Application of Human-biometeorological Comfort Conditions in Köppen-geiger Climate type for Different Cities of Gangetic West Bengal

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Short Research Article

ABSTRACT

Gangetic West Bengal (GWB) belongs to Aw climate type after Köppen-Geiger climate classification (KGC). Human thermal comfort (HTC) and vapour pressure (VP) conditions together can represent human-biometeorological comfort conditions. Physiological equivalent temperature (PET) is used for indexing HTC. 3-hr PET and VP values are calculated based on hourly meteorological data of six selected cities for 18 years (2000-2017) time period. RayMan model has been applied to calculate hourly PETs and VPs. PET and VP data are grouped by frequencies and time period into several classes. Spatial distribution and dispersion characters of biometeorological comfort conditions are measured by statistical techniques. Thermally heat stress is very high in Apr and May. Months of winter indicate the presence of different thermal conditions. Annual comfort is maximum in the coastal city when stressful condition mostly prevails over Krishnanagar (KNG). Puruliya (PRA) shows the driest condition. The obtained information can be applied in planning, healthcare, and tourism sector.

Keywords: Köppen-geiger climate classification; physiological equivalent temperature; vapour pressure; different time scales; Gangetic West Bengal.

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1. INTRODUCTION

The assessment of human thermal comfort (HTC) is necessary for outdoor environment due to its temporal changes in a climatic region. HTC is the expression of human satisfaction about their thermal environment [1,2]. HTC may be measured with a number of different indices but physiological equivalent temperature (PET) derives more comprehensive results to the planners [3,4]. PET has been applied to assess human thermal condition in a number of human-biometeorological assessment studies, especially in urban planning [5-8]. The thresholds used in microclimatic urban regional based studies cannot provide HTC conditions of a broad climatic region [9]. Therefore, the HTC conditions of a number of urban areas from a different location in a climate region can represent the human-biometeorological character of a climate type. The world climate classification after Köppen (1884, translated in 2011) has been updated to Köppen-Geiger climate classification (KGC) [10], is applied for linking PET with climate type in China by Yang and Matzarakis (2016). PET is derived from human energy balance [3,11] that can efficiently describe the thermal conditions (hot/cold) for a human being. Relative humidity (RH) highly depends on air temperature (T_a), therefore air vapour pressure (VP) can be more suitable for HTC measurement [12]. Furthermore, wet/dry conditions or humid conditions can be represented by VP [9]. The present study aims to show the HTC-VP conditions of different urban areas in Aw climate type of KGC to assess the characteristics of human-biometeorological conditions of four agro-climatic zones (ACZs) (West Bengal agriculture an overview-matirkatha) within Aw climate type in the study area.

2. STUDY AREA AND DATA USED

Gangetic West Bengal (GWB), a meteorological subdivision of India Meteorological Department (IMD), comes under Aw climate type of KGC. GWB consists of 15 districts of West Bengal and is situated in the southern part of Farakka barrage (24° 48′ N, 87° 55′ E). Six cities from four ACZs of GWB have been selected as the representative urban areas of each and every ACZ: Gangetic alluvial zone (Krishnanagar, KNG; Kolkata, KOL), Vindhyan alluvial zone (Burdwan, BRD; Shantiniketan, SKN), Red and lateritic zone (Puruliya, PRA), Coastal saline zone (Digha, DGA). The selected weather stations (Fig. 2) are supposed to represent meteorological conditions of respective ACZs of Aw type that can be obtained from KGC map (Fig. 1) [10]. Hourly meteorological data of six selected cities for 18 years time period (2000-2017) is obtained from http://ogimet.com/.

3. METHODOLOGY

The hourly data of meteorological parameters have been utilized in RayMan model [7,13] with default thermo-physiological inputs to get the 3-hr PET values (Fig. 3). RayMan model has been utilized in a number of studies [6,14,15] to calculate the thermal comfort indices such as PET with field validation [5,7,13,16,17]. As the PET is obtained from skin temperature that combines both air temperature and human energy balance [11], hence the hot/cold comfort condition can be assessed by PET [9]. VP can better present the humid condition in HTC measurement [12] thus wet/dry conditions are described by VP.

3-hr PET and VP of Aw climate type over GWB have been grouped by frequencies of 3-value and 5-value classes respectively. The 3-value classes for PET have been set as follows [9,18]:

- ≤ 10°C for cold stress
- 10°C to 35°C for comfortable
- ≥ 35°C for heat stress

Modified 5-value VP classes have been set for Aw type after studying the association between RH and VP in the work of Lin and Matzarakis (2008). The identified VP (hPa) classes are as follows:

- ≤ 15 for extremely dry
- 15-20 for dry
- 20-25 for moderate
- 25-30 for wet
- > 30 for wettest

Considering the seasonal characters of GWB (http://imd.gov.in/section/nhac/termglossary.pdf) the HTC-VP information can be grouped by periodic scales:

- The annual period (PET_a and VP_a);
- The hottest months (PET_s);
- The coldest months (PET_w);
- The moderate months (PET_m, PET_p, and VP_w);
- The driest months (VP_d);
- The wettest months (VP_{wt}).

