RESEARCH 4(16), October- December, 2018

ISSN 2394–8558 EISSN 2394–8566

Climate Change

Assessment of intensity and distribution of aridity over Bangladesh using different climate indices with GIS

Md. Ashraful Islam Chowdhury

Aridity is slowly lethal natural calamity for an agricultural county like Bangladesh. Due to aridity and scarcity of irrigational water the agricultural system of Bangladesh is being interrupted. De Martonne index (1923), Lang Rainfall factor (1915), Minar Moisture certainty, UNEP Arid Index (1997), Thornthwaite classification (1948), Pinna Combinative Index and Aridity index of Emberger (1932) were used to estimate the aridity of the whole country. Data from 34 meteorological station were used to reveals the aridity distribution and variation. A version of Arc GIS 10.1 was used for spatial distribution and map preparation. The study period was divided into two distinct time period of 1991-2000 and 2001-2010. The results showed that severity and distribution of aridity is in increasing pattern over the 20 years period. The lower values of all indices indicate the more arid region. The calculated values of all indices of 2010 is lower than the values of 1991, means aridity increases and disperse from 1991 to 2010. Only Embergeraridity index explore that the whole area is under humid climate because of temperature difference is very low. The most arid prone area is north-western and some of southern part of the country. Agriculture of those regions is highly affected by aridity and that contribute to country food security.

INTRODUCTION

Climatic indices is most suitable way to assess the aridity of a large area. From the view point of dryness aridity indices is widely used (Arora, 2002). The climatic indices is used to diagnostic and understanding the climate system and climate mechanisms (Deniz et al., 2011). Aridity is the degree to which a climate is lacks effective and that is opposite of humidity (AMS, 2006). Aridity is worst natural hazard, defined as the deficiency in precipitation over a long period of time. Among the extreme meteorological events, drought is possibly the most slowly developing and long existing event (Dunkel, 2009). In Bangladesh, whole county more or less experience aridity but it is common in the north-west part because of landscape and dry climate. Bangladesh is experienced historical drought and its severity and variation also change time to time. The climatic factors of Bangladesh is in changing pattern (Chowdhury et al., 2016). Severe drought occurred in 1966, 1969, 1973, 1978, 1979, 1981, 1982, 1989, 1992, 1994, 1995, 1998 and 2000, causing substantial reduction in food production (DCRMA, 2012). Drought occurrence in Bangladesh averagely is once in 2.5 years (Adnan, 1993; Hossain, 1990). The percentage of drought affected areas were 31.63% in 1951, 46.54% in 1957, 37.47% in 1958, 22.39% in 1961, 18.42% in 1966, 42.48% in 1972 and 42.04% in 1979 (Banglapedia, 2014). Agricultural production in north-west part of Bangladesh is highly vulnerable to climate variability (Masud et al., 2014). The main objective of this study is to determine the aridity intensity and distribution in whole country and showing the best representation of aridity in Bangladesh, that are more related with the precipitation, temperature and evapotranspiration.

Department of Environmental Sciences, Jahangirnagar University, Savar, Dhaka, Bangladesh; Email: sagorchowdhury6996@gmail.com; Mob: +8801915975341

METHODS AND MATERIALS

Study area

Due to the tropical climatic region, Bangladesh experiences heavy seasonal rainfall with high temperature. Bangladesh is situated at south east subtropical monsoon climate region (Chowdhury et al., 2016). Bangladesh is vulnerable to climate change, due to its geographical position (Chowdhury et al., 2016). Bangladesh having monsoon climate, some parts of Bangladesh experiencing annual rainfall over 3500mm (Hasan et al., 2013). For this study mainly 34 rain gauges station data were used. The Figure 1 represents the spatial distribution of annual rainfall and temperature for whole country from 1991 to 2000 and 2001 to 2010.

Data preparation and analysis

In this study 34 Meteorological station rainfall and temperature data were used. The evapotranspiration data were calculated using Thornthwaite formula (Table 1). This 34 BMD station are unevenly distributed in the whole country. For study purposes the whole study period is divided into ten years base period are 1991 to 2000 and 2001 to 2010.The overall procedures is schematically represented in Figure 2.

