Study of Spatio-temporal Variation of Humidity over the Southwestern Zone of Bangladesh

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Abstract

In the last fifty years, the pattern of humidity has changed due to natural and anthropogenic reasons in the southwestern part of Bangladesh. The humidity data was recorded at eight regional meteorological stations of the Bangladesh Meteorological Department over the period of 1974 to 2020 and is used for assessments of trends of humidity aspects in the context of seasonal variability and spatial distribution in the southwestern zone of Bangladesh. For this study, the humidity trend was analyzed through Microsoft Excel Software, and the Arc GIS tool was used for spatial distribution analysis. In Khulna, during the dry season maximum mean humidity was78.6% in 2008 and the minimum mean humidity was 63% in 1974. In the wet season, maximum mean humidity reached 87.5% in 1984 and minimum mean humidity was 78.8% in 1976. In Jessore, the maximum mean humidity in the dry season was 78.8% in 1998 and the minimum mean humidity was 65% in 1975. In the wet season, the maximum mean humidity was 84% in 1990 and the minimum mean humidity was 75.1% in 1979. In Mongla during the dry season maximum mean humidity was 78.6% in 2005 and the minimum mean humidity was 69.6% in 1989. In 2005, during the wet season maximum mean humidity was 86.2% and the minimum mean humidity was 82.7% in 2014. In Satkhira during the dry season maximum mean humidity was 79.2% in 1998 and the minimum mean humidity was 58.4% in 1984. In the wet season, the maximum mean humidity was 82.8% in 1997 and the minimum mean humidity was 72.7 % in 1979. In Barishal during the dry season maximum mean humidity was 83.4% in 1986 and the minimum mean humidity was 71.6% in 1978. In the wet season, the maximum mean humidity was 88.4% in 1975 and the minimum mean humidity was 82.4% in 1982. In Bhola during the dry season maximum mean humidity was 83.6% in 1990 and the minimum mean humidity was 74.4% in 1978. In the wet season, the maximum mean humidity was 89.5% in 1991 and the minimum mean humidity was 82.5% in 2017. In Patuakhali during the dry season maximum mean humidity was 85.8% in 2010 and the minimum mean humidity was 65% in 1982. In 1979, during the rainy season maximum mean humidity was 90.2% and the minimum mean humidity was 78.8%. In Khepupara during the dry season maximum mean humidity was 89% in 1987 and the minimum mean humidity was

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57% in 1979. In 1987, the rainy season's maximum mean humidity was 88% and the minimum mean humidity was 78.6%. in 1979. In the southwestern zone of Bangladesh, dry season humidity was consistently increasing trend while wet season humidity was decreasing.

Keywords: Spatial, Temporal, Relative Humidity, Variability, Trend Analysis, Climate, Interpolation.

1. Introduction

Climate change is a critical issue in today's modern world. A climate, according to the World Meteorological Organization, is defined as the 30-year average of meteorological parameters at a certain geographic place (Berger R, 2007). Various climatic variables, including rainfall, temperature, humidity, sunlight hour, and so on, have shown significant trends in different regions of the globe. Bangladesh is in the tropical monsoon area, with a climate defined by elevated temperatures, abundant rainfall, often extreme humidity, and significant seasonal fluctuations. It has dry and wet seasons. Due to climate change, Bangladesh is now one of the most climate-vulnerable states in the world, and it will become more so in the future. Floods, tropical cyclones, storm surges, and droughts are all expected to become more common and severe in the future years, according to climate scientists. In Bangladesh, the dry season is from November to March and the wet season is from April to October. During the dry and wet seasons, temperature, humidity, and rainfall change drastically. Temperature, precipitation, humidity, and wind speed fluctuations due to climate change have increased various problems throughout the world, including in Bangladesh. Khulna, Jessore, Satkhira, Barisal, Patuakhali, and Bhola is in the southwestern part of Bangladesh. Bangladesh is also known for its high humidity. When the water vapor content remains constant, whereas the temperature falls, the relative humidity rises. The relative humidity drops as the temperature rises, and the water vapor concentration remains constant. This is because colder air requires less moisture to become saturated than warmer air. The vapor has a significant impact on the dynamic properties of the global climate system. Humidity refers to the amount of water vapor in the air. In contrast, relative humidity encompasses the ratio of the current vapor pressure of the air to the saturated vapor pressure, which is usually stated as a percentage (Salman, 2020). Water vapor in the lower troposphere is the primary source of atmospheric precipitation and an essential component of the global water cycle. Moreover, water vapor is one of the greenhouse gases in the atmosphere, accounting for approximately 50% of the atmospheric greenhouse effect (Schmidt et al., 2010). Multiple climate models predict that the amount of water vapor in the atmosphere will rise because of global warming and that the additional water vapor

will exacerbate global warming due to the enhanced greenhouse effect, generating the increased destructive rebound. Bangladesh is a disaster-prone country. Over most of the western section of the country, March and April are the least humid months. In March, Dinajpur experienced the lowest average relative humidity (57%) of the year. January to March are the driest months in the eastern states. In March, Brahmanbaria recorded the lowest monthly average of 58.5 percent. From June to September, the relative humidity is somewhere over 80% everywhere. From 78.1 % in Cox's Bazar to 70.5 % in Pabna, the average relative humidity for the entire year is 78.1 % (Banglapedia, 2021). In this research, an attempt has been taken to analyze the spatial and temporal variation of humidity from 1974 to 2020 over a southwestern zone of Bangladesh.

2. Methodology

2.1 Study Area

In this study southwestern zone including Barishal, Bhola, Jessore, Khulna, Patuakhali, and Satkhira considered the study area. Barisal, Bhola, and Patuakhali districts belong to the Barisal division. Khulna, Satkhira and Jessore belongs to Khulna division. There are 19 coastal districts in Bangladesh, of which the above-mentioned districts are one of them. In these coastal districts, monsoon storms have a significant impact on agriculture. Figure1 illustrates the study area of the southwestern zone of Bangladesh.

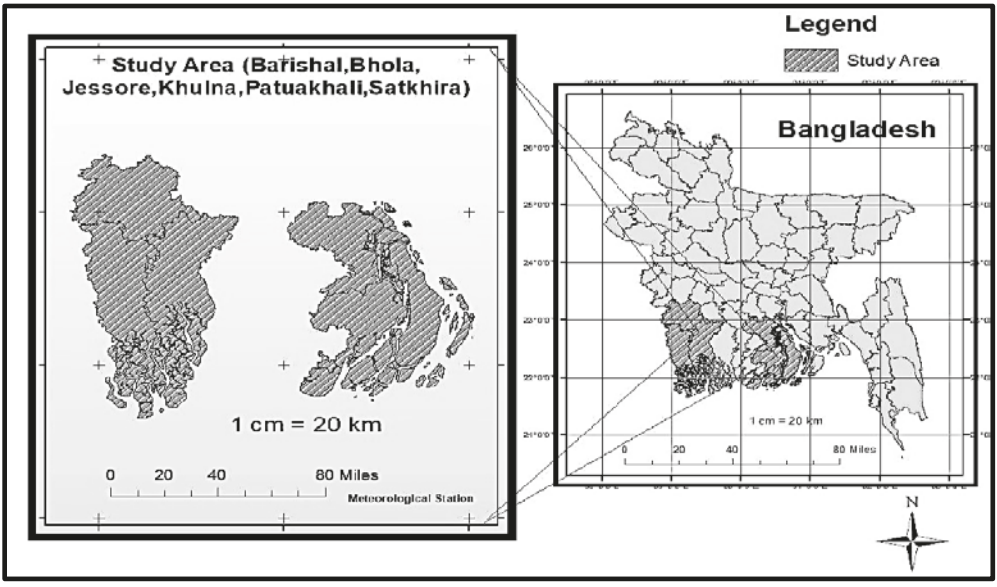

Figure 1: Study area of the south-western zone of Bangladesh

2.2 Geographic Location

Table-1: Geographic location of the study area

Station	Latitude	Longitude	Region
Barishal	22.717° N	90.367° E	Southwest
Bhola	22.683° N	90.650° E	Southwest
Jessore	23.184° N	89.161° E	West Central
Khepupara	21.983° N	90.2195° E	Southwest
Patuakhali	22.333° N	90.333° E	Southwest
Khulna	22.810° N	89.564° E	Southwest

