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Geospatial Modeling for Spatial Analysis of Climatic Elements: In search of Climatic Classification Map for Bangladesh

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Abstract: ***The present study attempts to develop a scientific climatic classification map of Bangladesh using the daily climatic data of rainfall, relative humidity, mean sea level pressure and surface wind speed of the Bangladesh Meteorological Department. There are only two climate classification maps (Koppen-Geiger and Rashid) available for Bangladesh. Rashid relies on a single variable to identically represent a climate zones. In Koppen-Geiger map two weather variables namely Rainfall and Temperature were employed. The Geostatistical tool of ArcMap 10.5 was employed to produce a spatial dataset of the climate classes. In the present climatic classification map, there were three major classes of Dry, Temperate and Humid Temperate and seven sub-classes of Extreme Dry, Dry Low Humid, Temperate with Humidity, Moist Temperate, High Humid and Moisture, Humid Temperate and High Wind Temperate identified. Low annual value of the selected variables found in western and north western part of the country where higher values were found for the south and southeastern part of the country. This research will help to understand the climatic zones and spatial pattern of climatic variables. This will also helpful for future climate, climate risk, hydrological and agricultural research of the country.***

Keywords: ***Bangladesh; Climate Variables; Geo-Statistics; Climate Classification; Climate Sub-classes***

I. INTRODUCTION

The climate of Bangladesh is characterized by subtropical monsoon climate when considering in global perspective [1]. The identical features of Bangladesh climate are high temperatures, heavy rainfall, excessive humidity and characteristical seasonal variation [2, 3]. There is a slight regional contrast of climate in this almost flat country [4]. In an updated Koppen-Geiger Global climate classification map there were four climate classes of Bangladesh was categorized namely Tropical savanna climate (Aw), Tropical monsoon climate (Am), Humid subtropical climate (Cwa) and Hot-summer Mediterranean climate (Csa) [5]. In this method, Koppen's climate classification scheme was followed where two variables of Temperature and Rainfall were used systematically for climate classification [5]. For Bangladesh, a more detailed climate classification map was produced by Harun-Er Rashid. Rashid classified Bangladesh into seven climatic zones namely the South-eastern zone, North-eastern zone, North-western, Western zone, South-western zone and South-central zone. He used a single climatic variable to identically categorize each of the climate zones [2]. Rashid did not follow Koppen's scheme to classify climate. These are the only two available climatic classification map of Bangladesh. But this early classification includes a small variable of few stations except rainfall and temperature data [2, 5]. Considering the importance, the present research aims to develop a detailed scientific climate classification map of Bangladesh by using climate data of Bangladesh Meteorological Department. In the present research daily climatic data of rainfall, relative humidity, mean sea level pressure and surface wind speed were used. The daily climatic data were converted into the annual values and classified according to the hierarchy. Geostatistical tool of ArcMap 10.5 were employed to classify the climatic zones of the country. So the objectives of this research were to measure the value of the variable using geospatial technique and to develop a map of climate classification map of Bangladesh.

II. GENERAL CHARACTERISTICS OF BANGLADESH CLIMATE

Meteorologically three seasons are recognized in Bangladesh [1, 2, 6]: summer (from March to May), rainy (from June to October) and winter (from November to February). The summer season is characterized by high temperatures during the hottest month when the average temperature varies from 27-28 oC in the south to 32-33 oC in the west-central part of the country. The spatial variation of rainfall during this season varies from 200-250 mm in the west-central part to 750-800 mm in the northeast of the country [7]. About 80% of the total rainfall of Bangladesh occurs during the rainy season and 85-90% of the total rainfall occurs between mid-April and the end of September [1].

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In winter, January is the coldest month with an average temperature ranging from 17 oC in the north to 20 oC in the south. During this season a small amount of rainfall occur which is less than 5% of the annual rainfall. In the west of the country, rainfall ranges from 10-20 mm and in the northeast and east, it ranges from 40-60 mm [8].