The PET_a and VP_a include respective frequencies of the entire year. Among the 6 identified classes extreme thermal and humid conditions can be represented by 4 classes: the hottest, coldest, driest, and wettest.

Five PET classes can be identified based on thermal periodic scales for grouping the 3-value classes:

- PET_s: PET of summer season (Mar-May);
- PET_m: PET of monsoon season (Jun-Sep);
- PET_p: PET of post-monsoon season (Oct & Nov);
- PET_w: PET of winter season (Dec-Feb);
- PET_a: Annual PET.

Similarly, four VP classes are identified based on humid periodic scales for grouping 5-value classes:

- VP_{wt}: VP of wettest months (Jun-Sep);
- VP_w: VP of wet months (Oct & Nov);
- VPd: VP of driest months (Dec-May);
- VP_a: Annual VP.

It is also important to visualize the distributional characters of the frequencies of human-biometeorological conditions for each city that can more comprehensively show the relative comfort conditions among the cities. Therefore, multivariate statistical techniques using SPSS have been applied to describe the characteristics of 3-hr PET and VP values.

4. RESULTS AND DISCUSSION

4.1 Biometeorological Conditions of Aw Type in KGC

Fig. 4 shows the thermal conditions of 6 cities in GWB. Presence of thermal stress conditions can be identified in all seasons. Percentage of thermal stress is highest for PET_s in the outdoor environment that may reach over 40% (i.e. in BRD & KNG). Winter shows extreme nature with the presence of cold and heat stress. That may be due to the combined effects of high diurnal temperature fluctuation and the presence of dry conditions. PET_w indicates simultaneous occurrences of thermally heat and cold stresses except for DGA but this extreme condition is most prominent for KNG. Annually DGA shows most comfortable thermal condition with about

19% PET above > 35°C. Overall thermally highest stressful conditions prevail over KNG. Monsoon heat stress occurrence surpasses PET_s in PRA. Urban areas like KOL, BRD, and DGA show almost equal shares in respective occurrences of PET values for summer and monsoon seasons.

The frequency of VP for wettest months (Jun-Sep) that is presented with values > 30hPa, is > 85% for KNG, KOL, and DGA. PRA indicates the prevalence of extremely dry condition both in VP_d and VP_a with respective percentages of 35 and 18 for ≤ 15hPa (Fig. 5). In the VP_w months frequency of > 25hPa is about 30% and 57% respectively for PRA and SKN whereas the percentage has increased to about 70% for BRD or even more in the eastern and coastal cities (KNG, KOL, & DGA) of GWB. Annually maximum wettest condition prevails in DGA simultaneously with the lowest percentage of the driest condition.

4.2 3-hr Mean Thermal Conditions of the Cities

An attempt has been made to compare diurnal distributions of 3-hr mean PET values for each month of 18 years study period (Figs. 6-9). During summer mid day PET values suggest the existence of heat stress in GWB that may shoot up to 45°C or more. In Apr and May thermally heat stress generally persist from 8:00 to 17:00 IST but the span may vary as it lasts for 8:00 to 14:00 hrs IST for both months in DGA and for Apr in BRD. Remarkable day and nighttime difference in mean PET can be noticed in PRA (in Apr) and in KNG (in Mar). In Jun and Jul diurnal PET distribution among the cities is very much uniform that indicates midday (11:00 to 14:00 hrs IST) heat stress in particular and presence of comfort condition mainly from 17:00 to 5:00 hrs IST. Last half of PET_m suggest mixed anomaly in the occurrences of heat stress in different ACZs that shows lowest mean in coastal and lower Gangetic alluvial area, moderate in western area and parts of vindhyan zone, and maximum in eastern part in KNG. Although mean PET_p indicates overall comfort condition for PRA and DGA in Nov in Oct presence of heat stress can be found all over the GWB. Winter is generally considered as an extreme season while the results of Dec, Jan, and Feb show different thermo-physiological conditions with the respective presence of cold thermal extremes, overall comfort conditions, and heat stress conditions.

4.3 Distributional Characters of HTC-VP Conditions

Tables 1, 2, 3 and 4 contain the distributional characteristics of 3-hr PET values based on seasonal frequencies. Diurnal mean values for summer season indicates thermal comfort condition but interestingly diurnal departures of 3-hr PET values may go above 10°C. During summer more than 25% frequencies of 3-hr PET go above thermally heat stress level over GWB. Mean PET_w over the study area is 20.8°C and it is lowest in PRA. Seasonal variability of PET is observed minimum in DGA. Tables 5, 6, and 7 represent data characters of 3-hr VPs. Inter-stational changes suggest up to a difference of 9 hPa in mean VP_d to 7.5 hPa in mean VP_{wt} over GWB.