2.3 Data Source and Methodology

The study used an empirical technique to investigate the temporal and spatial variation of humidity in Bangladesh's southwest and west-central regions over the last 46 years. The research utilized raw secondary data from 1974 to 2020 obtained from the Bangladesh Meteorological Department for 8 weather observation sites (BMD). The data has been analyzed by dividing the two seasons into 2 categories: dry and wet seasons. Microsoft Excel, python coding for time series analysis, and Arc GIS are used to analyze the spatial distribution map of the raw data. The majority of the graphs are bar charts, which are appropriate for demonstrating variation and trend analysis of mean humidity for the selected years 1974 to 2020. Regional variation in the humidity of BMD stations throughout the southern zone of Bangladesh has been illustrated using GIS software and the interpolation technique, which was implemented in this study.

$$m = \frac{sum\ of\ t_h\ e.terms}{number\ of\ terms} \quad \text{.....(1)}$$

Where,

m= mean

The following formula (equation -2) has been applied in to calculate the time series trend analysis of humidity from 1974 to 2020 over the southwestern and west-central zone of Bangladesh during the dry and wet season

$$y=bx+a \quad \text{.....(2)}$$

Where,

y - the dependent variable

x - the independent variable

a - the intercept

b - the slope

The following formula (equation -3) has been applied in to calculate the standard deviation of temperature, rainfall, and humidity from 1974 to 2020 over the south-western and west-central zone of Bangladesh during the dry and wet season

$$\sigma = \sqrt{\frac{\Sigma(xi - \mu)^2}{N}}$$

Where,

$\sigma =$ population standard deviation,

$N =$ the size of the population

$xi =$ each value from the population

$\mu =$ the population mean

3. Result and Discussion

3.1 Variation of Humidity Pattern over the southwestern zone of Bangladesh 1974 -2020

Figure 2 illustrates the seasonal variation of humidity in Khulna (1974-2020), the dry season. For this investigation, data on the relative humidity in Khulna is collected from Bangladesh Meteorological Department from 1974 to 2020. Bangladesh experienced significantly lower humidity during the dry season than in the wet season. Figure 2 shows that the relative humidity at Khulna in the dry season has quite an increasing trend. In the dry season, maximum mean humidity was observed at 78.6% in 2008 and minimum mean humidity was observed at 63% in 1974. In the dry season, the highest rate of humidity was found in January, November, and December. Humidity was above 80% in the mentioned months. There are two potential causes for the rising trend in humidity: one is related to increasing temperatures, and the other is due to increased land surface wetness.

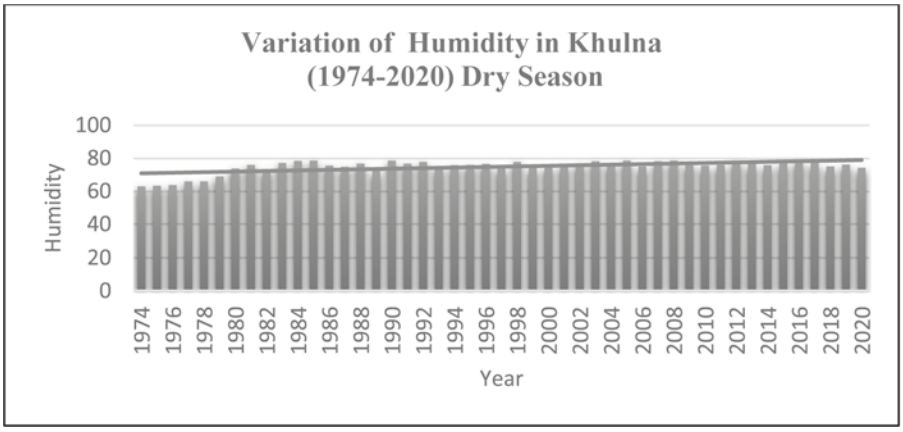

Figure 2: Seasonal variation of humidity in Khulna (1974-2020), dry season

Figure 3 illustrates the seasonal variation of humidity in Khulna (1974-2020), the wet season. For this investigation, data on the relative humidity in Khulna is collected from Bangladesh Meteorological Department from 1974 to 2020. During the dry season, Bangladesh experienced much lower humidity than in the wet season. Graph 3 shows that the relative humidity at Khulna in the wet season has quite a decreasing trend. In the wet season, maximum mean humidity was observed at 87.5 % in 1984 and minimum mean humidity was observed at 78.8 % in 1976. Based on historical statistics, the humidity level in Khulna is being substantially higher essentially every month during the wet seasons

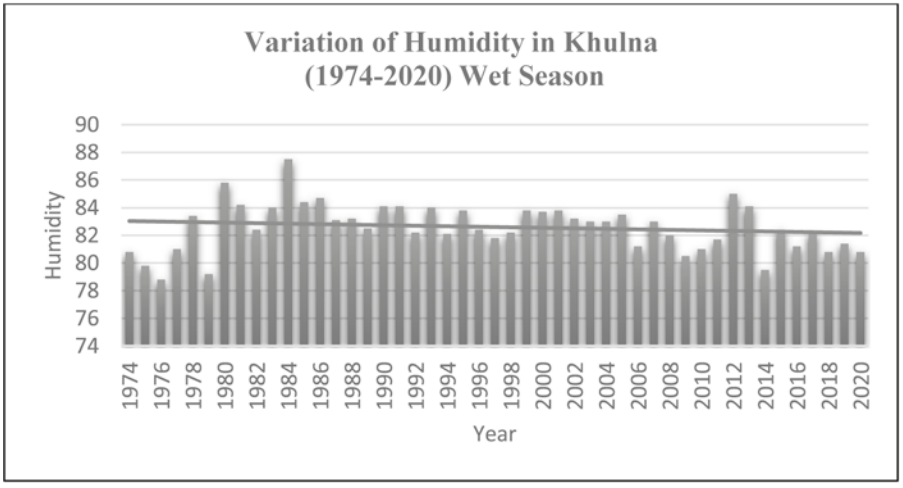

Figure 3: Seasonal variation of humidity in Khulna (1974-2020), wet season

Figure 4 depicts the seasonal variation of humidity in Jessore (1974-2020), the dry season. For this investigation, data on the relative humidity in Jessore is collected from Bangladesh Meteorological Department from 1974 to 2020. The dry season in Bangladesh has been much cooler than the wet season. Figure 4 shows that the relative humidity at Jessore in the dry season has quite an increasing trend. In the dry season, maximum mean humidity was observed at 78.8 % in 1998 and minimum mean humidity was observed at 65 % in 1975. Humidity has been on the increase over the past 10 years, from 1989 to 1999.

