variability. First numeral refers to day-time conditions, second numeral to night-time conditions.

and —2 respectively. Hence the categorisation of climates was terminated at the "Keen" on the colder continuum and extremely hot at the hotter end of the continuum.

The comfort indices used in determining human comforts are:

(*i*) Annual Cumulative Stress (CS),

(*ii*) Proportional Cumulative Stress (PCS), and

(*iii*) Annual Physioclimatic Regime (APR).

Spatial distribution of these indices is discussed below.

5. Annual cumulative stress

The annual cumulative stress is given by the expression:

$$CS = \sum_{1}^{12} (D^2 + N^2)$$

where, D and N are respectively the numericals representing day-time and night-time comfort indices. The annual CS for a given station is nothing but the sum of CS values for all the 12 months. Squares of D and N have been used because the physiological stress resulting from climatic stress appears to approach exponentially-shaped curves of intensity. CS index provides only a rough measure of relative stress whether the cumulative stress is due to heat, cold or a combination of both. Since it is centred on a comfort zone (O in the Comfort Index nomogram), the index also provides a measure of temperateness in relation to that zone. The results were plotted and isolines of the annual CS drawn and depicted in Fig. 2. The interval of drawing of isolines was arbitrarily chosen at CS value of 25.

The alignment of isolines is rather striking. Coastal areas both in east and west, appear to have CS values exceeding 100. Values of this magnitude can also be seen over extreme west Rajasthan. Kashmir valley, most parts of Peninsular India, hilly terrain of Assam also assumes CS values of about 100.

The configuration over the Peninsula is rather complex with lower stress values in the mountainous region around Mahabaleswar, Mount Abu, Pachmarhi and central Karnataka and adjoining Nilgiri and Palni hills, while the east coastal strip north of 15 deg. N and Ladakh region have the highest stress. For example, Mt. Abu has the lowest CS of 30 while Kalingapatnam on the Andhra coast has CS value of 160. High values in Ladakh result from the oppressive conditions in winter. Karnataka's low value, is mainly due to its rather mild winters and transitional seasons. The same reasoning may also apply to low CS values observed in isolated pockets in and around Bhopal-Pachmarhi, Pendra, Koraput and parts of Madhya Maharashtra. The configuration largely dispels the common belief that mild climates are found mainly in the coastal areas and that all high elevated regions are congenial as health resorts.

6. Proportional Cumulative Stress (PCS)

One of the shortcomings of CS index is that it cannot show the constituent factor which caused a particular value — heat or cold, or both. To overcome this lacuna, an additional cumulative stress (PCS) which is given by the index has been introduced called the proportional following expression :

$$PCS = 100 \sum_{1}^{12} (D_h^2 + N_h^2) / \sum_{1}^{12} CS$$

In deriving this expression, values of D and N which are zero or negative are discarded. Thus, in the above expression the suffix h is the heat stress in the comfort index. It may be mentioned that a high PCS value need not necessarily denote a high CS value. A value of PCS, *say* 30 would mean that 30 per cent of the stress is caused by heat and, therefore, the remaining 70 per cent by the cold. A value of 100 would indicate that the stress that is caused is entirly due to heat while a value of zero suggests just the opposite. Geographical distribution of this index has been depicted in Fig. 3.