The climate of Bangladesh is greatly affected by the heating of the Tibetian Plateau and the orographic impact of the Himalayan Mountain Range in the north and the evaporation of the Bay of Bengal in the south [3]. The summer wind blowing from the Bay of Bengal carries huge moisture that leads to excessive precipitation during the summer monsoon in Bangladesh. During winter dry and cold wind blows from the north. The major triggering force of the monsoon cycle in South Asian country is the thermal convection between landmass and the Indian Ocean which leads to the cross-equatorial pressure gradient makes the favourable condition to exchange moisture between land and ocean. The temperature gradient between the Indian Ocean and Tibetan Plateau plays a critical role in the inter-annual variability of the South Asian monsoon. All these factors regulate the regional climatic difference over Bangladesh [9-11].

III.DATA AND METHODS

Bangladesh Meteorological Department is the authorized government agency in Bangladesh that is responsible for collecting weather data over Bangladesh. The available data of daily total rainfall, daily average dry-bulb temperature, daily prevailing wind speed, daily average relative humidity and daily mean sea level pressure were collected for 70 Years (1948-2017) of 35 weather stations located over Bangladesh (Figure 1). These data are compiled daily to monthly and monthly to yearly.

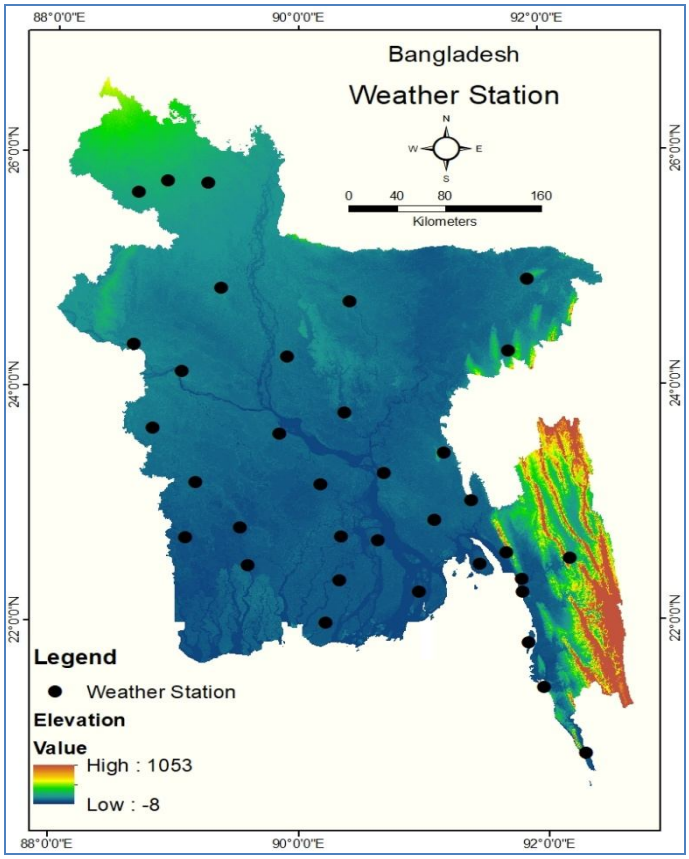


Fig. 1 Location of weather stations and elevation of Bangladesh

Annual data of each all the stations were converted into continuous surface data from individual point data by using thiessen polygon method of ArcMap 10.5 software. After that IDW method was employed to interpolate the data. IDW is a multivariate interpolation technique that uses known values of the neighborhood sample to calculate the predicted value of the un-sampled point. Generally, the predicted attribute value is the weighted average of the neighborhood sample value. By employing this technique a predicted spatial data can be produced by a number of sample input data [12-16]. The annual value of the variables was classified in a hierarchical manner and the hierarchical values for each station were summed up. Krigging was employed to interpolate hierarchical values and then climatic zones were classified.

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IV. RESULT AND DISCUSSION

The spatial distribution of annual Temperature shows a north-south pattern and it increases towards the south. Rainfall has an east-west pattern and towards the east, it increases. Highest rainfall found in the south-east part and in the north-east part of the country. Annual humidity has some microclimatic variation but it still follows north-west to the south-east direction and the lowest humidity found in the north and the highest humidity found in the south part of the country. Annual sea level pressure follows the west-east direction with increasing pressure from west to east. Annual wind speed has a random pattern. But there is a high wind speed belt in the coastal areas adjacent to the Bay of Bengal. Other high wind speed zone found in the western part and in the northern part of the country.