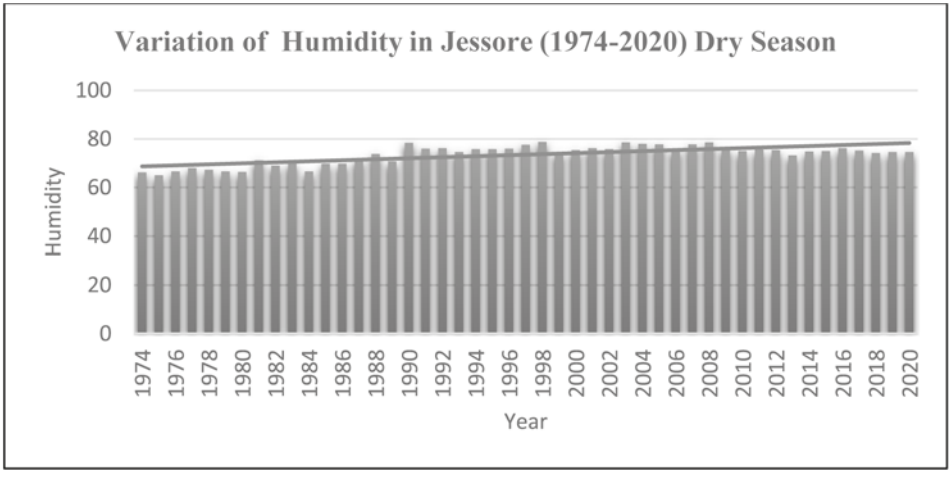

Figure 4: Seasonal variation of temperature in Jessore (1974-2020), dry season

Figure 5 depicts the seasonal variation of humidity in Jessore (1974-2020), the wet season. For this investigation, data on the relative humidity in Jessore is collected from Bangladesh Meteorological Department from 1974 to 2020. The dry season in Bangladesh often had less humidity than that of the wet season. Figure 5 shows that the relative humidity at Jessore in the wet season has quite a decreasing trend. In the wet season, maximum mean humidity was observed at 84 % in 1990 and minimum mean humidity was observed at 75.1 % in 1979. Humidity has been on the increase significantly since 1990 and 1993.

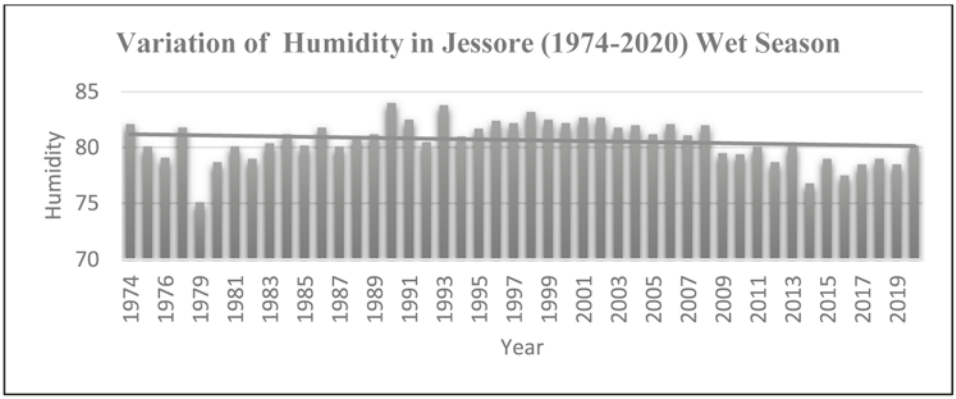

Figure 5: Seasonal variation of temperature in Jessore (1974-2020), wet season

Figure 6 depicts the seasonal variation of humidity in Mongla (1989-2020), during the dry season. For this investigation, data on the relative humidity in Jessore is collected from Bangladesh Meteorological Department from 1989 to 2020. Even during the dry season, Bangladesh received considerably low humidity than it was during the wet season. Figure 6 shows that the relative humidity at Mongla in the dry season has quite an increasing trend. In the dry season, maximum mean humidity was observed at 78.6 % in 2005 and minimum mean humidity was observed at 69.6 % in 1989. Between 1990 and 1993, the humidity level increased. In the following years, from 2003 to 2005 and 2009 to 2013 there is also a variety of humidity.

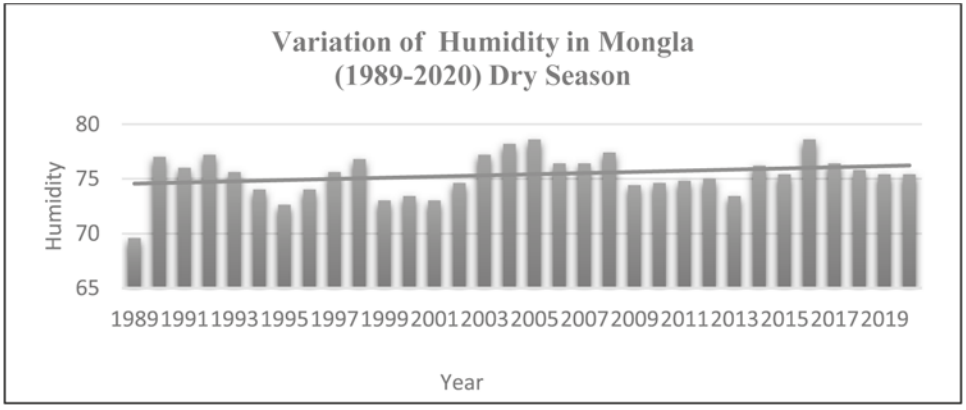

Figure 6: Seasonal variation of humidity in Mongla (1989-2020), dry season

Figure 7 illustrates the seasonal variation of humidity in Mongla (1989-2020), during the wet season. For this investigation, data on the relative humidity in Jessore is collected from Bangladesh Meteorological Department from 1974 to

2020. Bangladesh experienced significantly lower humidity during the dry season than in the wet season. Figure 7 shows that the relative humidity at Mongla in the wet season has quite a decreasing trend. In the wet season, maximum mean humidity was observed at 86.2 % in 2005 and minimum mean humidity was observed at 82.7 % in 2014. Humidity has been on the increase significantly from 2004 to 2006. From 2008 to 2019, humidity is rather low, but it began to rise again in 2020.

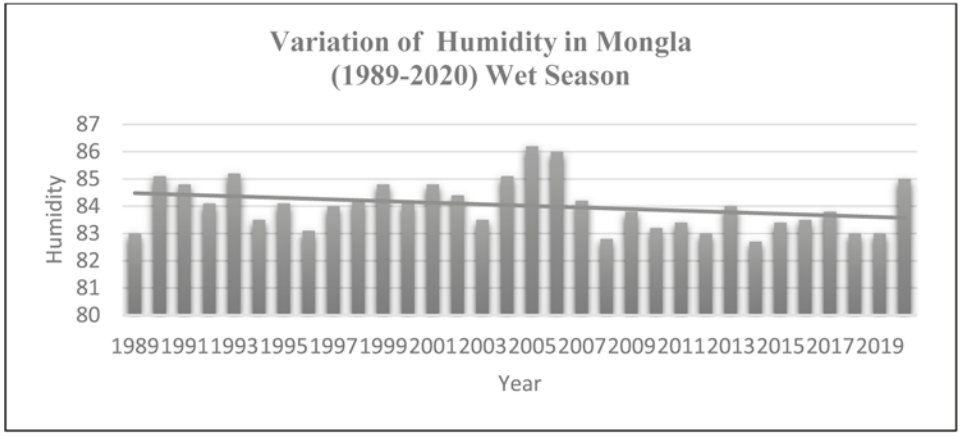

Figure 7: Seasonal variation of humidity in Mongla (1989-2020), wet season

Figure 8 depicts the seasonal variation of humidity in Satkhira (1974-2020), the dry season. For this investigation, data on the relative humidity in Jessore is collected from Bangladesh Meteorological Department from 1974 to 2020. Bangladesh experienced significantly lower humidity during the dry season than in the wet season. Figure 8 shows that the relative humidity at Satkhira in the dry season has quite an increasing trend. In the dry season, maximum mean humidity was observed at 79.2 % in 1998 and minimum mean humidity was observed at 58.4 % in 1984. In the following years, from 1982 to1988 there was also a variety of humidity.