Table 1. Statistical characteristics for PET_s (in °C)

Station	Max	Min	1st Q*	Med*	3rd Q*	Mean	SD*
PRA	49.6	13.8	21.4	28.3	41.8	31.6	10.9
SKN	49.0	11.9	25.9	32.7	40.8	32.0	10.2
BRD	47.9	12.8	26.7	29.5	38.5	32.4	8.5
KNG	55.4	14.6	25.9	30.2	43.9	34.1	11.2
KOL	49.5	11.9	27.0	29.2	38.8	31.6	8.4
DGA	40.3	20.7	26.0	28.8	36.1	30.7	5.9

*Q= Quartile; Med= Median; SD= Standard deviation

Table 2. Statistical characteristics for PET_m (in °C)

Station	Max	Min	1st Q	Med	3rd Q	Mean	SD
PRA	47.5	18.7	24.3	29.4	41.8	31.9	8.7
SKN	45.9	17.9	29.0	33.0	40.2	34.0	7.2
BRD	52.4	23.1	26.8	29.6	40.6	33.5	8.6
KNG	51.5	20.2	27.3	31.2	40.9	33.7	8.4
KOL	52.0	18.5	25.7	30.6	39.1	32.1	7.7
DGA	41.7	22.5	26.8	30.0	37.3	31.7	5.9

Table 3. Statistical characteristics for PET_p (in °C)

Station	Max	Min	1st Q	Med	3rd Q	Mean	SD
PRA	38.0	10.7	17.1	22.7	31.4	23.7	7.9
SKN	43.0	14.2	21.6	26.9	36.0	28.1	8.2
BRD	49.1	14.2	20.1	24.7	34.5	27.8	9.6
KNG	48.9	17.2	21.0	25.7	34.6	28.6	9.4
KOL	41.0	12.4	18.9	24.8	33.9	26.2	8.2
DGA	39.0	12.8	17.9	25.0	30.6	24.4	7.7

Table 4. Statistical characteristics for PET_w (in °C)

Station	Max	Min	1st Q	Med	3rd Q	Mean	SD
PRA	37.6	8.6	11.4	15.3	28.9	19.4	9.3
SKN	41.6	9.3	16.6	19.6	31.1	23.1	9.2
BRD	41.5	9.7	14.1	17.5	23.6	19.7	7.3
KNG	46.0	7.5	12.4	17.2	27.0	20.6	10.6
KOL	47.2	9.3	13.7	17.7	29.1	21.2	9.6
DGA	35.8	10.5	15.0	18.8	27.7	20.7	7.0

Table 5. Statistical characteristics for VP_d (in hPa)

Station	Max	Min	1st Q*	Med*	3rd Q*	Mean	SD*
PRA	23.0	9.9	11.4	12.3	15.1	13.9	3.9
SKN	34.8	14.4	15.5	21.0	28.2	22.6	7.5
BRD	32.4	13.7	16.8	22.4	31.3	23.2	7.2
KNG	34.8	12.3	16.7	19.0	26.1	21.8	7.4
KOL	31.6	14.9	16.9	20.5	29.4	22.3	6.4
DGA	34.8	16.1	18.9	24.6	32.5	25.3	6.9

Q= Quartile; Med= Median; SD= Standard deviation

Table 6. Statistical characteristics for VP_w (in hPa)