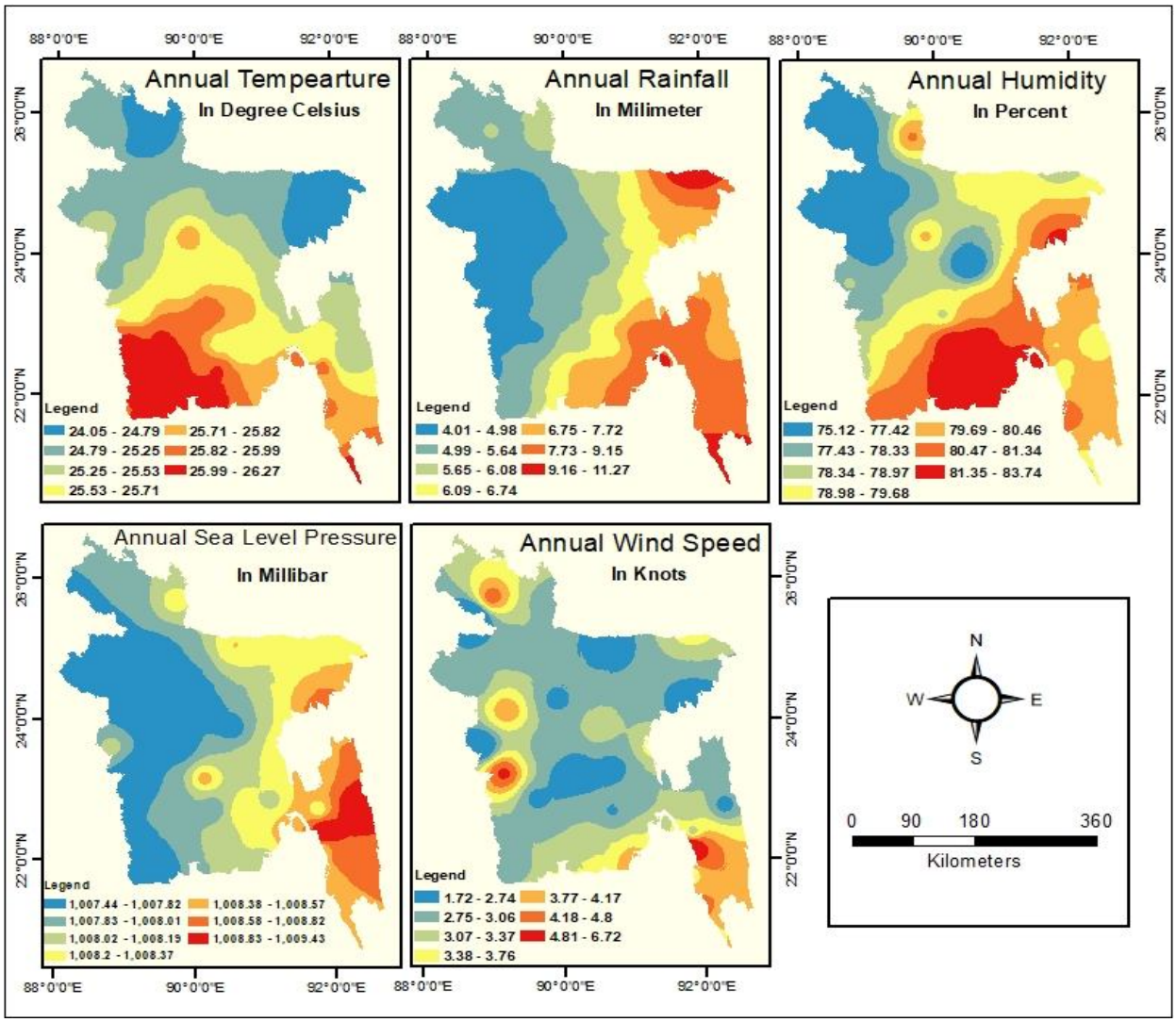


Fig. 2 Annual Temperature, Annual Rainfall, Annual Relative Humidity, Annual Sea Level Pressure and Annual Wind Speed

A. Annual Temperature

The mean yearly temperature of Bangladesh showed that in the coastal zone temperature varies between 18.9-21.32o C. The temperature of the north-west region (Rajshahi and adjacent areas) varies between 16.17-16.89 o C. In the middle part of the country (Dhaka, Mymensning, Tangail and adjacent district) it varies between 17.5o C and 18.9o C. Mean lowest temperature found in the month of January in Srimangal which is 15.85o C and the mean highest temperature found in Teknaf which is 21.32 o C.