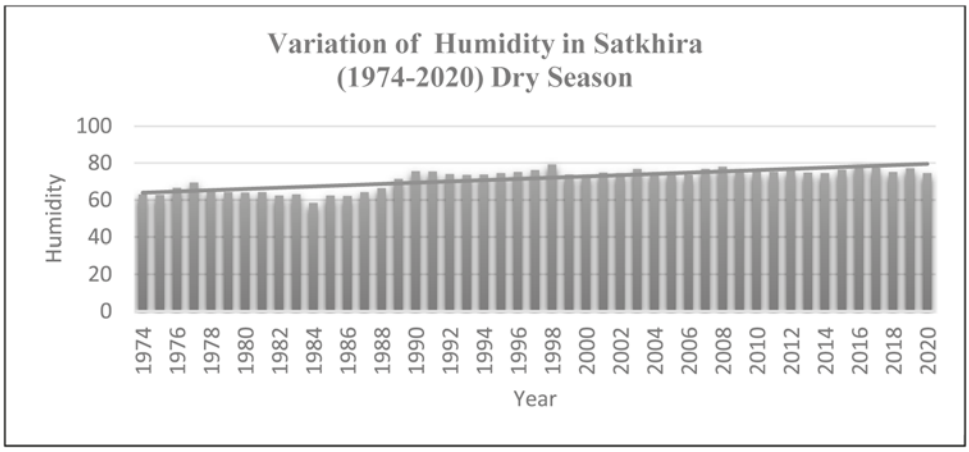

Figure 8: Seasonal variation of humidity in Satkhira (1974-2020), dry season

Figure 9 illustrates the seasonal variation of humidity in Satkhira (1974-2020), during the wet season. For this investigation, data on the relative humidity in Jessore is collected from Bangladesh Meteorological Department from 1974 to 2020. Figure 9 shows that the relative humidity at Satkhira in the wet season has quite an increasing trend. In the wet season, maximum mean humidity was observed at 82.8 % in 1997 and minimum mean humidity was observed at 72.7 % in 1979. Humidity has been on the decrease from 1979,1982 and 1984 to 1986. Humidity has been on the increase significantly from 1989 to 1992 and 1997 to 1999.

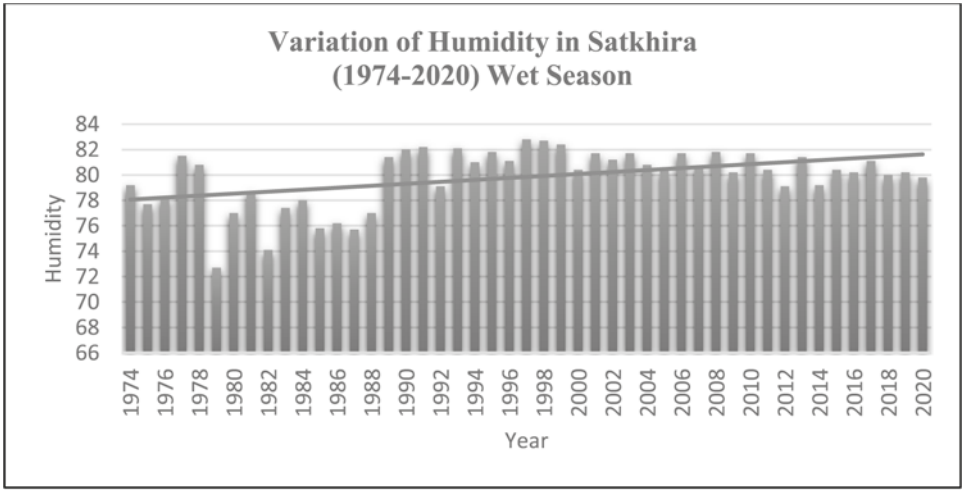

Figure 9: Seasonal variation of humidity in Satkhira (1974-2020), wet season

Figure 10 depicts the seasonal variation of humidity in Barishal (1974-2020), the dry season. For this investigation, data on the relative humidity in Barishal is collected from Bangladesh Meteorological Department from 1974 to 2020. Figure 10 shows that the relative humidity at Barishal in the dry season has quite an increasing trend.

In the dry season, maximum mean humidity was observed at 83.4 % in 1986 and minimum mean humidity was observed at 71.6 % in 1978. In the following years, from 1982 to1988, 1990 to 2005 there was also a variety of humidity.

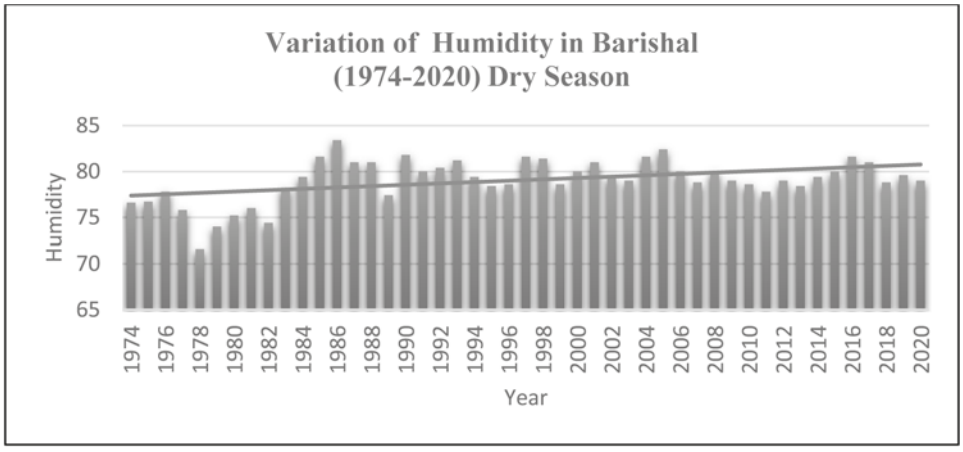

Figure 10: Seasonal variation of humidity in Barishal (1974-2020), dry season

Figure 11 illustrates the seasonal variation of humidity in Barishal (1974-2020), during the wet season. For this investigation, data on the relative humidity in Barishal is collected from Bangladesh Meteorological Department from 1974 to 2020. Figure 11 shows that the relative humidity at Barishal in the wet season has quite a decreasing trend. In the wet season, maximum mean humidity was observed at 88.4 % in 1975 and minimum mean humidity was observed at 82.4 % in 1982. Humidity has been on the decrease since 1976,1979,1982 and 2014. Humidity has been on the increase significantly from 1975, 1985,1993,2003, and 2017 .

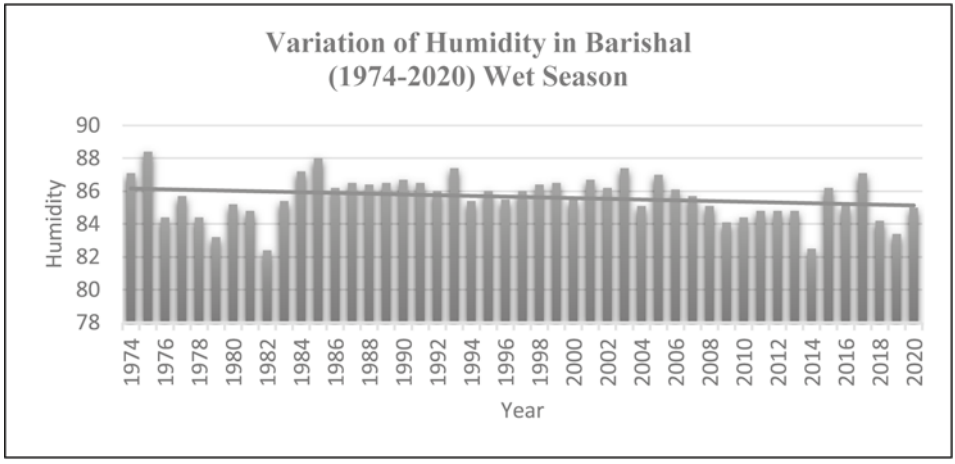

Figure 11: Seasonal variation of humidity in Barishal (1974-2020), wet season

Figure 12 depicts the seasonal variation of humidity in Bhola (1974-2020), the dry season. For this investigation, data on the relative humidity in Bhola is collected from Bangladesh Meteorological Department from 1974 to 2020. Figure 12 shows that the relative humidity at Bhola in the dry season has quite an increasing trend. In the dry season, maximum mean humidity was observed at 83.6 % in 1990 and minimum mean humidity was observed at 74.4 % in 1978. In the following years, from 1982 to1988 humidity has been increased significantly.