Climate indices

De Martonne's aridity index (I_{DM}): I_{DM} expressed as a ratio of precipitation (P) divided by temperature (T) proposed by De Martonne

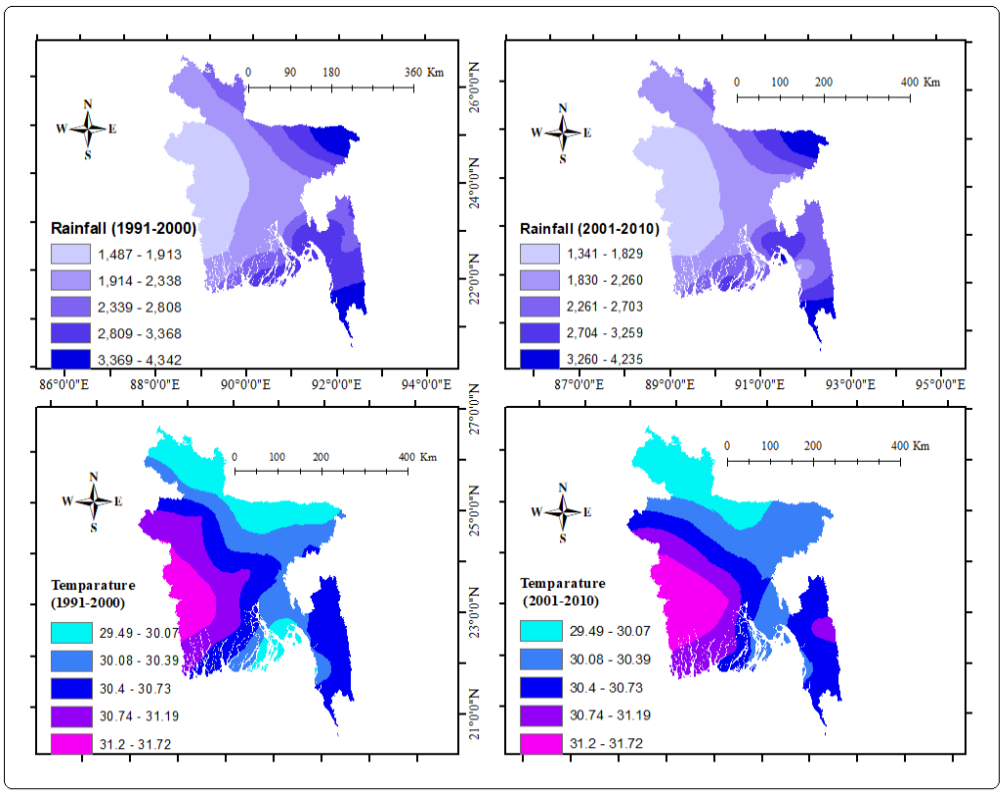

Figure 1 Rainfall and Temperature distribution over the study area.

