Geological Behavior (GBR)

DOI: http://doi.org/10.26480/gbr.02.2024.155.163

ISSN: 2521-0890 (Print)
ISSN: 2521-0491 (Online)
CODEN: GBEEB6

RESEARCH ARTICLE

TREND ANALYSIS OF RELATIVE HUMIDITY IN KHULNA OF BANGLADESH FROM HISTORICAL DATA

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ARTICLE DETAILS

Article History:

Received 21 August 2023
Revised 24 September 2024
Accepted 27 October 2024
Available online 11 November 2024

ABSTRACT

Bangladesh, despite having a subtropical climate, is characterized by dry winters and hot summers, ranks top among the most vulnerable countries to climate change. In recent years, climate change has drawn significant attention from academics, researchers, and policymakers worldwide. This study examines the trends in annual and monthly relative humidity in Khulna, Bangladesh, over a 15-year period (2007-2021). Its aim is to provide updated insights into weather patterns, particularly relative humidity, in Khulna. Secondary data on rainfall, temperature, and relative humidity were obtained from the Regional Inspection Center (RIC) of the Bangladesh Meteorological Department in Gollamary, Khulna. Mean, standard deviation (SD), and coefficient of variation (CV), were calculated to assess the annual and monthly distribution of relative humidity. Trend analyses were conducted applying bivariate analysis, and linear regression was utilized to examine the relationship between relative humidity and time. The associations between relative humidity and temperature, as well as between relative humidity and rainfall, were also assessed. Additionally, annual and monthly thermal heat index (THI) values were calculated. The findings revealed that annual relative humidity remained relatively stable, with minimal deviation across the years. Mean monthly relative humidity fluctuated significantly, ranging from 71.60% to 87.27%, following a tri-modal distribution pattern. When plotted against years, annual relative humidity showed a negative but non-significant trend ($y = -0.0823x + 245.86$, $R^2 = 0.0646$). Most months showed a declining trend in average relative humidity, with the most substantial and statistically significant reduction occurring in September. THI levels were generally uncomfortable for the human body across most months and years. Monthly average relative humidity displayed a negative relationship with mean monthly temperature and a positive association with mean monthly rainfall. Both relationships were found to be statistically significant ($p < 0.001$). This study highlights the urgent need for adaptive strategies to ensure sustainable agricultural productivity in Khulna and recommends improved monitoring systems due to the variability and uncertainty in relative humidity patterns.

KEYWORDS

Bangladesh, Khulna, Relative humidity, Trend, Thermal-heat index.

1. INTRODUCTION

Climate change and its effects, particularly global warming, have emerged as key issues of the 21st century, impacting a wide range of human activities (Andersen et al., 2006; Raimi et al., 2021; Guan et al., 2021; Huang et al., 2022). Global warming, compelled by the increasing accumulation of greenhouse gases in the atmosphere, is believed to affect the overall hydrological cycle (IPCC, 2007). The impacts of climate change become even more severe when associated with extreme events, especially in regions where vulnerable populations or valuable assets are at risk (Trenberth et al., 2007). Bangladesh, located in South Asia, is particularly susceptible to climate-related risks due to its unique geographical features, such as its flat topography, riverine flooding, rising sea levels, low elevation, high population density, and heavy reliance on natural resources (Jahan and Ali, 2017; Ara et al., 2022; Harmeling, 2008; Rajib et al., 2012). The country's climate is distinguished by elevated temperatures, heavy rainfall, and seasonal variations, setting it apart from other tropical regions (Hossain et al., 2014). Notably, Bangladesh ranks 7th on the Global Climate Risk Index 2021, developed by Germanwatch, which highlights the countries most at risk from climate-related disasters (Chowdhury, 2023).

In recent decades, numerous studies have focused on climate patterns, particularly rainfall and temperature, to examine how global warming has affected both global and local climates since climate change became more pronounced in the 1980s. A key concern is how global warming impacts humidity, which in turn influences human health (Mortuza et al., 2013). Atmospheric water vapor, a significant greenhouse gas, plays a critical role in regulating earth's climate due to the large amount of energy exchanged as water shifts between vapor, liquid, and solid phases (Abu-Taleb et al., 2007). On the surface, humidity is a crucial meteorological factor that affects human comfort (Changnon et al., 1996). Relative humidity (RH), which depends on temperature and water vapor concentration, significantly impacts atmospheric visibility and promotes the formation of clouds, fog, and smog (Elliott and Angell, 1997). RH also plays a key role in determining rainfall distribution, the intensity of tropical storms, and has far-reaching effects on terrestrial and aquatic ecosystems (Willett et al., 2007).