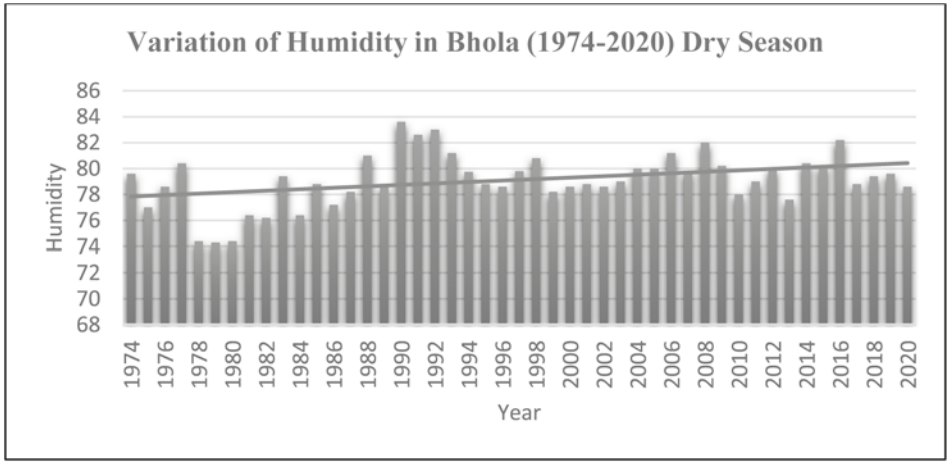

Figure 12: Seasonal variation of humidity in Bhola (1974-2020), dry season

Figure 13 illustrates the seasonal variation of humidity in Bhola (1974-2020), during the wet season. For this investigation, data on the relative humidity in Bhola

is collected from Bangladesh Meteorological Department from 1974 to 2020. Figure 13 shows that the relative humidity at Bhola in the wet season has quite a decreasing trend.

In the wet season, maximum mean humidity was observed at 89.5 % in 1991 and minimum mean humidity was observed at 82 % in 2017. Humidity has been on the decrease since 1982,1985,1986,2014, and 2017. Humidity has been on the increase significantly between 1974 and 1991.

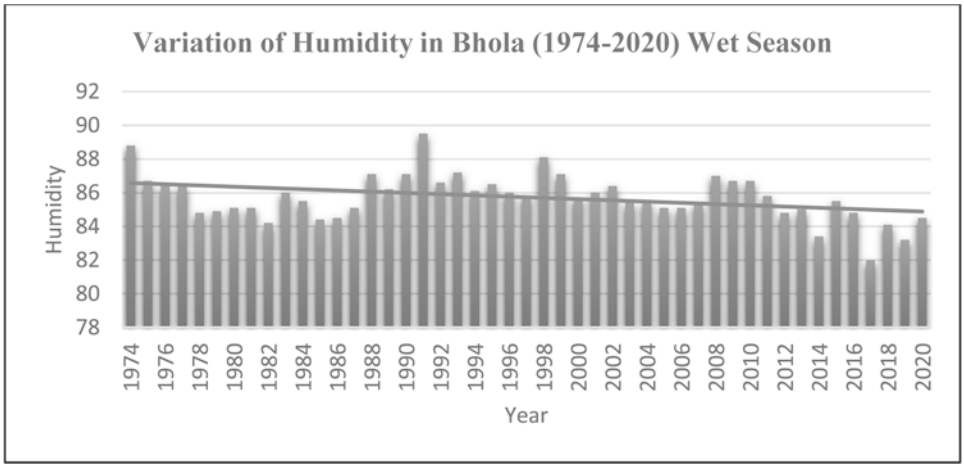

Figure 13: Seasonal variation of humidity in Bhola (1974-2020), wet season

Figure 14 depicts the seasonal variation of humidity in Patuakhali (1975-2020), the dry season. For this investigation, data on the relative humidity in Patuakhali is collected from Bangladesh Meteorological Department from 1975 to 2020. Figure 14 shows that the relative humidity at Patuakhali in the dry season has quite an increasing trend. In the dry season, maximum mean humidity was observed at 85.8 % in 2010 and minimum mean humidity was observed at 65 % in 1982. In the following years, between 2003 and 2010 humidity increased significantly.

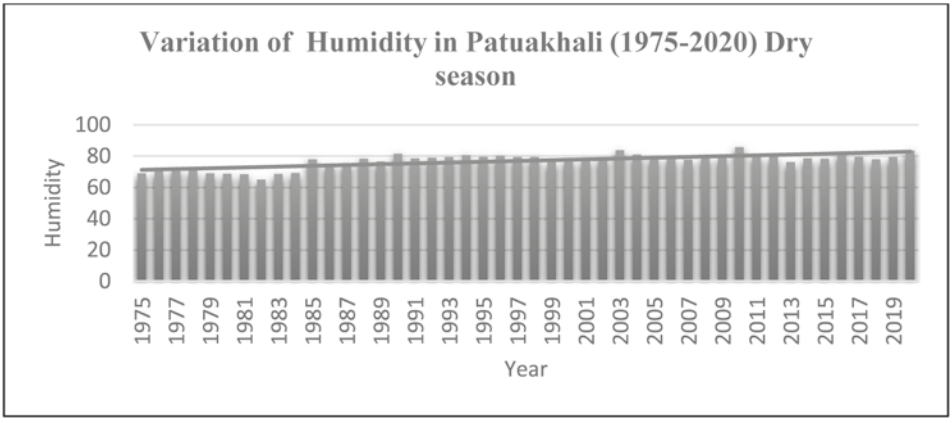

Figure 14: Seasonal variation of humidity in Patuakhali (1975-2020), dry season
Figure 15 illustrates the seasonal variation of humidity in Patuakhali (1974-2020), during the wet season. For this investigation, data on the relative humidity in Patuakhali is collected from Bangladesh Meteorological Department from 1974 to 2020. Figure 15 shows that the relative humidity at Patuakhali in the wet season has quite an increasing trend. In the wet season, maximum mean humidity was observed at 90.2 % in 2010 and minimum mean humidity was observed at 78.8 % in 1979. Humidity has been on the decrease since 1980 and 1982. Humidity has been on the increase significantly from 2001 to 2005, 2010, and 2020.

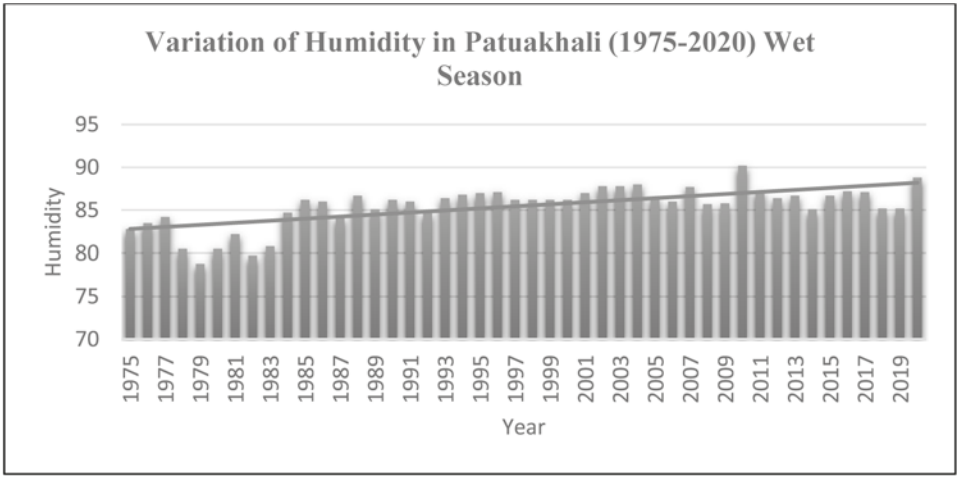

Figure 15: Seasonal variation of humidity in Patuakhali (1975-2020), wet season
Figure 16 depicts the seasonal variation of humidity in Khepupara (1974-2020), the dry season. For this investigation, data on the relative humidity in Khepupara is collected from Bangladesh Meteorological Department from 1975 to 2020.