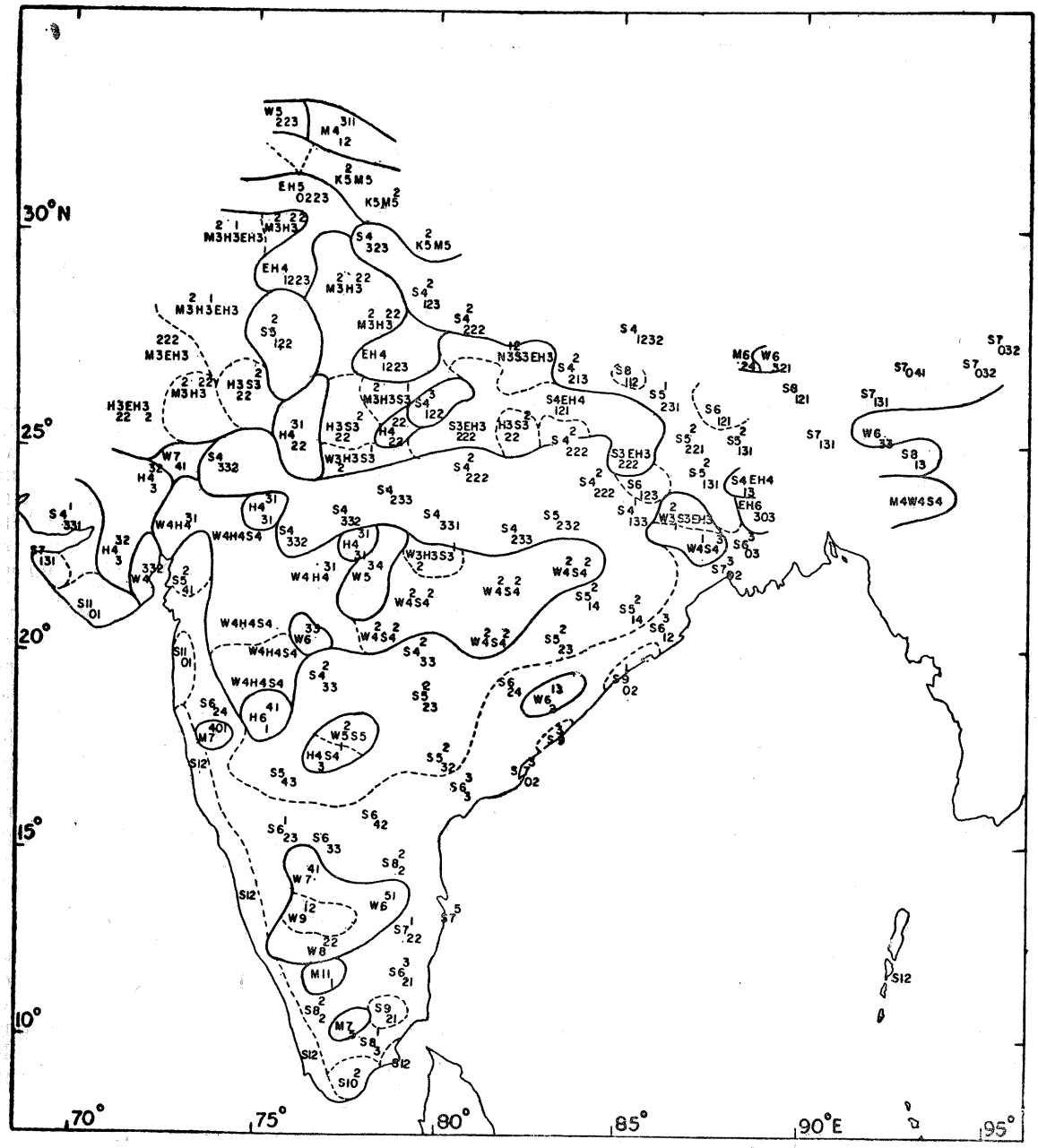

Fig. 4. Symbolic representation of dominant/transitional regime

The high altitude locations, Jammu & Kashmir, Himachal Pradesh, hills of west Uttar Pradesh, Sub-Himalayan West Bengal, Mt. Abu and hill stations of Peninsula, have PCS values lower than 40 (sometimes as low as zero). The stress over these areas is entirely caused by cold. Over the rest of the country, the pattern of PCS is generally identical to that of CS. Thus, over the most parts of the country, like any tropical country, most of the physiological strain is caused by heat and accounts for nearly 80 per cent of the stress. In fact, in coastal areas south of 20 deg. N in both east and west, the only stress that is caused is due to heat. In Tamilnadu even the interior areas have PCS values as high as 100. Vast areas of the country have

large PCS values indicating that cold is not a real problem except for brief periods, and that major environmental stress is derived from heat. Large parts of Gujarat and west Rajasthan which is mostly arid, carry the connotation of 'hot' desert, their CS forming a substantial part (80 to 90 per cent) of PCS, unlike coastal areas, where cold hardly causes any stress.

The application of the above system over India results in three basic belts: those owing their CS entirely due to heat, those owing it entirely to cold and the transitional belt due to both the influences. In the third category, the transitional climate is analogous to 'mid-latitude climate'.

7. Annual Physioclimatic Regime (APR)

The PCS index divides the total stress into heat and cold components and the CS only measures the degree of comparativeness. Both these indices take into account night-time conditions as well. It is well known that, by and large, the nights except for a few isolated cases observed at the height of the summer season, are cool and comfortable over India as a whole.