Mean yearly lowest temperature found in Sylhet, Maulvibazar, Habiganj and portion of Sunamganj district located in the north-east part of Bangladesh vary between 24.05-24.79o C. Then a large belt found in the northern part of Bangladesh having temperature of 24.79-25.5 oC. The temperature gradually increases towards the south and in the coastal part it reaches up to 26.27o C. So temperature is changing according to the latitude

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B. Annual Rainfall

The lowest annual rainfall found in Rajshahi and Chuadanga is 4.01 mm. The highest rainfall found in Teknaf and Sylhet they are 11.27 and 11.07 respectively. In Bogra, Khulna, Tangail, Faridpur, Dinajpur, Mongla, Madaripur, Dhaka, Sydpur, Chandpur, Barisal, Rangpur, Myemnsingh mean yearly rainfall differs in a threshold of 0.7 mm. Rainfall increases from west to the east.

C. Annual Humidity

March and April are the least humid months over most of the western part of the country. The lowest average relative humidity (57%) has been recorded in Dinajpur in the month of March [17]. The least humid months in the eastern areas are January to March. Here the lowest monthly average of 58.5% has been recorded at Brahmanbaria in March. The relative humidity is everywhere over 80% during June through September [17].

Except for some microclimatic variation, humidity increases following the west to the north-east direction. Lowest annual humidity found in the west and north-west part of the country which varies between 75.12-77.42%. It increases towards the south-east. In the south, over the whole Barisal division and adjacent areas, it increased up to 81.35-83.74%. There is a small high humid zone found in Kurigram and Lalmanirhat district where it varies between 78.98-80.46%. In the Chittagong Hill Tracts, it varies between 80.47-81.34%.

D. Annual Sea Level Pressure

Mean Sea Level Pressure increased from west to east except for a few microclimatic variations. A large low-pressure zone found in the western part of Bangladesh and in the middle part of this low pressure zone propagates up to the Dhaka district. In this low pressure zone, sea level pressure varies between 1007.44-1007.82 millibar. The Chittagong Hill Tracts showed the highest annual sea level pressure of 1008.38-1009.43 millibar. The highest sea level pressure was found in Ambagan Station of Chittagong District which was 1008.95 millibar.

E. Annual Wind Speed

Wind speed showed a random pattern over the country. Annual high wind speed found in the coastal areas. The annual highest wind speed found in Chittagong is 6.71 knots. Another highest wind speed found in Cox's Bazar is 5.56 knots and in Jessore which is 5 knots. Another area of highest wind speed found in Dinajpur, Nilphamari, Lalmanirhat, Panchagarh. Except for this, the whole country has wind speed between 1.72-4.56 knots. But in most of the areas, it varies between 2.75-3.06 knots.

F. Climate Classification of Bangladesh

Wind speed The climate of Bangladesh was classified into three groups and seven subgroups according to their climatic characteristics showed by the annual values of the variables. There were seven climatic zones found for Bangladesh. They are Extreme Dry (Ed), Dry Low Humid (Dlh), Temperate with Humidity (Th), Moist Temperate (Tm), High Humid & Moisture (Hhm), Humid Temperate (Ht) and High Wind Temperate (Thw). Descriptive statistics of the climate variables of these climate zones are tabulated in Table 1.