Table 1 Climatic indices with their equation, classification and remarks

Index	Classification	Remarks	Reference
$I_{DM=\frac{Pav}{Tav+10}}$	I_{DM} <10 Arid; 10-20: Semiarid; 20-24: Mediterranean; 24-28: Semi-humid; 28-35: Humid; 35-55: Very humid; >55: Extremely humid	I_{DM}= De Martonne's index, P_{av}= average rainfall, T_{av}= average temperature.	1. De Martonne's arid index (De Martonne, 1923)
$l = \frac{R}{T}$	*I*< 40: Arid; 40-60: Semi-arid; 60-100: Humid; >100: Per-Humid.	*I*= Lang's rainfall factor, R = Average rainfall, T= Average temperature.	2. Lang's Rainfall factor (Neira et al., 2010)
$J = \frac{R - 30(t-7)}{t}$	*J*<-4-0: Highly-Arid; 1-7: Arid; 8-14: Semi-Arid; 15-21: Stable; 22-28: Semi-Humid; 29-35: Humid; >35: Per-Humid.	J = Minar's moisture certainty, R = Average rainfall, t = average air temperature.	3. Minar's Moisture certainty (Sobisek,1993)
$PE = \sum_{1}^{n=12} 115\left(\frac{P}{T-10}\right)^{10/9}$	*PE*<16 Arid; 16 – 31 Semiarid; 32 – 63 Sub humid; 64 – 127 Humid; > 127 Wet.	PE= Thornthwaite index, P = Monthly precipitation (inches), n = equal to 12 months, T = mean monthly temperature (°F).	4. Thornthwaite index (Thornthwaite index, 1948)
$IU = \frac{P}{PET}$	*IU*< 0.05 Hyper-arid; 0.05 – 0.2 Arid; 0.2 – 0.5 Semiarid; 0.5 – 0.65 Dry sub humid; 0.65 - 1 Sub-humid; > 1 Humid.	IU= UNEP Arid Index, P = Precipitation, PET= Potential evapotranspiration.	5. UNEP Arid Index (UNEP, 1993)
$I_P = \frac{1}{2}\left(\frac{P}{T+10} + \frac{12Pd}{Td+10}\right)$	I_p<10 arid climate;10 – 20 Mediterranean semi-dry; >20 Humid	I_p= Pinna Combinative Index, P= Yearly precipitation, T= Temperature means, Pd and Td= Precipitation and Temperature means in the driest month.	6. Pinna Combinative Index (Baltas, 2007)

$I_P = \left(\frac{100 \times P}{T^2 - t^2}\right)$	I_p> 90 Humid; 50 – 90 Subhumid; 30 – 50 Semiarid ;< 30 Arid.	I_p = Emberger index, P = Average annual precipitation, Tmax= Average maximum temperature of warmest month, Tmin= Average minimum temperature of coldest month.	7. Emberger index (Emberger, 1932)

In where Potential Evapotranspiration (PET) is calculated by;

Thornthwaite formula as: $PET = 16 \times \mathrm{Nm} \times \left(\frac{10 \times Pm}{I}\right)^a$

Where; $I = \sum_{i=1}^{12} \left(\frac{Tm}{5}\right)^{1.514}$

a= 6.75×10-7×I3-7.1×10-5×I2+0.01792×I+0.49239

PET= Monthly potential evapotranspiration (mm), Tm= Mean monthly temperature (°C), Nm= Adjustment factor related to hours of daylight, I= Heat annual index.

Monthly potential evapotranspiration

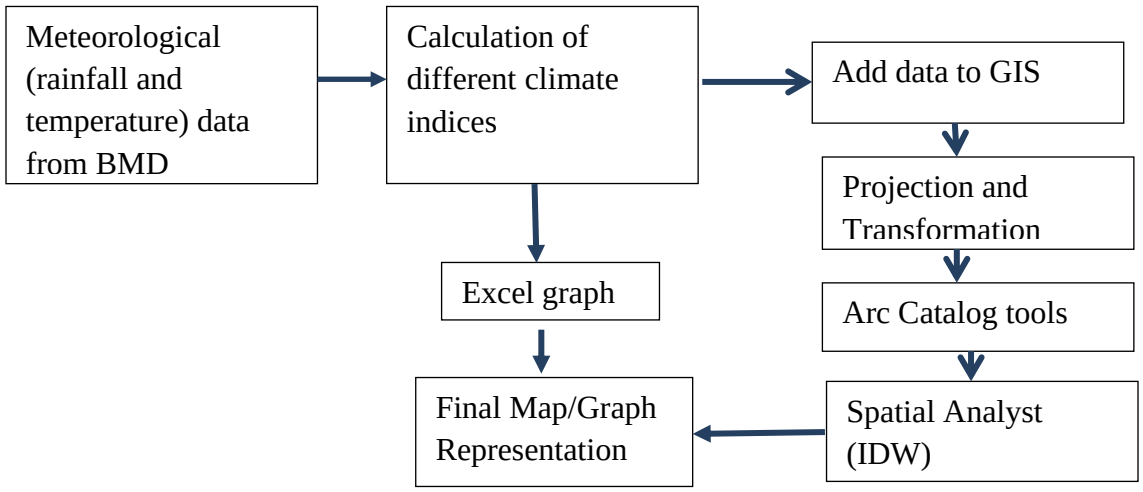

Figure 2 Schematic representation of Data preparation and Analysis procedure

(Mohamed & Mohamed, 2010). De Martonne's aridity index (Table 1) used to measure aridity in a location by comparing the annual average rainfall and annual air temperature. De Martonne's aridity index is still used to identify aridity of different region though it is one of the oldest indices (Coscarelli et al., 2004; Baltas, 2007; Shahid, 2008; Zarghami et al., 2011; Hrnjak et al., 2013).