In the present study an index has been evolved out for day-time conditions only. This enables us to identify and quantify different types and also affords a measure of the amplitude of the annual variability. It may be mentioned that in a realistic study of the stress, the wind effect should also be taken into consideration. The expression for APR is given by

$$\text{ARP} = \sum_{1}^{12} C_{ID}$$

where C_{ID} is the mean monthly day-time index.

A high value of the index would imply uncomfortable day while low or negative would suggest that during the day, conditions are congenial. The pattern for APR (Fig. 5) appears somewhat similar to PCS particularly in coastal areas, Jammu & Kashmir and Assam. APR values are zero or negative over hills of Uttar Pradesh, Himachal Pradesh, Kashmir, Sub-Himalayan West Bengal. The lowest minimum value was observed in Ladakh (APR is equal to —16. The values ranged between —8 to —10 in the hills of west Uttar Pradesh and Himachal Pradesh and in the hilly terrain of Sub-Himalayan West Bengal. This suggests that in these areas even day-time conditions cause some stress particularly during winter months. Large values of these index in the range of 30-40 are observed over the west coast. Values over the extreme west Rajasthan, in the core of the Thar desert around Jaisalmer, are also large. Small cells around Pendra and Jaipur, hilly areas

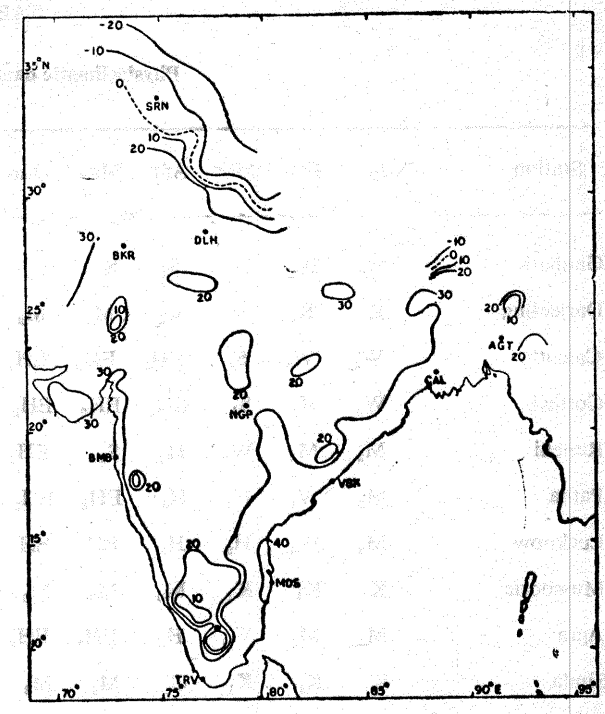

Fig. 5. Annual Physioclimatic Regimes (APR)

around Mt. Abu, Mahabaleshwar and Coonoor-Kodaikanal (Palni hills) show low values, *i.e.*, less than 20. Values of this magnitude are also observed in south Interior Karnataka.

Apart from the above analysis based on the absolute value of APR, making use of the monthly distribution of this index, the space has been divided into two broad types of climate:

(*i*) Dominant type where one type occurs more frequently than the others.

(*ii*) Transitional or intermediate type where no type is predominant.

The climates that constitute dominant type are extremely hot (EH), sultry (S), hot (H), warm (W), mild (M), cool (C) and keen (K) depending upon the physioclimatic type of the dominant month. Each of the dominant types is further subdivided as per the arrangement and number of other types. One can therefore have a type dominating all the 12 months (*e.g.*, all 12 months being sultry) or a type where two different physioclimates occur each for 6 months indicating beginning of intermediate type.