Figure 16 shows that the relative humidity at Khepupara in the dry season has quite an increasing trend.

In the dry season, maximum mean humidity was observed at 89 % in 1987 and minimum mean humidity was observed at 57 % in 1979. In the following years, between 1985 and 1988 humidity increased significantly.

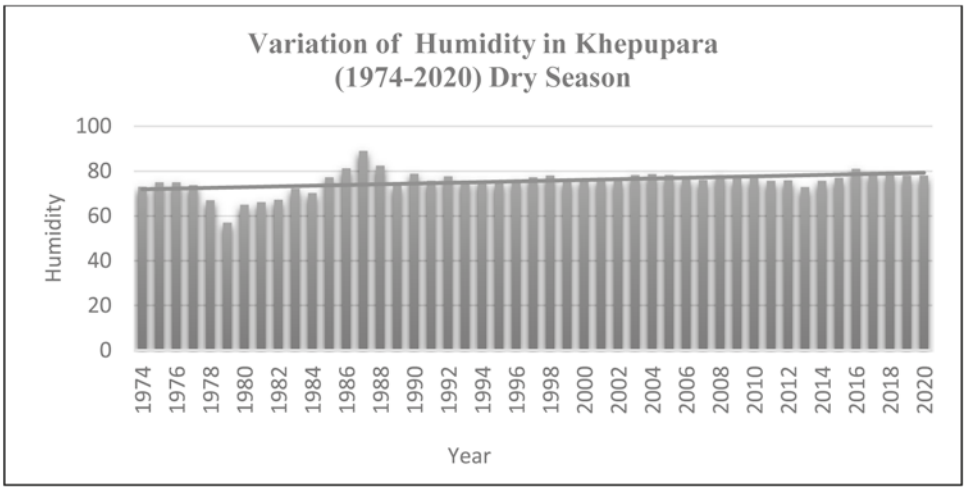

Figure 16: Seasonal variation of humidity in Khepupara (1974-2020), dry season

Figure 17 illustrates the seasonal variation of humidity in Khepupara (1974-2020), during the wet season. For this investigation, data on the relative humidity in Khepupara is collected from Bangladesh Meteorological Department from 1974 to 2020. Figure 17 shows that the relative humidity at Khepupara in the wet season has quite an increasing trend. In the wet season, maximum mean humidity was observed at 88 % in 1987 and minimum mean humidity was observed at 78.6 % in 1979. Humidity has been on the decrease from 1978 to 1980 and 1982 to 1985. Humidity has been on the increase significantly from 1986 to 1987 and in 2013.

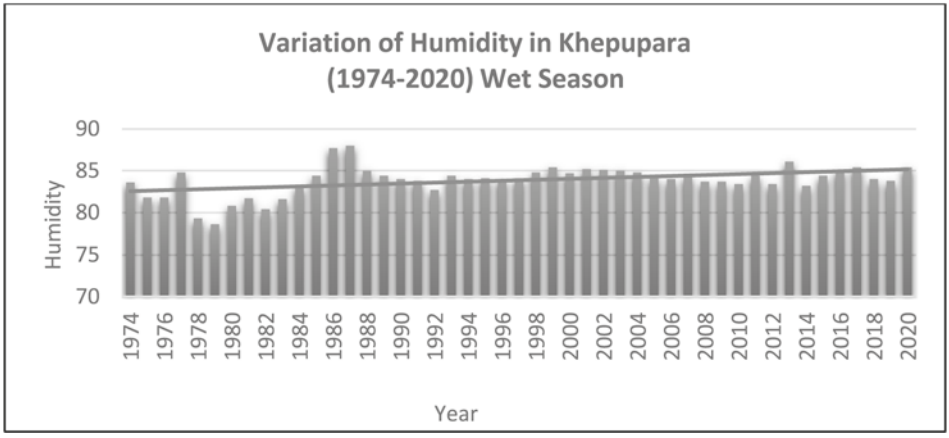

Figure 17: Seasonal variation of humidity in Khepupara (1974-2020), wet season

3.2 Spatial Distribution of Humidity over the Southwestern Zone of Bangladesh 1974 -2020

Figure 18 illustrates the spatial distribution of the mean annual humidity of the dry season (1974-2020) using the technique of inverse distance weighted (IDW) interpolation.

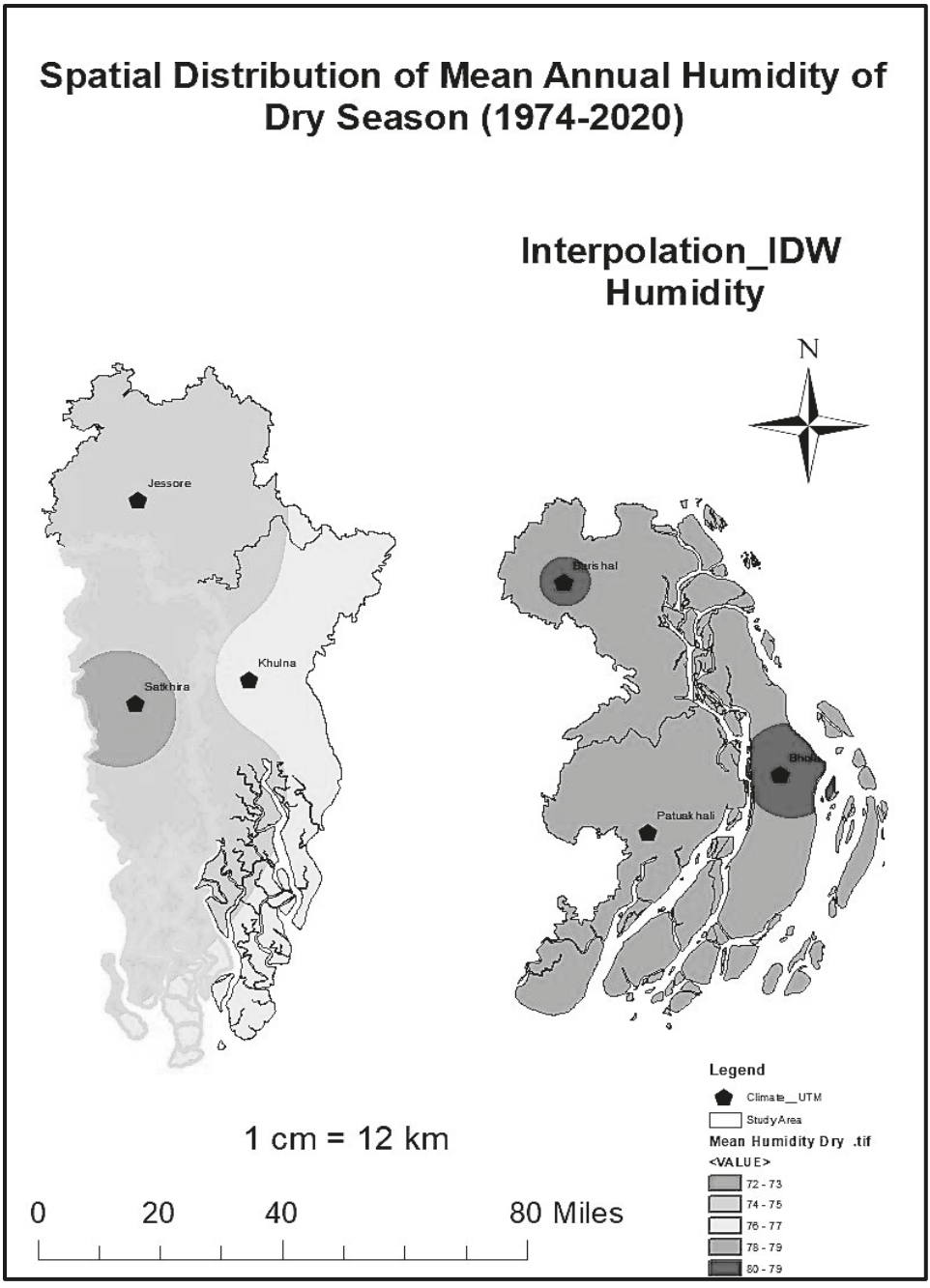

Figure 18: Spatial distribution of mean annual humidity of dry season (1974-2020) by using inverse distance weighted technique

Figure 19 illustrates the spatial distribution of the mean annual humidity of the dry season (1974-2020) using the kriging interpolation technique.