Lang's Rainfall factor (*l*): Lang's rainfall factor (Table 1) expresses natural irrigation conditions of landscape by the relationship between rainfalls and air temperature (Sobisek, 1993; Dufkova and Toman, 2004). By comparing average annual rainfall with average temperature the Lang rainfall factor value were calculated.

Minar's Moisture certainty (*J*): Minar's moisture certainty (Table 1) is indicating the moisture in specific locations, but it is closely related to the rainfall and temperature. Ratio of average rainfall amount in a certain time and of average air temperature of the same period, gives rainfall amount that falls on every degree of average temperature of the definite period (Brablec, 1948; Dufkova and Toman, 2004).

Thornthwaite index (*PE*): Thornthwaite index (Table 1) also known as Precipitation Effectiveness index (PE).Precipitation effectiveness index (PE) is the monthly values of precipitation and temperature (Barzan et al., 2017). That was calculated using equation in Table 1.

UNEP Arid Index (*IU*): UNEP arid index (Table 1) is the ratio of the precipitation (P) and potential evapotranspiration (PET) (Neira et al., 2010). Where the PET is calculated using the Thornthwaite formula Table 1.

Pinna Combinative Index (I_p): Pinna combinative index (Table 1) was developed by Pinna (Zambakas, 1992; Baltas, 2007; Deniz et al., 2011). The mean value of precipitation and temperature was P and T, where Pd and Td is the precipitation and temperature in the driest month. $I_p$was calculated using equation in Table 1.

Emberger index (I_p): Emberger index (Table 1) is the ratio of mean annual precipitation and the difference of temperature of both the hottest and coldest month and based on data that associated with vegetation zones (Hrnjak et al., 2013).

Final map preparation

Arc GIS 10.1 was used for final map preparation and graph was prepared by using Ms-Excel. GIS provide a management solution with extensive number of application for massive spatial climate dataset (Franke, 1982; Burrough, 1986; Hrnjak et al., 2013). The IDW interpolation tool of GIS was used for spatial distribution. For determination of climatic condition of a region the spatial distribution of various climatic indices is excellent (Deniz et al., 2011). It is obvious that the spatial distribution of the mean annual air temperature is not uniform (Baltas, 2007). So some data that found is slightly deviated. Final results were found in change of color variation. The graphs that covey the statistics is clear indication of final results.