TABLE I
Descriptive statistics of the climate variable of the climate zones

Variable	Climate Class	Mean	Min	Max	Standard Deviation	Range
Temperature (degree celsius)	Ed	25.15	24.87	25.33	0.12	0.46
	Dlh	25.17	24.87	25.55	0.16	0.68
	Th	25.29	24.28	25.98	0.35	1.70
	Tm	25.35	24.07	26.27	0.52	2.21
	Hhm	25.50	24.27	26.28	0.50	2.00
	Ht	25.79	25.46	26.06	0.11	0.59
	Thw	25.93	25.84	26.16	0.09	0.32
Rainfall (millimeter)	Ed	4.53	4.01	5.24	0.33	1.23
	Dlh	4.74	4.01	5.70	0.39	1.70
	Th	5.54	4.12	8.08	0.83	3.95
	Tm	6.17	4.76	9.16	0.85	4.40

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Variable	Climate Class	Mean	Min	Max	Standard Deviation	Range
	Hhm	7.13	5.26	10.82	1.26	5.56
	Ht	7.97	6.13	9.94	0.73	3.82
	Thw	9.25	8.18	10.86	0.77	2.69
Humidity (percentage)	Ed	79.07	75.69	81.26	1.36	5.56
	Dlh	77.55	75.71	79.82	0.81	4.12
	Th	78.41	75.12	80.73	1.00	5.61
	Tm	79.75	78.14	81.88	0.64	3.74
	Hhm	80.49	78.44	83.73	0.97	5.29
	Ht	81.17	79.26	83.74	0.99	4.48
	Thw	80.14	78.90	81.17	0.58	2.27
Sea Level Pressure (millibar)	Ed	1007.72	1007.52	1007.77	0.03	0.25
	Dlh	1007.74	1007.52	1008.09	0.10	0.56
	Th	1007.97	1007.52	1009.31	0.34	1.79
	Tm	1008.15	1007.44	1008.69	0.24	1.25
	Hhm	1008.22	1007.44	1009.30	0.36	1.86
	Ht	1008.37	1007.79	1009.43	0.28	1.64
	Thw	1008.51	1008.47	1008.55	0.02	0.08
Wind Speed (knots)	Ed	2.84	1.73	3.10	0.18	1.36
	Dlh	3.08	1.75	4.44	0.37	2.69
	Th	3.15	2.25	5.02	0.41	2.77
	Tm	2.79	1.92	3.52	0.22	1.60
	Hhm	3.09	2.48	4.13	0.27	1.65
	Ht	3.58	2.70	6.72	0.57	4.02
	Thw	4.01	3.47	4.30	0.17	0.83

Each climate class of Bangladesh has distinct characteristics though annual value shows a minor spatial variation over the country. Some of the identical characteristics of the seven climate zones are tabulated in table-2.

TABLE IIIII
Descriptive statistics of the climate variable of the climate zones

Class	Sub-class	Major Characteristics
Dry	Ed	High and low average temperature variation. Low mean annual rainfall <4.75 mm Low humidity <77%
	Dlh	High and low average temperature variation. Low mean annual rainfall <5.35 mm Comparatively high humidity <78.4%
Temperate	Th	High average temperature. Medium rainfall. Medium humidity (78.3-79.7%).
	Tm	Annual rainfall is 5.3-7 mm. Annual relative humidity (79.7-80.5%) Wind Speed 2.7-3.2 knots.
Humid Temperate	Hhm	Annual relative humidity is above 80.5%.

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Class	Sub-class	Major Characteristics
		Annual rainfall is 6-9.5 mm Annual wind speed is above 2.8 knots.
	Ht	Annual temperature is above 25.5 degree Celsius. Annual rainfall is >8.15 mm. Annual relative humidity is above 80.5% Annual wind speed is around 3.86 knots.
	Thw	High wind speed and high sea level pressure with little spatial variation. Annual temperature is above 25.5 degree Celsius. Annual rainfall is >8.15 mm. Annual relative humidity is above 80.5% Annual wind speed is >4.9 knots.

1) *Extreme Dry (Ed)*: This climate sub-class comprises most of the Rajshahi, Chapainawabganj and Naogaon districts and a small part of the Dinajpur district (Figure 3). These regions receive the lowest annual rainfall. Due to high elevation, the sub-class shows hot summer and cold winter that produces a medium value of annual temperature comparing to other areas. During winter, the Indian continental dry and cold wind hits this region. All these factors make this region dry and less humid. The sea level pressure is also low due to the high elevation (Figure 1 and 2). Due to a long distance from the sea, the wind speed shows a low value.