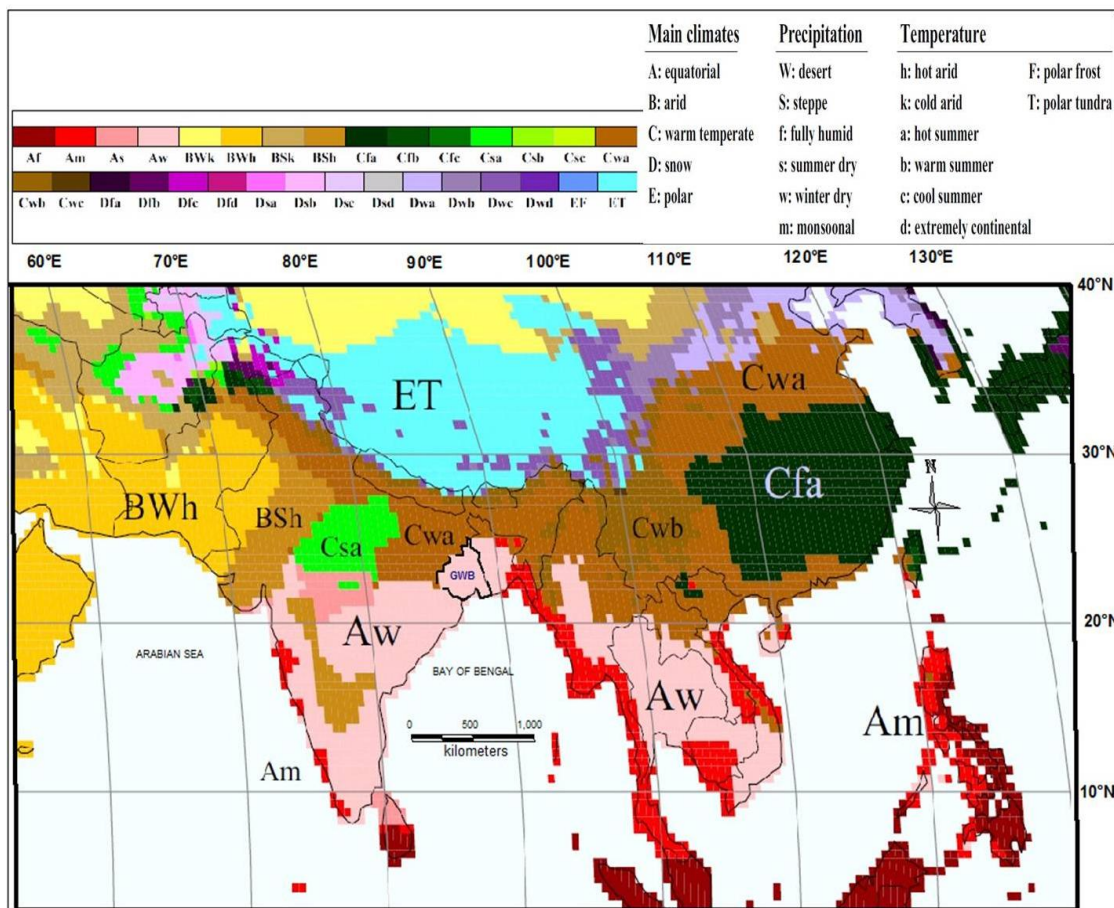| Station	Max	Min	1st Q	Med	3rd Q	Mean	SD
PRA	26.7	13.7	13.7	17.8	23.0	19.0	6.4
SKN	31.5	20.4	20.6	25.2	30.2	25.6	5.9
BRD	31.2	20.3	21.2	25.3	29.6	25.5	5.4
KNG	32.4	15.8	18.3	22.0	29.2	23.5	7.0
KOL	33.9	18.8	20.9	21.3	30.4	25.1	6.7
DGA	31.9	18.9	21.1	21.4	29.8	24.6	5.8

Fig. 1. Climate types in Indian subcontinent and surrounding regions according to KGC (after Kottek et al. [10])
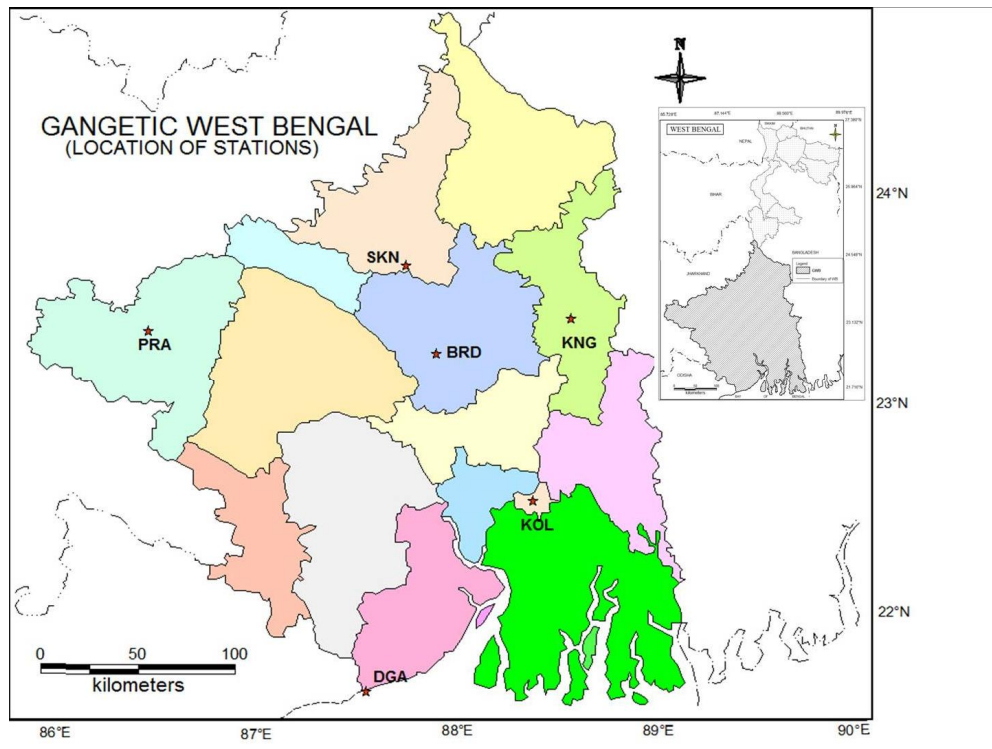
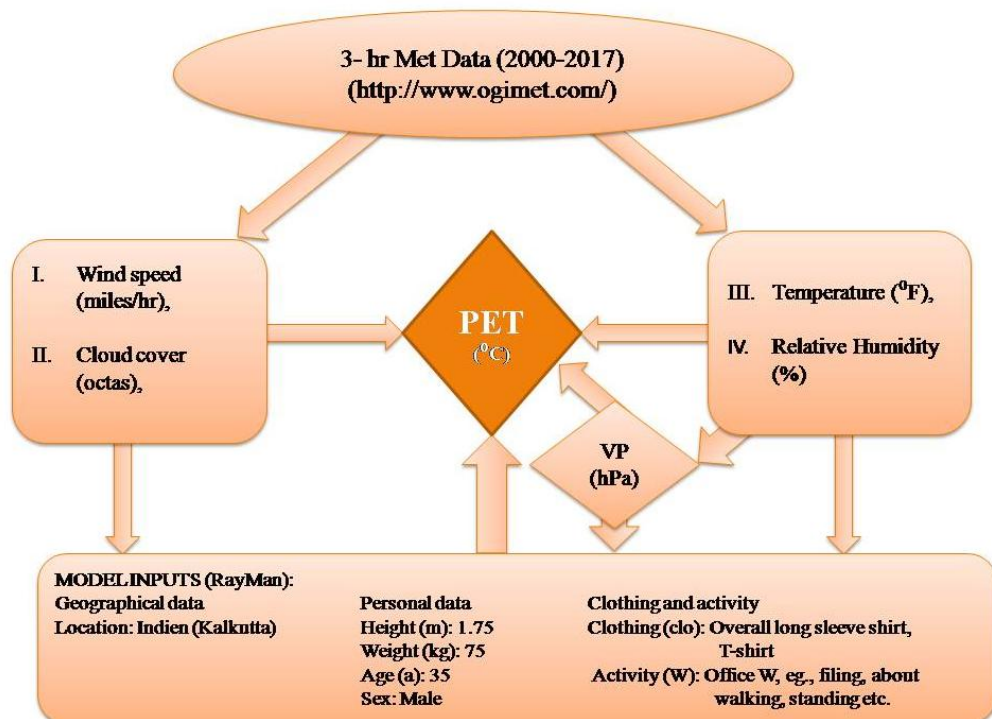**Fig. 2. Distribution of selected stations in GWB**

