Revisiting climatic classification in India: a district-level analysis

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Often geographical boundaries of the climatic zones identified differ from the administrative boundaries. Eventually planners and administrators are unable to use these classifications while formulating new developmental programmes. Though few studies attempted to bring the climatic classification to district level in the past, the climatic datasets used in such studies were found to be relatively old. Climate change literature pertaining to India showed evidence of rising mean temperatures during post-1970 period. The temperature rise affects potential evapotranspiration and consequently the aridity is expected to increase at least at macro level though there may be spatial variation at a smaller geographical scale. In the present study, an attempt has been made to assess the climate at district level using latest data and examine climatic shift occurred, if any, as compared to the climatic classification given by Krishnan in 1988. The study used 0.5° × 0.5° grid level rainfall data and average potential evapotranspiration for 144 stations located across India to compute moisture index needed for delineation of different climatic zones. Both datasets refer to the period 1971–2005. Significant reflections resulting from the study indicated a substantial increase of arid region in Gujarat and, a decrease of arid region in Haryana. Other notable observations included the increase in semi-arid region in Madhya Pradesh, Tamil Nadu and Uttar Pradesh due to shift of climate from dry sub-humid to semi-arid. Likewise, the moist sub-humid pockets in Chhattisgarh, Orissa, Jharkhand, Madhya Pradesh and Maharashtra states have turned dry sub-humid to a larger extent. Updated climatic classification of this sort at district level shall be useful to various stakeholders for agricultural planning, assessment of water demand by different sectors, drought preparedness, assessment of climate driven pests/diseases in humans, crops and livestock, etc.

Keywords: Climate change, climatic classification, district, moisture index.

CLIMATE being a key driver for choice of crops in a region, delineation of homogenous climatic zones has always received thrust. It paves way for identifying potential productivity zones for various crops. Subrahmanyam *et al.*[1], Rao *et al.*[2] and Bhattacharjee *et al.*[3] delineated climatic zones of India using Thornthwaite and Mather[4] approach. However, planners and administrators are unable to use these classifications while formulating new developmental programmes as geographical boundaries of the climatic zones identified differ from the administrative boundaries and datasets used in these studies are quite old. The Planning Commission of India had emphasized the need for district-level plans and the district is the focal unit for several development schemes in the XII Five Year Plan. Though the study by Krishnan[5] brought the climatic classification to district level, climatic datasets used are old (not later than 1970). The classification was based on moisture index of Thornthwaite and Mather[4], computed using average annual data of rainfall and potential evapotranspiration (PE). The climatic classification used by the Ministry of Rural Development (MoRD)[6] in reviewing districts' eligibility to Drought Prone Area Programme (DPAP) and Desert Development Programme (DDP) in 1994, largely coincides with the one given by Krishnan[5]. Gore *et al.*[7] identified the districts where aridity was increasing, comparing the two periods between 1901–1950 and 1941–1990. The study was confined to arid, semi-arid and dry sub-humid districts only. The climatic datasets used are relatively old (rainfall up to 1990 and PE data published in 1971).

Climate change literature pertaining to India shows enough evidence of rising mean temperatures during post-1970 period. Krishna Kumar *et al.*[8] observed greater warming (mean annual surface air temperature) of 0.21°C/10 years during post-1970 period as compared to 0.51°C/100 years during the past century. On the other hand, all-India average monsoon rainfall is found trendless over an extended period starting from the year 1871, though significant spatial variations are found at division level. At macro level (country), rising temperature along with no significant trend in monsoon rainfall may cause aridity to rise. However, if we examine at smaller geographical scale such as district, there may be different trends in few districts. In view of this, a need was felt for revisiting district-level climatic classification using latest available climatic datasets.

Daily rainfall data for the period 1971–2005 published by Rajeevan and Bhate[9] at a spatial resolution of 0.5° × 0.5° grid have been used in the study. Data of about 6000 raingauge stations spread all over the country were used in developing it. PE data referred to the period 1971–2005 published by IMD[10] for fairly distributed 144 locations in India have been used in the study. It was computed using FAO[11]-recommended Penman–Monteith equation. Average of annual rainfall was computed for each grid point within the national boundary. The influential area of a grid point was computed using Thiessen polygon method in a Geographic Information System (GIS) environment. Further, area of different polygons lying in a district was also derived. Rainfall value at dis-

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trict level was estimated using the weighted average of rainfall, with weights proportional to area of polygons lying within that district. As the data of PE for 144 stations were provided as annual average (1971–2005), they were directly brought to GIS environment using their latitude and longitude values. Spatial variability in PE being low, PE values for regular grid of $0.5° \times 0.5°$ were estimated from 144 stations' data using inverse distance weighting interpolation method. The PE values at district level were estimated using area weighted average. The rainfall and PE values derived for each district as above were put into the formula of moisture index given by Thornthwaite and Mather[4] and simplified by Venkataraman and Krishnan[12] using annual averages as shown below:

$$\mathrm{MI} = \left[\frac{(\mathrm{P} - \mathrm{PE})}{\mathrm{PE}}\right] \times 100,$$

where MI is the moisture index, P the average annual rainfall and PE is the average annual potential evapotranspiration.