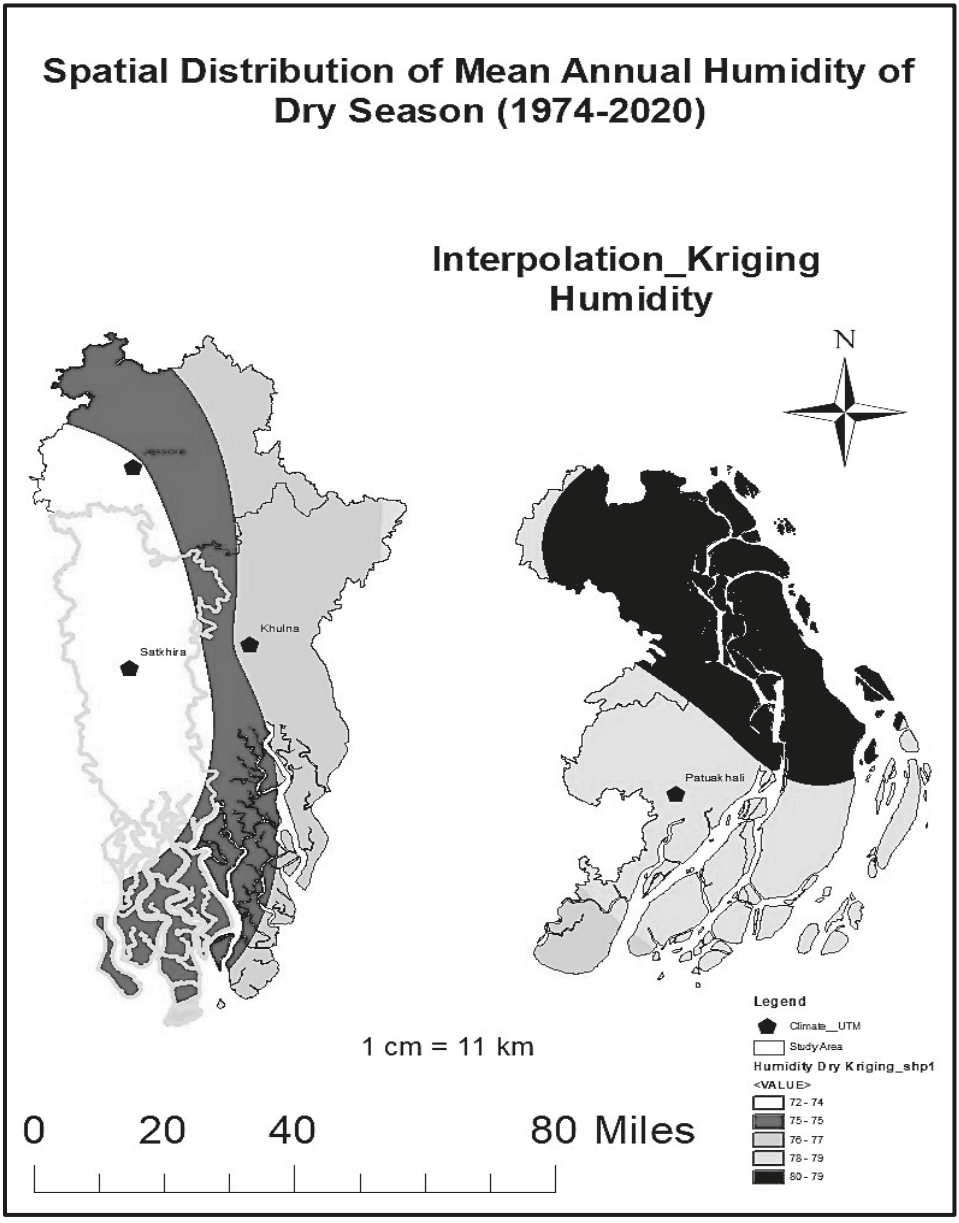

Figure 19: Spatial distribution of mean annual humidity of dry season (1974-2020) by using the kriging technique

The spatial distribution map of figures 18 and 19 shows that in the dry season highest humidity is 79 % at Bhola and the lowest at 71% at Satkhira.

Figure 20 illustrates the spatial distribution of the mean annual humidity of the wet season (1974-2020) using the technique of inverse distance weighted (IDW) interpolation.

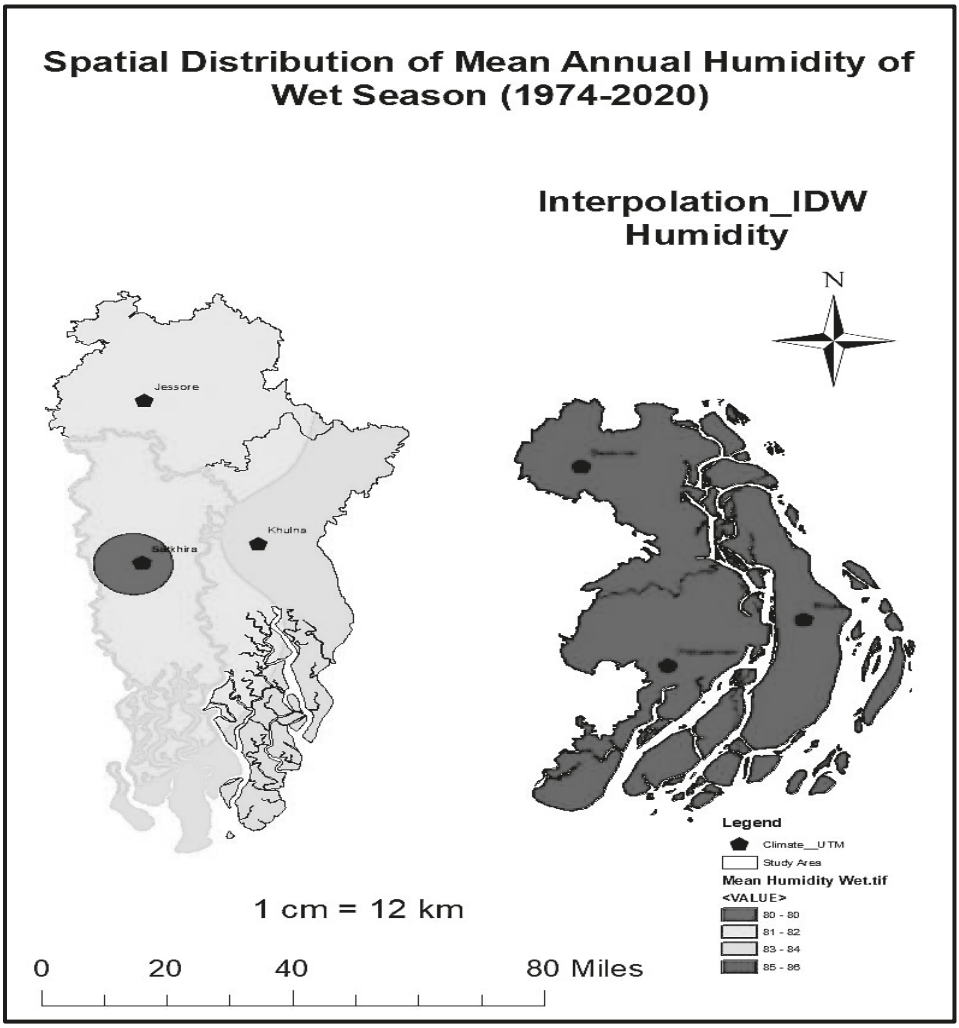

Figure 20: Spatial distribution of mean annual humidity of wet season (1974-2020) by using inverse distance weighted technique

Figure 21: illustrates the spatial distribution of the mean annual humidity of the wet season (1974-2020) using the Kriging interpolation technique.