Quick Response Code	Access this article online	
	Website: www.geologicalbehavior.com	**DOI:** 10.26480/gbr.02.2024.155.163

Cite The Article: Md. Sarwar Jahan (2024). Trend Analysis of Relative Humidity in Khulna of Bangladesh from Historical Data. *Geological Behaviour 8(2): 155-163.*

Agriculture, the main pillar of Bangladesh's economy, plays a vital role in the livelihoods of its population, contributing 12.91% to the domestic GDP, reducing poverty, and ensuring food security. Approximately 42.7% of the population is employed in agriculture, with around 60% dependent on it for their livelihoods (Chowdhury, 2023). However, the sustainability of agriculture in Bangladesh is heavily influenced by climate, as the sector relies on natural conditions. Predicted climate change impacts, including rising temperatures, altered rainfall patterns, humidity shifts, prolonged droughts, and flooding, are expected to directly affect crop yields (Abrol and Ingram, 1996; Adams et al., 1998; Mendelsohn, 2008; Mendelsohn and Reinsborough, 2007; Mendelsohn et al., 1994).

The southwestern coastal region of Bangladesh, including Khulna, has a unique saline water ecosystem due to tidal effects. This area, consisting of low-lying lands surrounded by man-made polders, is highly vulnerable to climate change-related hazards. The region faces heightened susceptibility to water-related disasters due to extreme weather variability, which is influenced by the spatial and temporal distribution of water resources (Mondal et al., 2013; Shariot-Ullah et al., 2021). Additionally, the region is challenged by socio-economic hardships and frequent disasters such as heavy rainfall, flooding, cyclones, salinity, and prolonged droughts (Bhuiyan et al., 2018). Bangladesh requires effective policy measures to address climate change challenges. Empowering local communities and valuing local resources are essential for sustainable adaptation to climate change. Monitoring climate variability at the local level and enabling communities to develop their own adaptation strategies is the most effective way to build resilience.

Investigating long-term trends in climate variables and evaluating their statistical significance are essential tools for detecting climate change (Huth and Pokorna, 2004). Although many scholars worldwide have studied the impacts of climate change, few have explored trends in relative humidity compared to temperature and rainfall. Studies on relative humidity trends indicate varied patterns globally. The study observed a significant declining trend in relative humidity across Canada from 1953 to 2003 (van Wijngaarden and Vincent, 2003). In contrast, others found an increase in seasonal and annual relative humidity in Jordan (Abu-Taleb et al., 2007). An analysis reported a declining trend in average relative humidity in arid and semi-arid regions, particularly in recent years up to 2000 (Kousari and Zarch, 2010).

In Khulna, Bangladesh, studies on climatic variables, particularly relative humidity, are limited. The analysis of examined temperature and rainfall variability over 20 years (2003-2022) in Khulna, finding upward trends for temperature but declining pattern for precipitation (Jahan et al., 2024a, 2024b). After analyzing data from 1961 to 2010, research concluded that relative humidity in most parts of southern coastal Bangladesh ranged from 78% to 82% (Mortuza et al., 2013). The study reported relatively high humidity in Khulna, ranging from 80% to 90% Acharjee et al., 2020). Another research noted the lowest relative humidity in Khulna (75.16%) in 2003 and the highest (82.41%) in 1977 (Choudhury et al., 2014). A group of researcher through bivariate analysis of data from 1974 to 2020 for six stations in southwestern Bangladesh, found a declining trend in monsoon season humidity and an increasing trend in dry season humidity for Khulna (Hasan and Hoque, 2022). And it is a common agreement that continuous monitoring of climatic variables is crucial for climate forecasting, extreme weather prediction, drought detection, and agricultural production.

This study focuses on how climate change manifests at the local level in southern Bangladesh, with the objective of identifying trends in relative humidity on both annual and monthly scales over the period 2007–2021 in Khulna, Bangladesh.

2. METHODOLOGY

2.1 Study Area

Khulna district is located between latitudes 21°41' and 23°00' N and longitudes 89°14' and 89°45' E, along the banks of the Rupsha and Bhairab rivers, at an altitude of 9.0 meters above sea level (Fig. 1). According to Köppen's climate classification, Khulna has a tropical wet and dry climate (Wikipedia, 2024). With average daily maximum temperatures exceeding 30°C, it is one of the hotter regions in Bangladesh. The area experiences significant seasonal variation in relative humidity, ranging from 65% to 86% throughout the year. July is particularly uncomfortable, with an average humidity of 86%, while March offers some relief with a lower average humidity of 65% (Weather and Climate, 2024).

2.2 Data Collection and Tabulation

The investigation utilized secondary data, with climatic information sourced by researchers from the Regional Inspection Center (RIC) of the Bangladesh Meteorological Department (BMD) in Gollamary, Khulna. Monthly data on relative humidity (%), temperature (°C), and rainfall (mm) were gathered for the period 2007–2021. After data collection, it was meticulously compiled and thoroughly reviewed. A master sheet was then created to organize the data, integrating all individual variables into a comprehensive dataset.