A similar classification can be done for the intermediate type. To represent the above in a symbolic form, a set of alphabets, numerals, subscript and super-script have been introduced. First a spectrum of hot or cold is developed, for example EH - S - H - W - M - C - K. Secondly, super-scripts are considered as the warmer type

TABLE 2

Physioclimatic data for selected stations

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	CS	PCS	APR
Gauhati	M_3	W_4	H_5	S_4	S_4	S_3	S_3	S_3	S_3	S_4	W_3	W_4	91	81	$S7_{131}$
Darjeeling	K_1	K_1	K_1	C_2	M_3	M_2	M_2	M_2	M_3	M_3	C_2	K_1	57	00	$M6_{24}$
Calcutta	W_4	W_3	S_4	EH_3	EH_3	EH_1	S_1	S_1	S_1	S_3	S_5	W_4	154	93	$S6^3{}_{03}$
Cuttack	W_3	H_3	S_4	EH_3	EH_3	EH_3	S_3	S_3	S_3	S_3	S_4	W_4	120	96	$S6^3{}_{12}$
Ranchi	M_3	M_3	W_4	H_3	S_4	EH_4	S_3	S_3	S_4	W_3	W_4	M_3	82	74	$S4^1{}_{133}$
Patna	M_3	W_4	H_4	H_3	EH_3	EH_3	EH_1	S_1	S_3	S_4	W_4	M_3	123	86	$S3EH3_{222}$
Lucknow	M_3	W_4	H_5	H_3	EH_3	EH_3	EH_1	S_1	S_3	S_4	W_4	M_3	126	84	$S3EH3_{222}$
Mussoorie	K_1	K_1	K_1	M_3	M_3	M_3	W_3	W_3	M_3	M_3	K_1	K_1	64	03	$K5°M5^2$
Agra	M_3	M_3	W_4	H_3	EH_4	EH_3	EH_3	EH_3	S_3	H_4	W_4	M_3	108	81	$EH4_{1223}$
Simla	K_1	K_1	K_1	C_2	M_3	M_3	M_2	M_2	M_3	C_2	K_1	K_1	64	00	$K5^2M5$
Ambala	M_3	M_3	W_4	H_4	H_3	EH_3	EH_3	EH_3	EH_3	H_5	W_4	M_3	107	77	$EH4_{0323}$
New Delhi	M_3	M_3	W_4	H_3	H_3	EH_3	EH_3	S_3	S_4	H_4	W_4	M_3	88	76	$M3^2H3^{22}$
Srinagar	K_2	K_2	K_1	C_2	M_3	W_4	H_4	W_3	W_4	M_3	K_2	K_2	90	08	$K5^{1231}$
Bikaner	M_3	M_3	W_4	H_3	H_2	EH_3	EH_3	EH_3	S_3	H_4	W_4	M_3	97	78	$M3^2H3^1EH3$
Jaipur	M_3	M_3	W_4	H_4	H_3	S_3	S_3	S_3	S_4	H_4	W_4	M_3	75	71	$S4_{323}$
Bhopal	M_3	W_4	W_4	H_3	H_3	S_4	S_3	S_3	S_4	H_4	W_4	M_3	74	72	$S4_{332}$
Ahmedabad	W_4	W_4	H_4	H_3	H_2	EH_1	S_1	S_3	S_3	H_3	W_4	W_4	101	83	$W4H4^{31}$
Bhuj	M_3	W_4	H_4	H_3	S_3	EH_3	S_3	S_3	S_3	H_3	W_4	W_4	89	81	$S4^1{}_{331}$
Bombay	H_3	S_4	S_4	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_4	S_4	110	100	$S11_1$
Goa	S_4	S_4	S_4	S_3	S_3	S_3	S_3	S_3	S_3	S_3	S_4	S_4	115	100	S12
Aurangabad	W_4	W_4	H_4	H_3	H_3	S_4	S_4	S_4	S_4	H_3	W_4	W_4	73	77	W4H4S4
Nizamabad	W_4	H_4	H_3	H_3	S_3	S_3	S_3	S_3	S_3	S_4	W_4	W_4	87	85	$S6_{33}$
Hyderabad	W_4	W_4	H_3	H_3	S_3	S_4	S_3	S_3	S_4	S_4	W_4	W_4	85	81	$S6_{24}$
Madras	S_4	S_4	S_4	EH_3	EH_3	EH_3	EH_3	EH_3	S_3	S_3	S_3	S_4	151	100	$S7^5$
Gulbarga	W_4	H_4	H_3	H_3	EH_3	S_4	S_4	S_4	S_4	H_3	W_3	W_4	82	88	$H4_3S4^1$
Bangalore	W_4	W_4	W_3	H_3	H_3	H_3	W_2	W_2	W_2	W_2	W_3	W_4	35	60	$W9^3$
Mercara	M_3	W_4	W_3	S_4	W_2	W_2	M_1	M_1	W_2	W_2	M_2	M_3	29	52	$W6_5{}^{01}$
Gauhati Airport	M_3	W_4	H_5	S_4	S_4	S_3	S_3	S_3	S_3	S_4	S_5	W_4	99	83	$S8_{121}$
Ferozpore	C_2	M_3	W_4	H_4	S_4	EH_3	EH_3	EH_3	S_4	H_4	W_4	M_3	102	77	$EH3_{22221}$
Nagpur	W_4	W_4	H_4	H_3	EH_3	EH_3	S_3	S_3	S_3	S_4	W_4	W_4	102	83	$W4^2S4^2$
Anantapur	W_3	H_4	H_3	H_2	S_3	S_4	S_4	S_4	S_4	S_4	W_2	W_3	74	96	$S6_{33}$