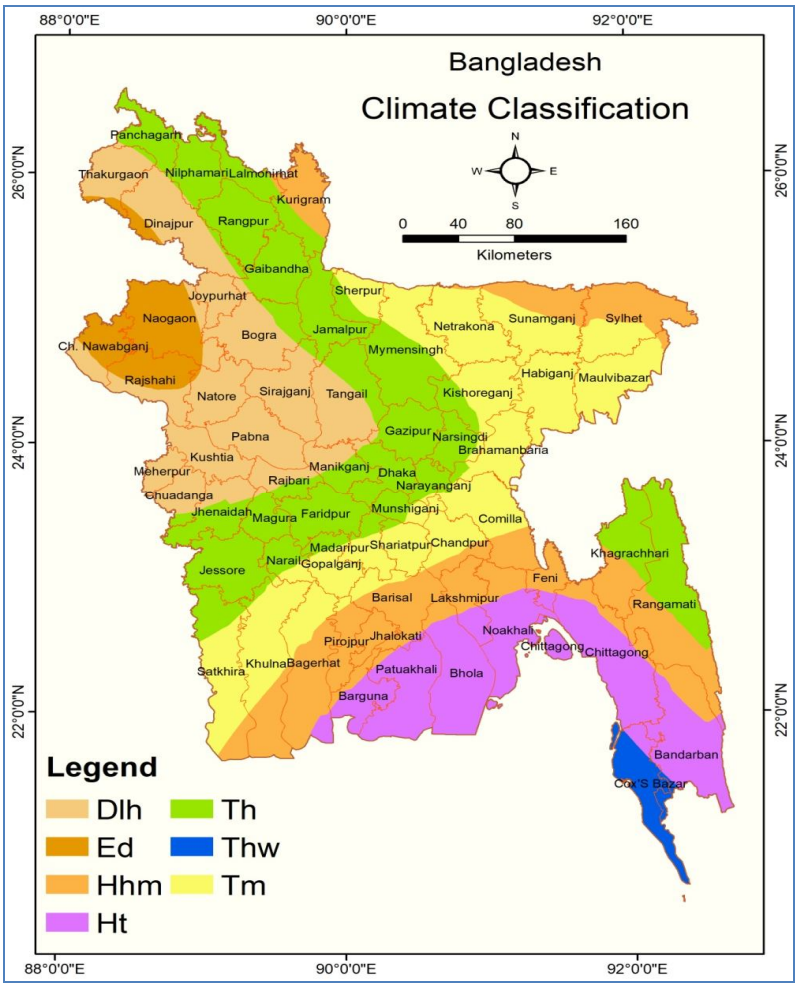


Fig. 3 Climate Classification of Bangladesh

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2) *Dry Low Humid (Dlh):* This climate class comprises Meheprpur, Chuadanga, Kushtia, Pabna, Sirajganj, Natore, half of Tangail, Bogra Joypurhat, Dinajpur, Tahkurgaon, parts of Jhenaidah, Rajbari and Manikganj District (Figure 3). This region is adjacent to the Ed and shows almost similar characteristics to Ed. But it receives relatively higher rainfall than Ed. Presence of water bodies and rivers and due to low elevation than Ed this region has a favourable condition for agriculture.
3) *Temperate with Humid (Th):* This climate class comprises a small portion of Satkhira, Jessore, Magura, Narail, Faridpur, Munsiganj, Manikganj, Dhaka, Narayanganj, Narshingdi, Gazipur, parts of Kishoreganj, North part of Tangail, South part of Mymensingh, Jamalpur, part of Sherpur and Bogra, Gaibandha, Rangpur, Nilphamari, Lalmanirhat and Panchagrah District (Figure 3). This region receives more rainfall and a mixed temperature pattern. From north to south, the temperature increases. Parts of the Rangamati and Khagrachhari district also showed this climate because of the impact of high humidity and high sea level pressure (Figure 2) over these two districts. But the rainfall and temperature of parts of Rangamati and Khagrachhari districts showed similarities with the climate of the surrounding hilly areas.
4) *Moist Temperate (Tm):* This climate class comprises Satkhira, Khulna, the south portion of Bagerhat, Gopalganj, Madaripur, Shariatpur, Chandpur, Comilla, Brahmanbaria, Kishoreganj, Habiganj, Maulvibazar, Nterokona, north part of Mymensingh and Sherpur, south part of Sunamganj and Sylhet (Figure 3). The temperature of this region has the highest standard deviation (Table 1). Because the distribution of the climate class starts with a narrow strip along Sundarbans in the southwest and then it propagates towards the northeast up to Comilla and then it covers the Haor depression (Figure 1) located at Kishoreganj, Habiganj, Maulvibazar, Nterokona, Sunamganj and Sylhet (Figure 1 and 3). After that, the region slightly propagates towards North West at the northern part of Mymensingh and Sherpur. Because of the diversity of physiography from southwest to North East this region showed the highest variation (standard deviation) in temperature and rainfall (Figure 2 and Table 1). The impact of the Bay of Bengal at the south and Haor depression in the northeast makes the region increases the moisture in the air comparing to other surrounding areas by providing excess humidity.
5) *Level-3 Heading:* This climate class comprises the southernmost part of Satkhira and Khulna, south part of Bagerhat, north part of Barisal Division (Pirojpur, Jhalokati, Barisal and a small portion of northern part of Patuakhali and Barguna), north part of Lakshmipur, Noakhali, South part of Comilla, North part of Feni, South part of Khagrachhari and Rangamati, a small portion of the northern part of Chittagong and Bandarban, North part of Sylhet and Sunamganj and