Further, the climate prevailing in each district during the study period was assessed as following:

Value of MI	Climatic zone
< –66.7	Arid
–66.6 to –33.3	Semi-arid
–33.3 to 0	Dry sub-humid
0 to + 20	Moist sub-humid
+20.1 to + 99.9	Humid
100 or more	Per-humid

Inter-district variation in annual rainfall in the country can be seen in Figure 1. The rainfall is least (< 500 mm) in a majority districts of Rajasthan, and a few districts in Gujarat, Punjab and Haryana. In the districts adjoining these districts and in a number of districts spread across Maharashtra, Karnataka, Andhra Pradesh, the rainfall is between 500 and 750 mm. Most parts of eastern India and most parts of Himachal Pradesh and Uttarakhand receive an annual rainfall ranging from 1000 to 1500 mm. Figure 2 depicts spatial variation in PE. PE was found to exceed 1750 mm in western Rajasthan, larger parts of Gujarat and Tamil Nadu and over parts in Maharashtra, Andhra Pradesh, Madhya Pradesh and Karnataka. In most of the northern, north-eastern and eastern districts, the PE ranged from 1000 to 1500 mm. The PE was less than 1000 mm in some districts of Jammu and Kashmir.

Figure 3 depicts the climatic zones delineated by the authors with district as a unit of study. The climatic shifts which occurred in the districts as compared to the climatic classification given by Krishnan[5] are furnished in Table 1. It revealed climatic shift in about 27% of the geographical area in the country. A substantial increase of aridity was well evident in Gujarat, as the climate of districts, viz. Patan, Porbandar, Amreli and Bhavanagar changed to arid from semi-arid. Arid zone as a whole decreased in Haryana as Sonipat, Rohtak, Jhajjar,

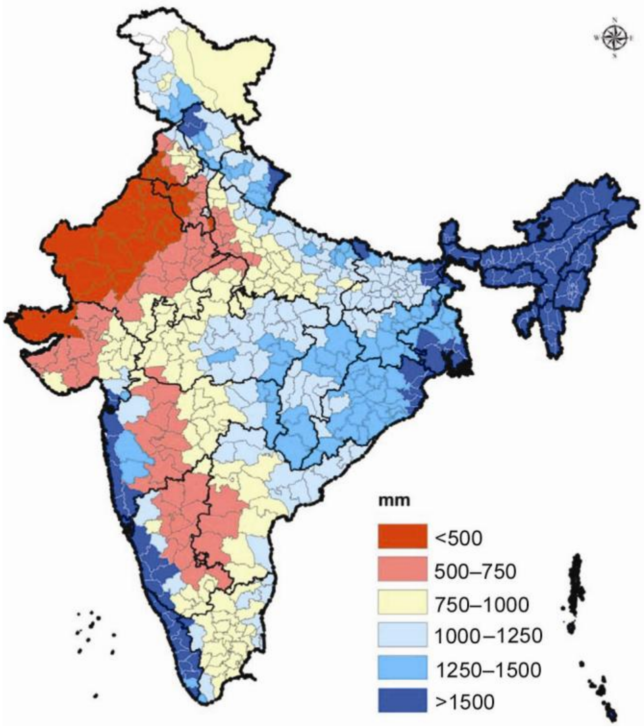

Figure 1. Estimated district-level annual rainfall in mm (based on $0.5° \times 0.5°$ grid data for 1971–2005).

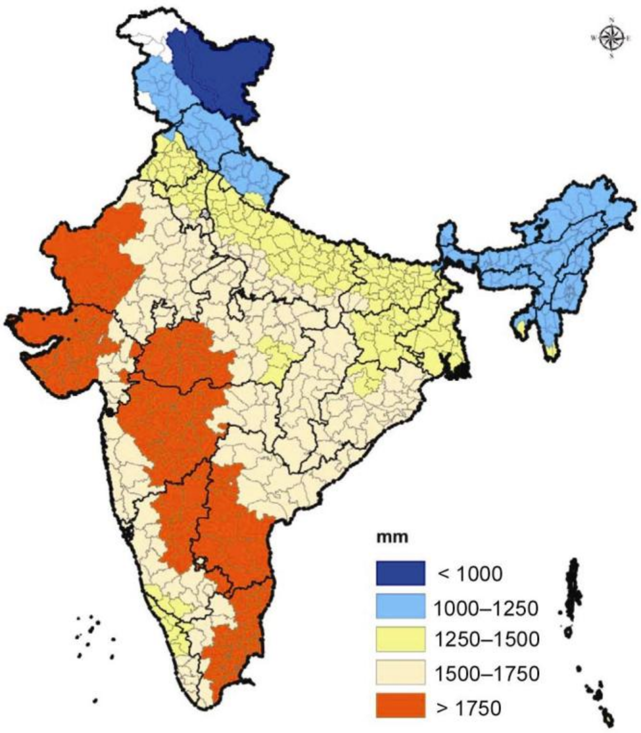

Figure 2. Estimated district level annual potential evapotranspiration in mm (1971–2005).