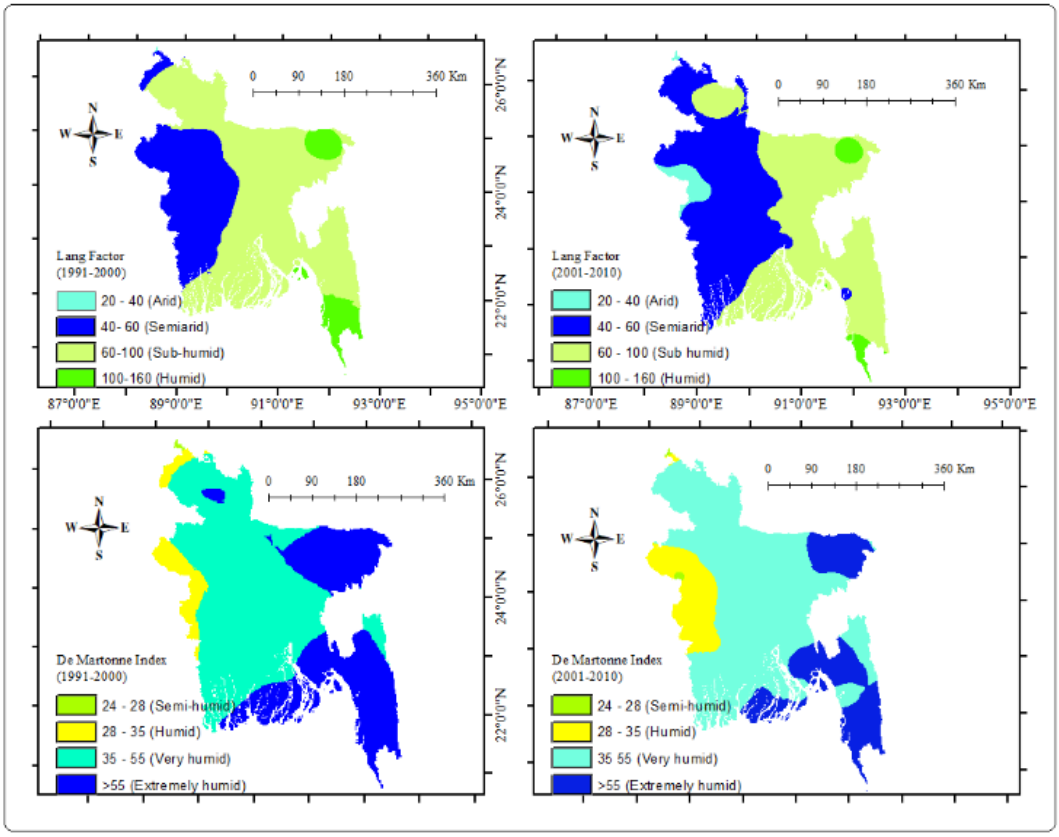

Figure-3a Spatial Distribution of Lang's Index and De Martonne's index

RESULTS AND DISCUSSION

Due to the geographical and physiological condition Bangladesh is vulnerable to Floods and Drought. The present study reveals the aridity condition of whole Bangladesh. The study mainly based on the 07 (seven) climatic indices named De Martonne's index, Lang's Rainfall factor, Minar's Moisture certainty, UNEP Arid Index, Thornthwaite classification, Pinna Combinative Index and Aridity index of Emberger. Results that reveals in this study is individually assume that aridity in Bangladesh is increase and disperse. Figure 3(a, b, c) exposed the spatial distribution of results of different climatic indices that was calculated using the equation from Table 1. Figure 3(a, b, c) exposed the aridity condition of Bangladesh from 1991 to 2010. Low values indicating severe aridity and the high values indicate the wet or humid region for all seven indices.

Lang's index (Figure 3a) expose that in 1991 to 2000, there is no arid area in the whole country and maximum area of the country is under sub-humid region. But this scenarios has been changed in the time period of 2001-2010, where some area of the country goes to the arid region and maximum area is semi-arid region. From figure 4 (lang index), it also shows that the ishordi and rajshahi (north-western) region fall under the arid region in period of 2001-2010. The maximum region of the country converted sub-humid to semi-arid region in 2001-2010 (Figure 3a).

De Martonne's aridity index (Figure 3a) interpret that, in 1991-2000 some part of the country is fall under humid region where the maximum portion is under very humid condition. But in 2001-2010 this very humid region of the country is converted to humid region. It also found that some of the area of the country also faces semi-humid environment. According to De Martonne's index the country is not presently experience the aridity but from figure 4 it has been clearly seen that the area is in transition period. Because the value of some station is nearly 24 and bellow this value the Mediterranean started, which is the prior to the semiarid region.

Figure 3b is the interpolated result of Minar and Thornthwaite classification indices. From Minar index it can be seen that in 1991-2000negligible amount of area is under stable condition most of the area is under pre-humid condition then humid condition. But in 2001-2010 this negligible stable area converted to significant stable area, beside pre-humid area converted to more dry area as semi-humid and humid area. From Thornthwaite classification it also seen that the arid area increases and the aridity is increased in mainly north-western region of the country.