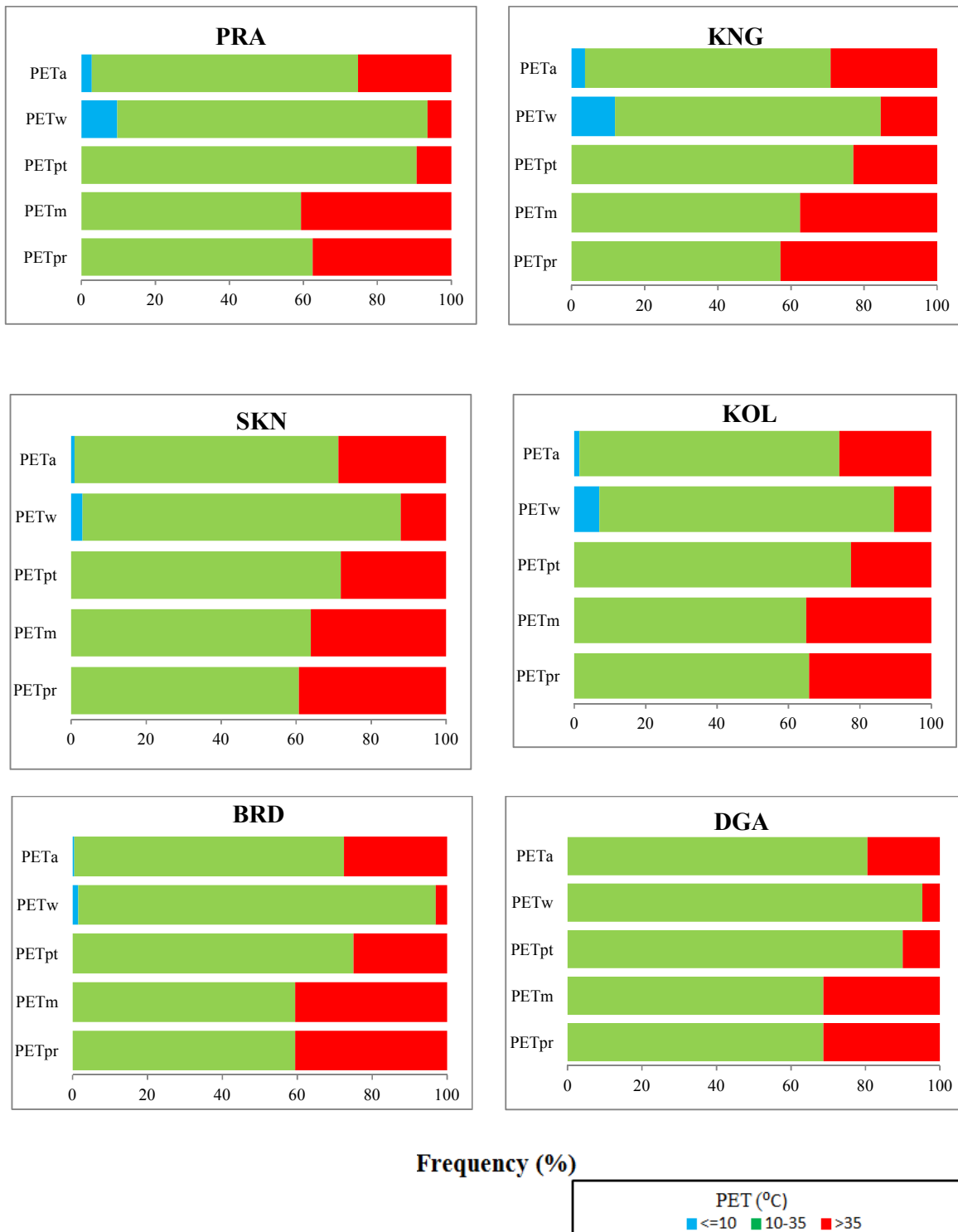**Fig. 3. Steps are followed for PET and VP calculations**