Kurigram (Figure 3). This climate class also has a large variety in spatial distribution. Mainly the upper portion of the coastal area is dominated by this climate class. But the north part of Sylhet and Sunamganj, and Kurigram have similar characteristics. The orographic impact of the Khasia Hills and Meghalaya plateau makes favourable conditions for Sylhet and Sunamganj regions to receive extensive rainfall (Figure 2). Because of this condition, Sylhet and Sunamganj have relatively high humidity, high sea level pressure and low annual temperature. In this climate sub-class, high rainfall and high humidity is the dominant feature.
6) *Humid Temperate (Ht):* This covers a large portion of the coastal belt. The districts of Barguna, Patuakhali, Bhola, Noakhali, Chittagong, the north part of Cox's Bazar, large south part of Bandarban are in this sub-class (Figure 3). The climatic subclasses shift from northwest to the south-east according to the increasing value of the variables, particularly with the increase of rainfall, humidity and sea level pressure. This sub-class is dominating by high rainfall, high sea level pressure, very high humidity, relatively high wind speed and comparatively low temperature (Figure 2 and Table 1). Because of the presence of the Bay of Bengal adjacent to this sub-class, the region has high humidity, high wind speed and a low annual temperature. Also, the sub-class receives a high amount of annual rainfall and has high sea level pressure.
7) *High Wind Temperate (Thw):* This climate class comprises Cox's Bazar district and a small portion of Bandarban district adjacent to Cox's Bazar district (Figure 3). All the highest values of the climatic variables occur in this region. As this sub-class is open to the sea, the sub-class receives the highest wind speed over the year so that it had less standard deviation in wind speed even having the highest wind speed (Table 1 and Figure 2). The sub-class also has high temperature and rainfall with a low standard deviation (Table 1) which is similar to wind speed. Due to the high wind speed, the region has less humidity comparing to other coastal areas.

V. CONCLUSIONS

A climatic classification map was produced by using annual value of daily total rainfall, daily average dry-bulb temperature, daily prevailing wind speed, daily average relative humidity and daily mean sea level pressure. Though confined in a small territory, Bangladesh has different climate variation due to its physiographic difference and altitude. Employing the present method seven climate sub-zones were identified namely Extreme Dry (Ed), Dry Low Humid (Dlh), Temperate with Humidity (Th), Moist Temperate (Tm), High Humid & Moisture (Hhm), Humid Temperate (Ht) and High Wind Temperate (Thw). Among the variables temperature, rainfall, humidity and sea level pressure plays a critical role in discriminating regional climate. This climatic

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classification will contribute to regional climate studies, national policymaking, climate risk analysis and mapping, agriculture and forestry.