Table 1. Climatic shifts in different districts along with per cent geographical area

Shift from	Districts	Geographical area (%)
Arid to semi-arid	Moga, Sonipat, Rohtak, Jhajjar, Rewari, Gurgaon, Raichur, Bellary	0.87
Arid to dry sub-humid	Ladakh	1.43
Arid to moist sub-humid	Kargil	0.44
Semi-arid to arid	Jind, Ajmer, Patan, Porbandar, Amreli, Bhavanagar	1.16
Semi-arid to dry sub-humid	Una, Hoshiarpur, Shahid Bhagat Singh Nagar, Rupnagar, Jaunpur, Nalanda, Patna, Pune, Satara, Adilabad, Khammam, Coimbatore	2.64
Semi-arid to moist sub-humid	Chikmagalur	0.23
Semi-arid to humid	Kolhapur, Shimoga, The Nilgiris	0.59
Dry Sub-humid to semi-arid	J.B. Phule Nagar, Lucknow, Ghazipur, Sant Ravidas Nagar, Buxar, Guna, Tikamgarh, Rajgarh, Vidisha, Bhopal, Sehore, Betul, Harda, Daman and Diu, Wardha, Thiruvallur, Kancheepuram, Villupuram, Cuddalore, Nagapattinam, Thiruvarur, Thanjavur, Puducherry	3.07
Dry sub-humid to moist sub-humid	Anantnag, Maharajganj, Birbhum, Burdwan, Bankura, Pakur, Dumka	1.06
Dry sub-humid to humid	Valasad, Dadra and Nagar Haveli	0.11
Moist sub-humid to dry sub-humid	Champaran East, Madhepura, Saharsa, Ranchi, Gumla, West Singbhum, East Singbhum, Baragarh, Jharsuguda, Sambalpur, Deogarh, Sundargarh, Kendujhar, Jagatsingpur, Cuttack, Kandhamal, Rayagada, Koraput, Malkangiri, Koriya, Sarguja, Jashpur, Raigadh, Kanker, Bastar, Dantiwara, Umaria, Shahdol, Dindori, Mandla, Balaghat, Bhandara, Gondia	7.23
Moist sub-humid to humid	Araria, Kishanganj, 24-Paraganas (North), 24-Paraganas (South)	0.59
Humid to dry sub-humid	Budgam, Kinnaur, Bilaspur (Himachal Pradesh), Shimla, Gurdaspur, Pauri Garhwal, Udham Singh Nagar, Kollam	0.88
Humid to Moist sub-humid	Kupwara, Baramulla, Poonch, Rajouri, Jammu, Kathua, Kulu, Lahul & Spiti, Mandi, Hamirpur (Himachal Pradesh), Solan, Sirmaur, Uttarkashi, Chamoli, Rudraprayag, Tehri Garwal, Almora, Champawat, Nainital, Thiruvananthapuram	2.50
Humid to per-humid	Mamit, Kolasib, Aizawl, Champhai, Serchhip, Lunglei, Lawngtlai, Saiha, West Tripura, Dhalai, North Tripura, Sonitpur, Jorhat	1.16
Per-humid to moist sub-humid	Wayanad	0.07
Per-humid to humid	Mon, Tuensang, Mokokchung, Zunheboto, Wokha, Dimapur, Kohima, Phek, Senapati, Tamenglong, Churdchandpur, Bishnupur, Thoubal, Imphal East, Ukhrul, Chandel, Ri-Bhoi, Kamrup, Nalbari, N C Hills, Dinajpur (Uttar), Dinajpur (Dakshin), Sindhudurg, Uttara Kannada, Kodagu/Coorg, Goa, Malappuram, Palakkad, Thrissur, Eranakulam, Idukki, Kottayam, Alappuzha, Pathanamthitta	3.34

Climatic classification was not clear in Krishnan[5] for Rajouri and Udhampur districts of Jammu and Kashmir and Kullu, Kinnaur and Lahul and Spiti districts of Himachal Pradesh. Humid climate prevailing in neighbouring districts was assumed for these districts.