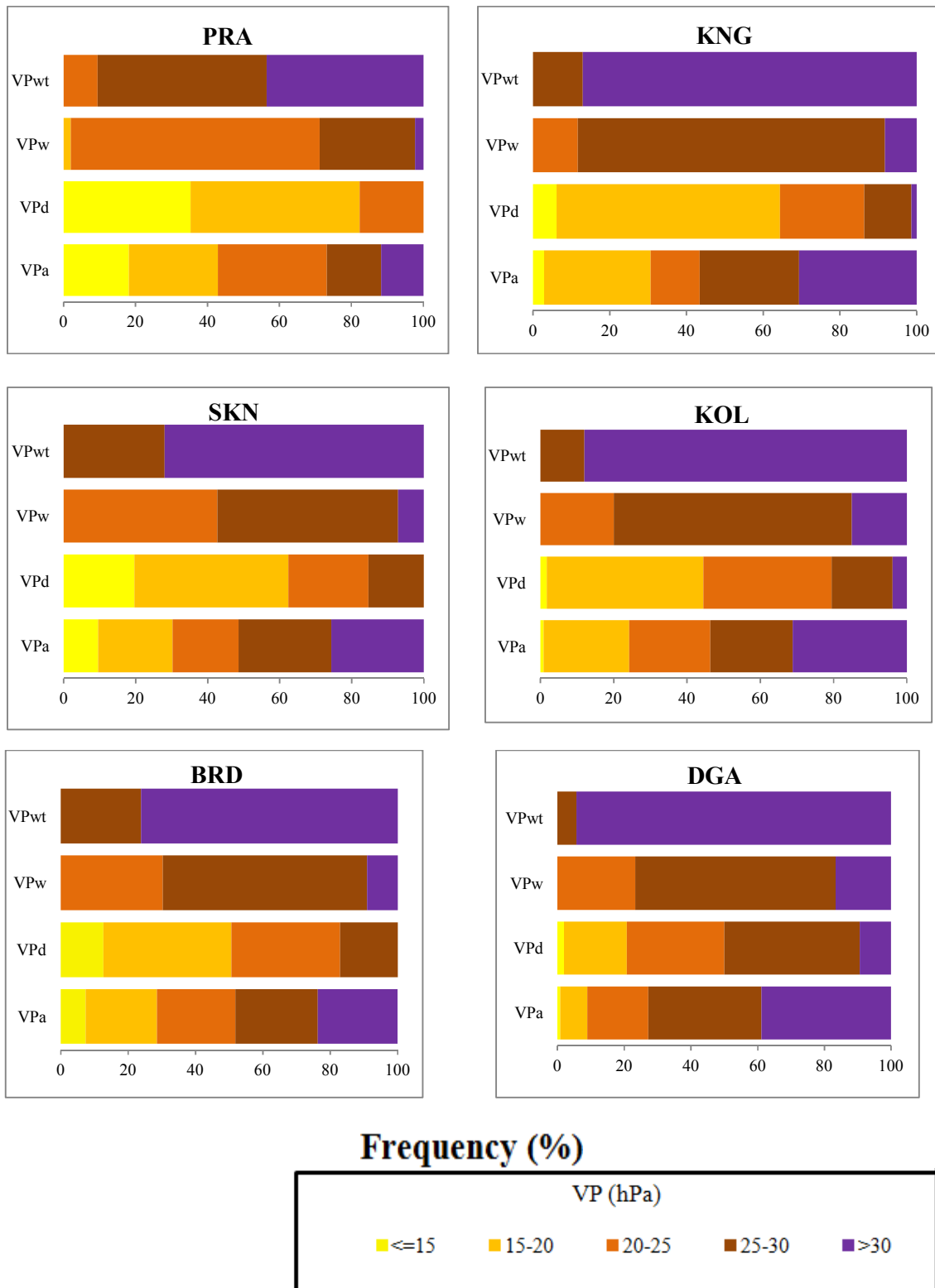**Fig. 4. Thermal comfort conditions for selected cities of GWB**