Figure 3c where UNEP and Pinna Combinative Index were interpolated. Both of the image present that the in 1991-2000 the maximum area of the country is humid. But this area is converted to sub-humid and semi-dry region in 2001-2010. According to Emberger index (which is not present in the image) it is found that the whole country is under humid region. This is because the Emberger index is calculated in difference between hottest and coldest month temperature and the temperature variation of all station is very low (Neira et al., 2010), so this index miss interpret the country actual conditions.

Figure 4 is the graphical representation of index results. Where it has been found that the driest area of the country is the north and north-western part of the country. Mainly the Rajshahi, Ishordi, Bogra, Dinajpurand some southern part of country as Satkhiraregion. In Bangladesh Meteorological Aridity is a very common phenomena in north-western part (Shahid, 2008). More or less the whole country is going to under dry climatic region from 1991 to 2010. The most wet

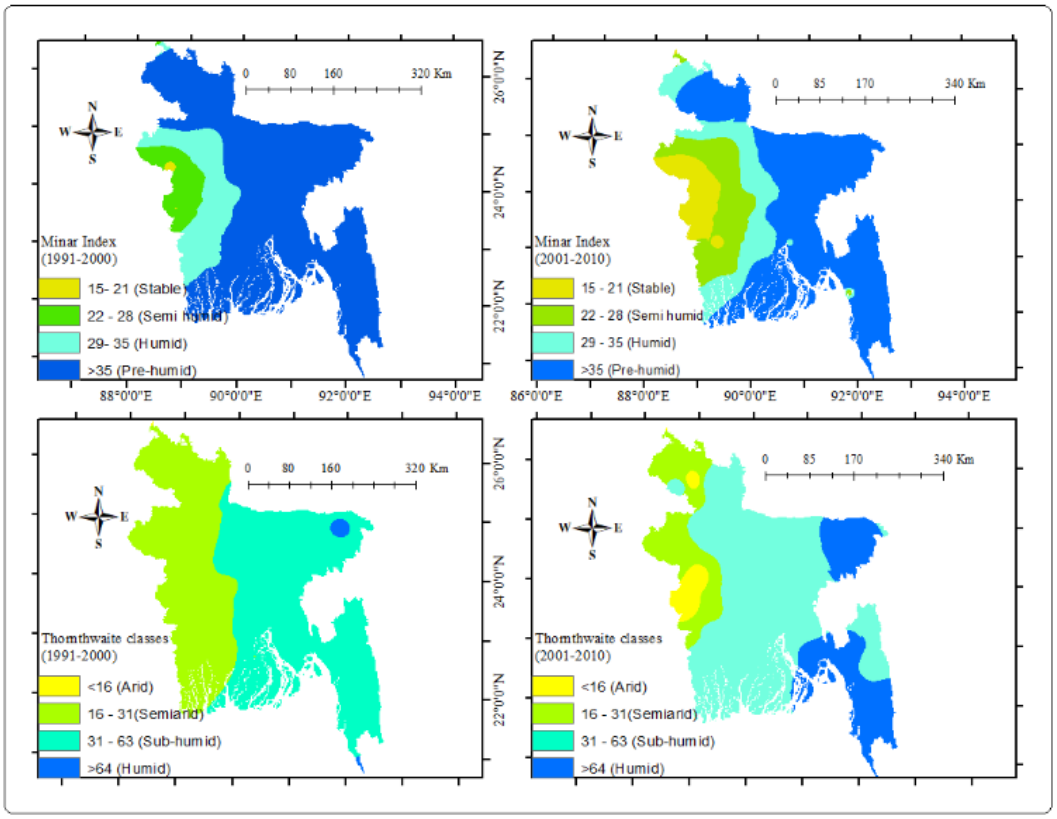

Figure-3b Spatial Distribution of Minar index and Thornthwaite Index

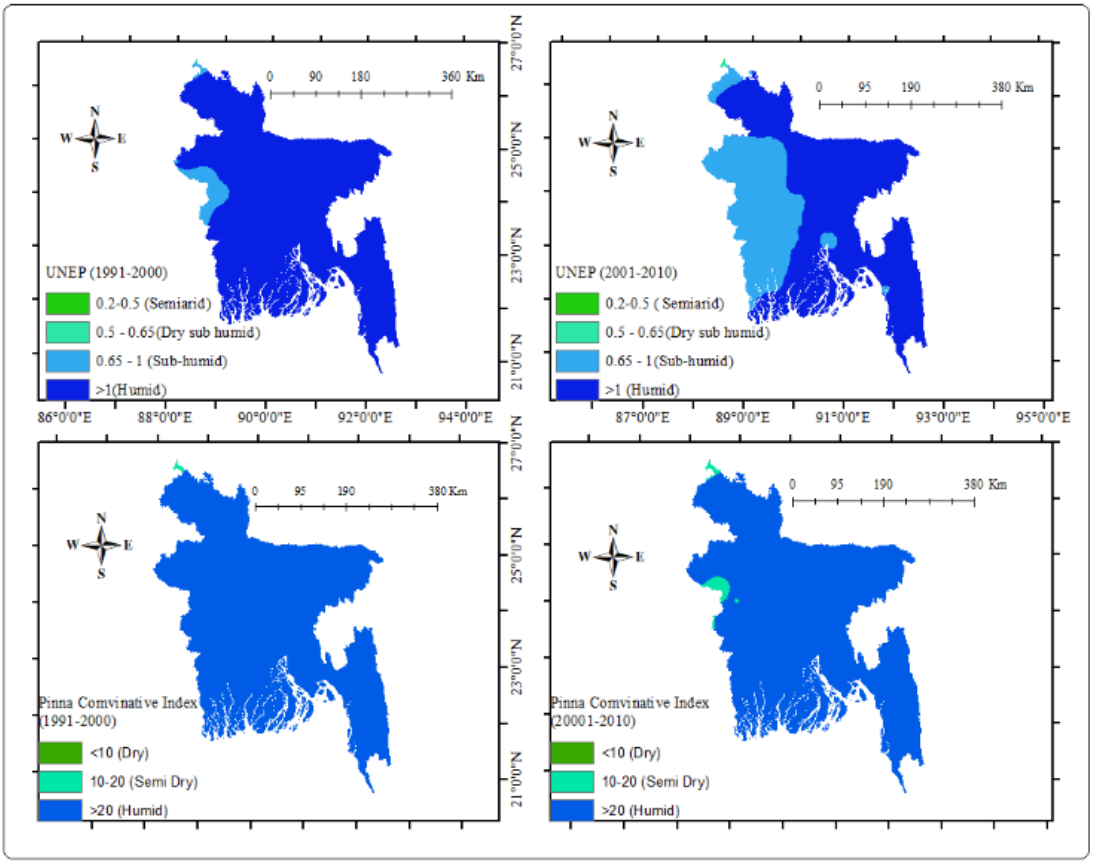

Figure-3c Spatial Distribution of UNEP Index and Pinna Combinative Index

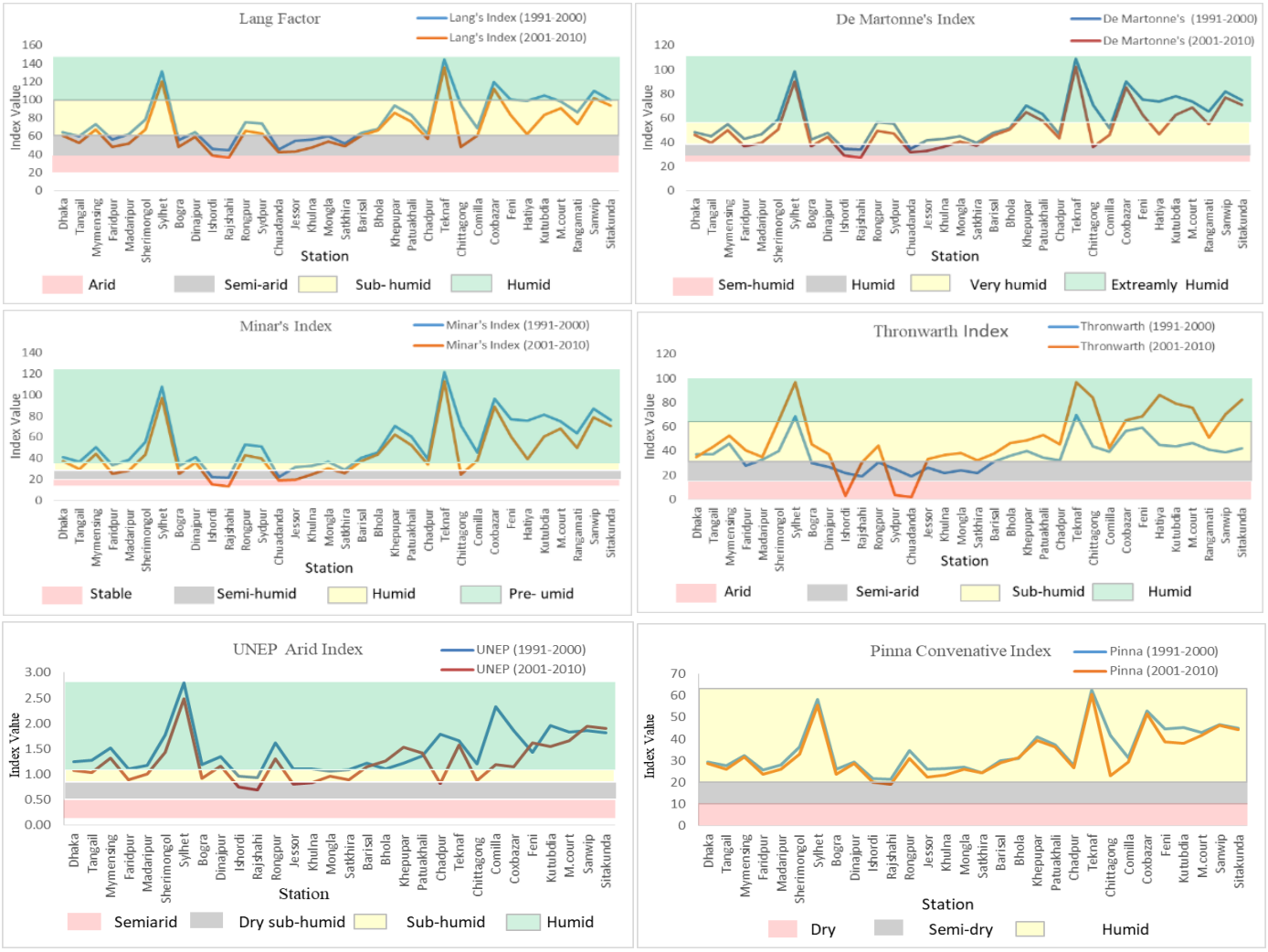

Figure 4 Graphical presentation of station-wise results of different indices.

region of the country is the northern (sylhet, sherimongol) and eastern (teknaf, coxbazar) part. Figure 4 presents that the line of the 2001-2010 is always under the line of 1991-2000. This indicates that the aridity is also scatters in pattern, because the lower value indicates the drier region. The increase of lower values of all seven aridity indices from 1991-2010 indicates that the aridity is increasing in pattern.

CONCLUSION

It is well known that Bangladesh is vulnerable to aridity. About 80% of people in Bangladesh are depends on the agriculture but Aridity is a curse for this county. By this study it is reveal that the Aridity severity is increasing in whole country. It is considering that the aridity prone area is mainly the north, north-western part in the country but the study clearly expose that not only the north, north-western part but also most of the part is under the transition period of arid condition. The study it also reveals that the aridity severity is not only increased but also its distribution over the country is also increase as the same way from time to time and in near future the whole country will face an arid climate. Proper action as proper use of monsoon water, aridity tolerance crop introduce, crop rotation technology should be taken to control the slowly poisonous agricultural calamity.

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Article Keywords
Aridity, Arc GIS, Aridity Index, Intensity, Distribution

Article History
Received: 26 June 2018
Accepted: 4 August 2018
Published: October - December 2018

Citation
Md. Ashraful Islam Chowdhury. Assessment of intensity and distribution of aridity over Bangladesh using different climate indices with GIS. *Climate Change*, 2018, 4(16), 743-749