month and sub-scripts the colder type in comparison with the dominant months. The sequence and arrangement of numerals and alphabets indicates position in the warm/cold sequence, the number succeeding the alphabet denotes number of months that particular type has occurred.

Thus, for instance a location experiencing 6 months of a dominant climate of type, warm (W), one month of H, 3 of S and 2 months of type M will appear as $W6_2^{13}$. When there is no continuous sequence in the APR region, 0 is substituted for the gap. For example the symbol $W6^{01}_{5}$ represents 6 warm months, no hot month, one sultry month on the warmer side and 5 months of mild type. Location having all the 12 months as warm would be denoted by W12.

The intermediate type is also treated in the same way. In the sequence the colder type month comes first. For example, 3 months of sultry, 3 months hot and 3 months mild with 2 warm months and one month EH would appear as M^23H3S3^1.

The symbolic representation of the types is depicted in Fig. 4. For a few selected stations this is presented in Table 2. One of the most striking features observed is the vast expanse of a large variety of the S regime (extremely sultry type in the coastal belts to lightly sultry in the interior). The "core regime" with all 12 months displaying a single physioclimate occurs only in case of sultry type in the west coast. Because of large areas occupied by S type, it has been further sub-divided by dotted lines.

It may be emphasised that the number of months a dominant type occurs is inversely proportional to the 'noise' introduced in the system; less number of 'dominant months' would create more 'noise'. This means that the set becomes less of a pure type, *i.e.*, it introduces more of sub-script and super-scripts. In other words it approaches the intermediate type. For example a $W7_{41}$ (in Mt. Abu) is quite different from $K6^{13}_{2}$ (Koraput in Orissa). In Koraput the type contains 2 months of mild conditions, one hot month and three months of sultry conditions whereas at Mt. Abu, it contains 4 of mild and one month of cold conditions and no months have hot or sultry type.

The annual amplitude is a function of super-script and sub-scripts; the larger the number of digits in these two attributes, the more is the annual variability of the APR. In the extremely hot regime in Punjab and Haryana and UP, the annual amplitude appears large. In the north-east Madhya Pradesh (*i.e.*, Jabalpur, Satna, Mandla-Umaria) and parts of Bihar Plateau, northern parts of UP also exhibit large amplitude. Over large areas, the S regime appears less variable. Similarly other dominant regimes, wherever they occur, have low annual variability.

Whereas dual intermediate type (equal number of months in two types) with warm and sultry conditions prevail in central parts, the triple type, M, S, EH is seen over NW Rajasthan and central UP; M, H, S being around Aligarh and Lucknow, Gonda and Varanasi, W, S, EH near Purulia and M, W, S around Agartala.

8. Conclusion

The classification made above has a number of applications, chief among them being :

(*i*) It is of great value in medical geography for specifying areas ideal for habitation of persons suffering from weather-related diseases.

(*ii*) It provides a realistic guide for tourists.

(*iii*) It simplifies knowledge regarding housing needs, internal heating requirements for identified regions.

(*iv*) It provides a useful guide in estimating the climatic potential of a region.

The above analysis enables us to divide the country into 6 broad and dominant climatic regimes, *viz.*, extremely hot, sultry, hot, warm, mild and keen. Thus practically for the country as a whole, the classification is towards the warmer end. This gives rise to a large variety among many sub-types. Among them, west coast islands in the Arabian Sea and Bay of Bengal exhibit extremeness in the sultry-type. Mediterranean type with the basic regime of K occurs only in Kashmir and M around Mahabaleshwar, Ootacamund, Kodaikanal and Darjeeling.

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