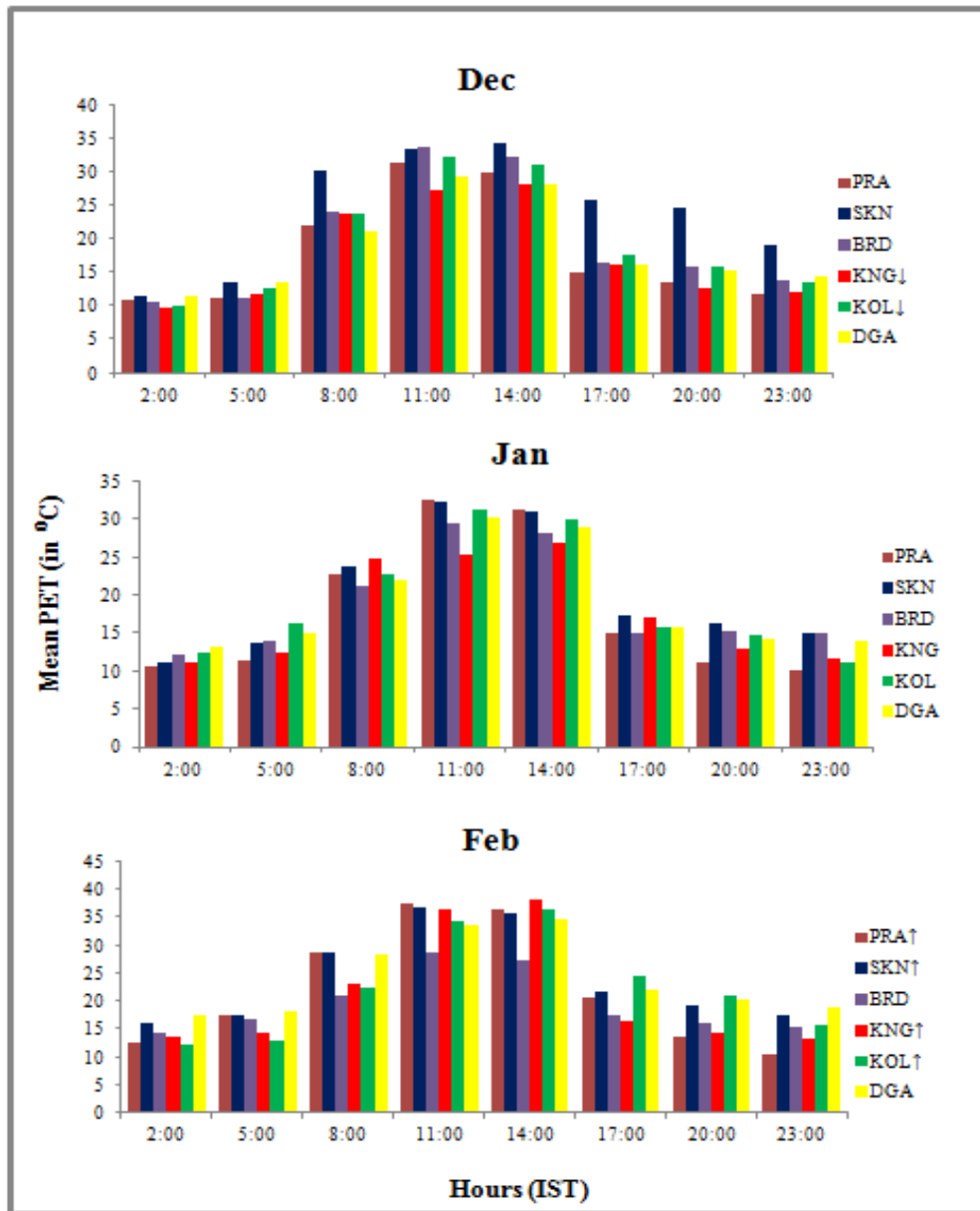**Fig. 5. Humid comfort conditions for selected cities of GWB**

Fig. 6. Hourly occurrences of mean PET$_w$ conditions in the cities of GWB. ↑ and ↓ symbols indicate the presence of heat and cold stress conditions respectively

Table 7. Statistical characteristics for *VP$_{wt}$* (in hPa)