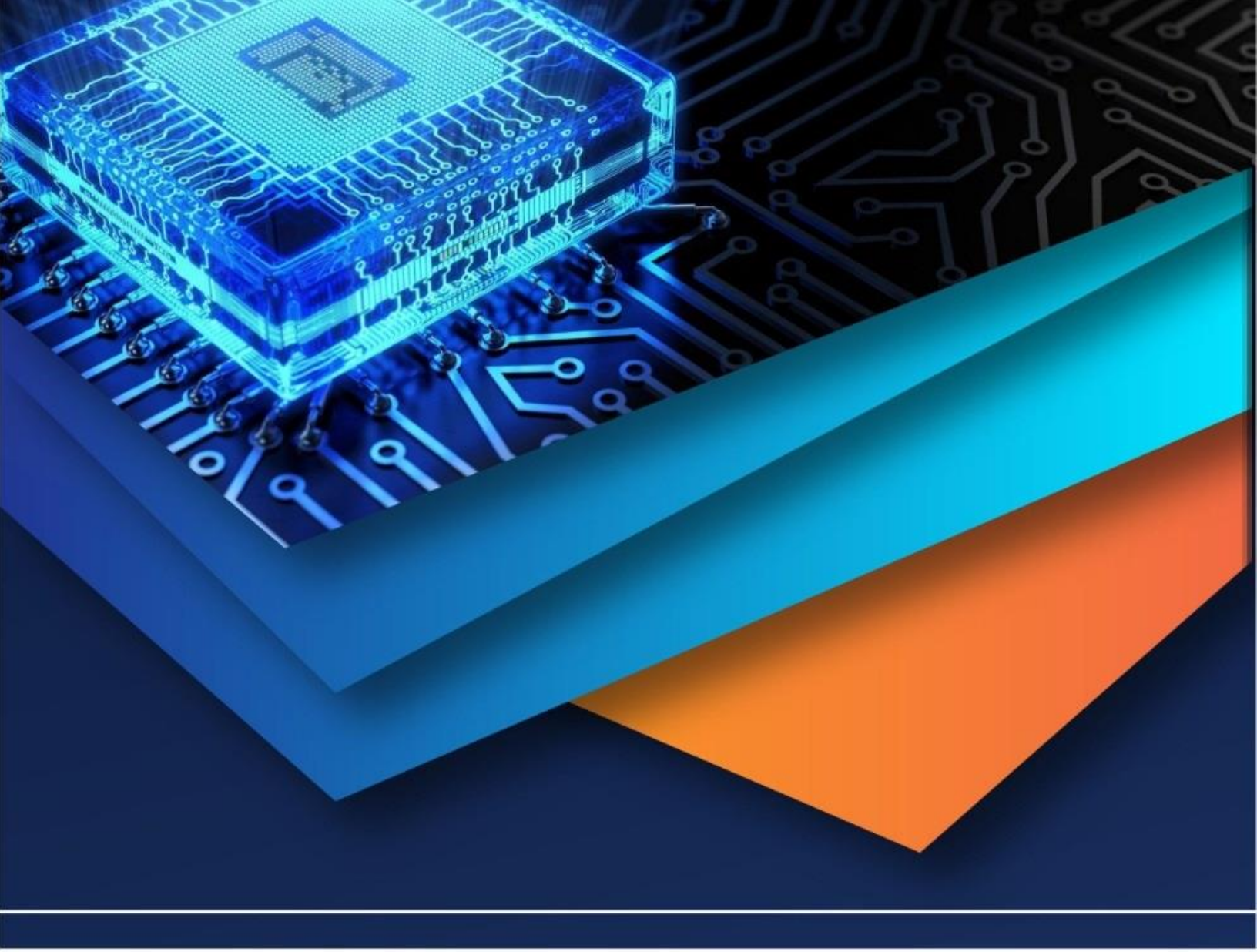
VI. ACKNOWLEDGMENT

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