Rewari and Gurgaon districts became semi-arid. Ladakh district of Jammu and Kashmir which was found to have cold arid climate earlier is now classified as dry sub-humid. A slight reduction in arid zone in the southern peninsula was observed as the districts of Raichur and Bellary in Karnataka now figured under semi-arid zone. However, it is to be noted here that these two districts are still at the margin of being semi-arid with an MI value of –66.1 (Raichur) and –66.2 (Bellary) and may be better considered as arid while planning for any developmental intervention.

Number of districts with semi-arid climate increased in Madhya Pradesh (8 districts), Tamil Nadu (7 districts) and Uttar Pradesh (4 districts) due to the shift of climate from dry sub-humid to semi-arid. However, the districts of J.B. Phule Nagar (MI = –34.28) and Ghazipur (MI = –34.12) in Uttar Pradesh and Buxar (MI = –33.78) in Bihar were still under the transition stage. As a whole, this shift was observed in 3.07% of the geographical area. On the other hand, climate in three districts of Punjab, Una of Himachal Pradesh, Jaunpur (at margin with an MI value of –32.55) of Uttar Pradesh, two districts each of Bihar, Maharashtra and Andhra Pradesh and Coimbatore district of Tamil Nadu changed to dry sub-humid from being semi-arid which constituted about 2.64% of the geographical area. A slight reduction of semi-arid zone in Andhra Pradesh and Maharashtra was an important observation. The most important difference observed between Krishnan[5] and the present study was shift of climate from moist sub-humid/humid to dry sub-humid in Orissa (12 districts), Chhattisgarh (7 districts), Jharkhand (4 districts) and Madhya Pradesh (5 districts) to a great extent. Among various shifts observed, the shift from moist sub-humid to dry sub-humid was the largest (7.23% geographical area). About half of the moist sub-humid districts in eastern India (other than West Bengal) became dry sub-humid. However, the shift of climate in West Bengal was towards humid. A good number of humid districts of Jammu and Kashmir, Uttarakhand and Himachal Pradesh turned moist sub-humid. In Mizoram and Tripura, the shift was towards per-humid from the earlier humid climate.

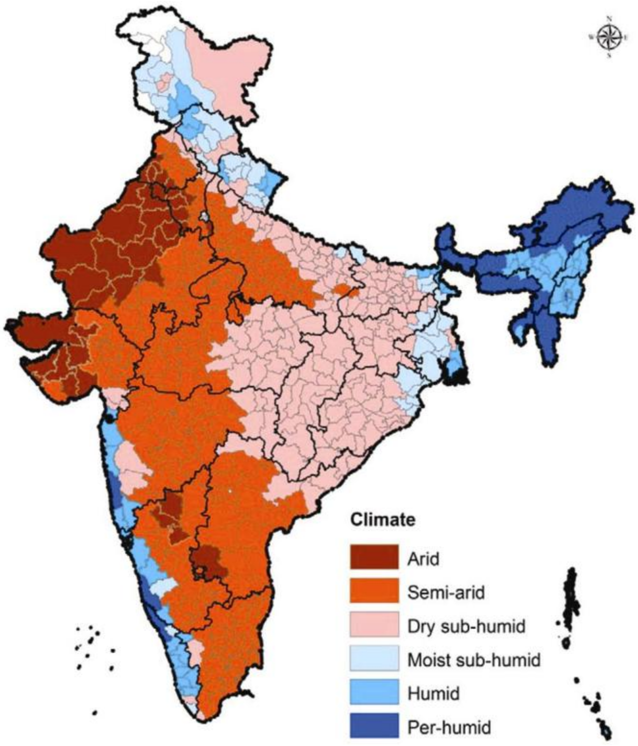

Figure 3. Climatic classification at district level (1971–2005).

The climatic classification needs to be revisited at least once in 30 years; may be more frequently in future since more warming trends have been projected for future. Such an exercise may not reveal a substantial change in the overall area under different climates, even then may reveal spatial shifts of climatic zones, which has bigger implications for crop planning, water resources assessment and launching of special schemes on drought and floods including disaster management. Based on the revised classification, there is an urgent need to revisit the present DPAP and DDP districts in the country, previously reviewed by MoRD[6] in 1994 under the chairmanship of C. H. Hunumantha Rao.

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Soil bacterial metagenomic analysis from uranium ore deposit of Domiasiat in Northeast India

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Total bacterial community analyses were performed for uranium ore deposit soil samples of Domiasiat utilizing cultivation-independent approach. Screening based on amplified ribosomal DNA restriction analysis (ARDRA) using *Msp*I and *Hae*III was performed to analyse 150 clones which generated 59 distinct ribotypes from the clone library. Representative 96 clone partial 16S rRNA gene were phylogenetically related to 10 different bacterial groups. *Proteobacteria* and *Acidobacteria* were the most abundant bacterial group while 7% of the clones represented novel bacterial lineages. The bacterial diversity obtained by the culture-independent approach presented a larger diver-

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