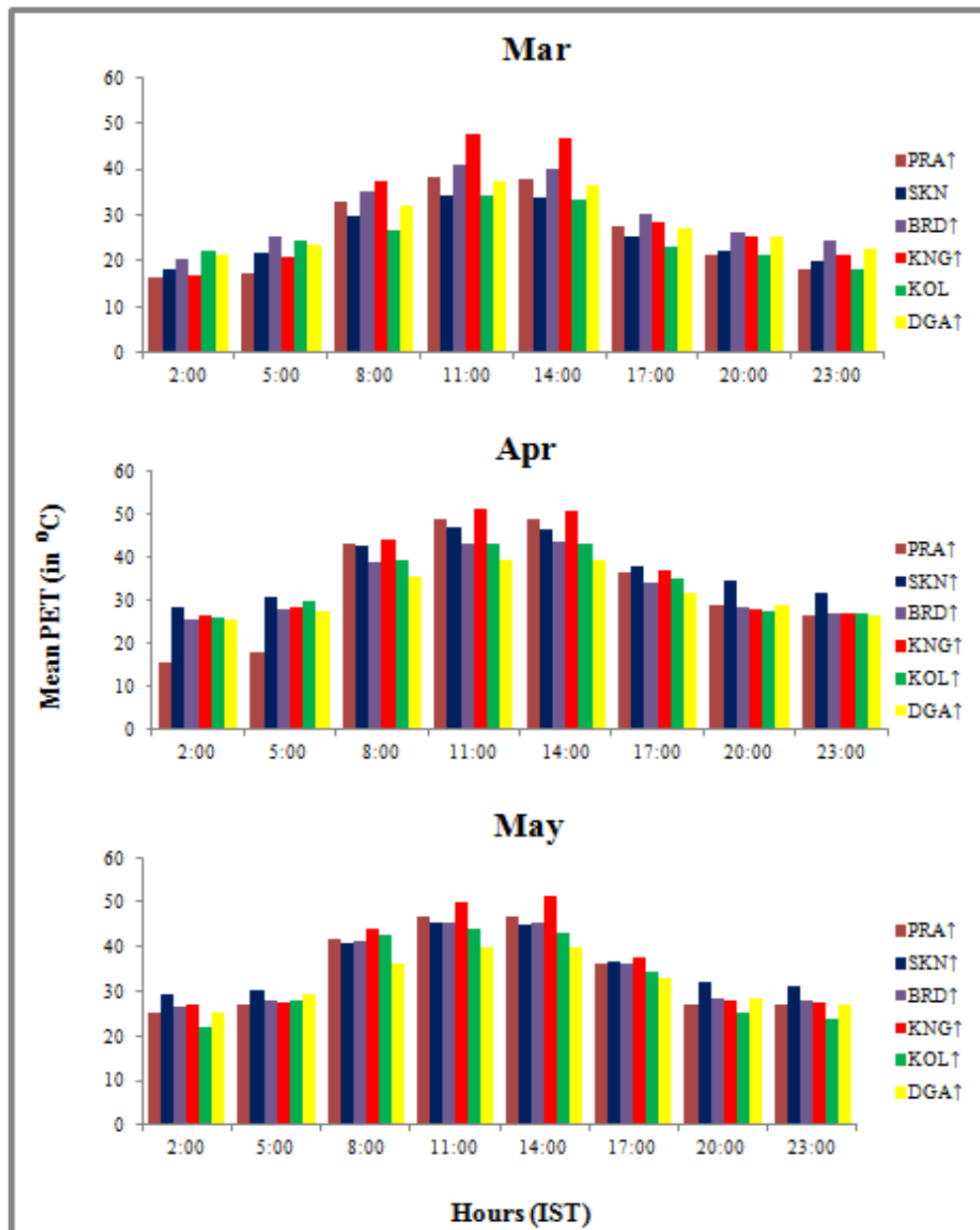| Station	Max	Min	1st Q	Med	3rd Q	Mean	SD
PRA	29.8	25.0	26.3	26.7	29.4	27.5	1.9
SKN	35.2	25.8	34.8	34.8	35.0	33.8	3.0
BRD	33.7	30.9	32.6	33.1	33.6	32.9	0.9
KNG	36.8	28.6	35.4	35.7	36.0	34.6	2.7
KOL	37.2	33.3	33.8	34.1	34.5	34.3	1.1
DGA	35.9	33.7	34.7	35.1	35.3	35.0	0.7

Fig. 7. Hourly occurrences of mean PET$_s$ conditions in the cities of GWB. ↑ symbol indicates same as in Fig. 6

5. SUMMARY AND CONCLUSIONS

Although KGC suggests equatorial climate with dry winter i.e., the Aw climate type for GWB that may suit well for the present study area but in describing the HTC-VP conditions rationally for a selected climatic region some other prominent climatic characteristics such as seasonality should take into consideration. The present study emphasizes on the fact that within a major climatic region there may persist differences with some prominent climatic characters that should be considered when analyzing rationally the HTC-VP conditions in a part of a major climatic type. Therefore, except dividing Aw type for GWB rigidly into two major seasons, several seasonal periods have been considered to understand actual HTC-VP conditions. In summary, the following points can be highlighted:

- A possible methodology has been made in respect to Aw climate type to link the HTC-VP conditions with KGC;
- The key step of this methodology is to utilize the frequencies of PET and VP in the specific seasonal and annual time period;
- Through the utilization of frequency in seasonal, monthly, and hourly scale the variation of data characters can easily be observed. Thus, frequencies of PET and VP can provide more accurate thermal and humid conditions;
- The approach of study can be applied in any climate type of KGC;
- The distributional statistics of PET and VP frequencies can provide easy visualization of dispersion and variability;

Overall analysis of 6 cities of GWB shows maximum human comfort in DGA while KNG indicates maximum extremities. PRA shows driest conditions in GWB. The results of the current study regarding human comforts may provide close insights in HTC-VP conditions. Furthermore, these results are useful for urban and regional planning, healthcare, and tourism industry.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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