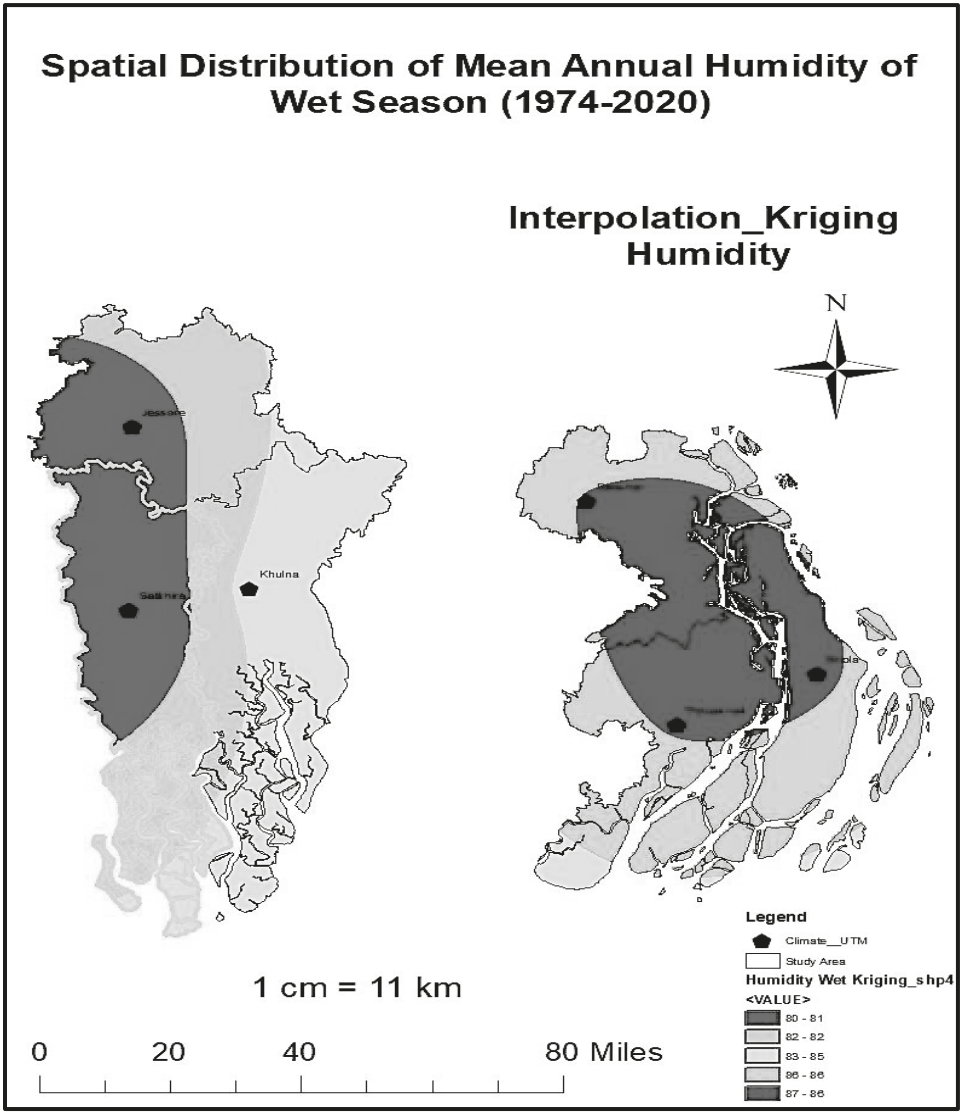

Figure 21: Spatial distribution of mean annual humidity of wet season (1974-2020) by using the kriging technique

The spatial distribution map of figures 20 and 21 shows that in the wet season highest humidity is 85 % at Bhola and the lowest at 79% at Satkhira.

3.3 Comparative Variation of Humidity in the Southwestern Zone of Bangladesh

Figure 22 illustrates the comparative analysis of mean annual humidity in the southwestern zone of Bangladesh wherein the wet season Bhola area has the maximum mean humidity at 85.7% and mean minimum humidity of 79.8 % in the Satkhira area. In the dry season, the Bhola area has the maximum mean humidity of 79.2 % and the minimum mean humidity of 71.7% in the Satkhira area.

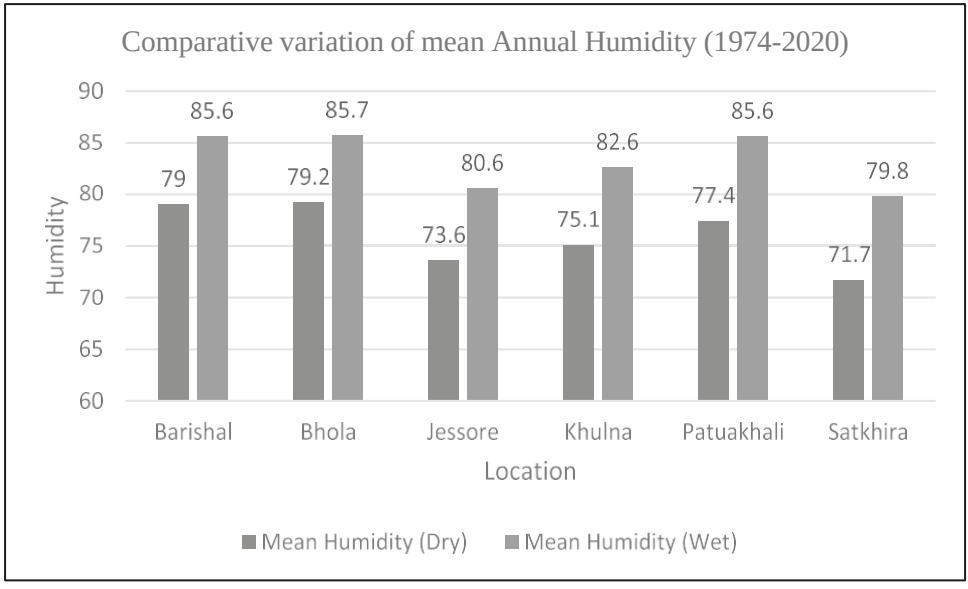

Figure 22: Comparative analysis of mean annual humidity in the southwestern zone of Bangladesh

4. Conclusion

This study assessed the spatial and temporal variation of humidity over the southwestern zone of Bangladesh from 1974 to 2020. Analysis of dry and wet season data of the last 50 years shows that dry season humidity was always upward while wet season humidity was downward in the southwestern region of Bangladesh. However, especially in the Patuakhali region, the trend of humidity

was on the rise during the wet season. The average monthly relative humidity ranges from 45 % in March to 79 % in June, with an average annual relative humidity of 65.8%. The ideal humidity is 30 to 60 %. However, an analysis of the data from the last 50 years in the southwestern region of Bangladesh indicates that humidity has always been above 70% or more in the dry season and above 80% or more in the wet season. Due to climate change, there has been a huge fluctuation in humidity in the southwestern region of Bangladesh.

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