2.3 Temperature-humidity index (THI)

The Temperature-Humidity Index (THI), a type of thermal stress index, is calculated using temperature and humidity data. It is useful for assessing heat and cold stress throughout the year, as it examines the impact of temperature and humidity on human activities (Rosu et al., 2022). The various categories of the THI, which indicate conditions of cold and heat stress based on the perceived temperature of the human body, are outlined in Table 1 (Yao et al., 2021). The THI is calculated using the following equation:

$$THI = (1.8 \times T + 32) - 0.55\,(1 - H/100) \times (1.8 \times T - 26)$$

Where, THI is the temperature-humidity index, T is the air temperature in ^{0}C and RH is the relative humidity.

Table 1: Temperature-humidity index (THI) classification standards (the shaded value is the value range where the human body feels comfortable).

THI value	Human sensation	Symbol	Comfort class
≤ 40	Extremely cold	e	Extremely uncomfortable
40-45	Cold	d	Uncomfortable
45-55	Slightly cold	c	Less comfortable
55-60	Cool	b	Sub-comfort
60-65	Slightly cool	A	Comfort
65-70	Warm	B	Sub-comfort
70-75	Hotter	C	Less comfortable
75-80	Sultry	D	Uncomfortable
≥80	Extremely stuffy	E	Extremely uncomfortable

2.4 Data Analysis

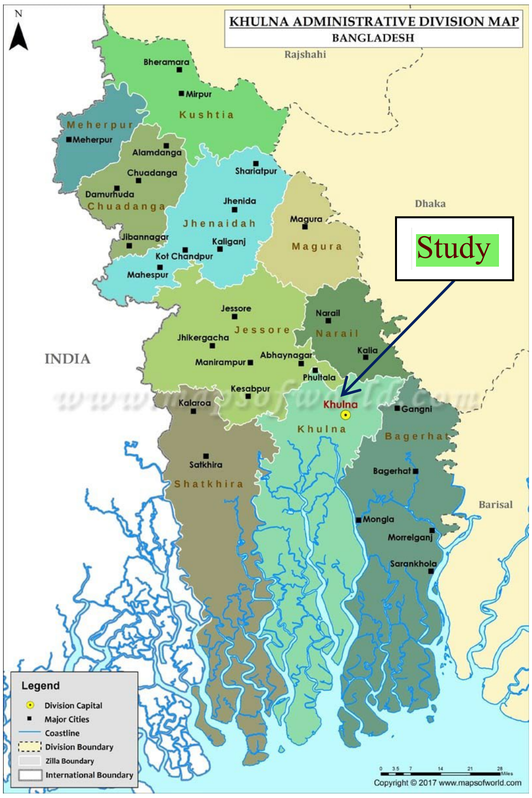


Figure 1: Location of Khulna in Bangladesh (Source: Maps of World, 2022-2024).

A trend is defined as the general direction of a data sequence over an extended period or the long-term change in a dependent variable over time (Webber and Hawkins, 1980). In this study, trends were identified by analyzing the relationship between relative humidity and the time period. Regression analysis (parametric test), a method used to estimate the relationship between a dependent variable and one or more independent variables, was applied to examine the functional relationship between years and the average monthly relative humidity. Additionally, the mean, range, standard deviation, and coefficient of variation for relative humidity were calculated using MS Excel.

3. RESULTS AND DISCUSSION

3.1 Variability in Relative Humidity during 2007-2021.

The relative humidity in Khulna from 2007 to 2021, expressed as a percentage, is presented in Table 2. An analysis of seasonal relative humidity (%) over this 15-year period revealed no significant variations between different years. The data showed a narrow range of relative humidity (78.33%–82.75%), with most values falling between 79% and 83%, and an average of 80.09%. These findings align with those, who reported that the average relative humidity in the Khulna division was 80.30% between 1976 and 2015 (Chowdhury et al., 2018). A different study also observed that the average relative humidity across Bangladesh was around 79% during 1972–2014 (Chowdhury and Khan, 2015). Similarly, after analyzing 50 years of data (1961–2010), it was found that relative humidity in most parts of southern coastal Bangladesh ranged from 78% to 82% (Mortuza et al., 2013). Others also concluded that Khulna experiences relatively high humidity, ranging from 80% to 90% (Acharjee et al., 2020). Given this narrow range of relative humidity, fluctuations are unlikely to have significant impacts (Enete et al., 2011).

Table 2: Mean monthly relative humidity (%) in Khulna over years (2007-2021)

Year	Mean monthly relative humidity (%)
2007	82.00
2008	80.92
2009	78.75
2010	78.33
2011	78.67
2012	82.75
2013	80.83
2014	78.83
2015	81.42
2016	81.25
2017	80.50
2018	78.75
2019	80.33
2020	79.25
2021	78.33
Mean (%)	80.09

Table 2 shows that the highest average relative humidity was recorded in 2012 (82.75%), closely followed by 2007 (82.00%). The lowest values were observed in 2010 and 2021 (78.33%). The years with average relative humidity below the mean occurred in 2009, 2010, 2011, 2014, 2018, 2020, and 2021, while the years exceeding the mean were 2007, 2008, 2012, 2013, 2015, 2016, 2017, and 2019 (Table 2). A group identified the lowest relative humidity (75.16%) in Khulna during 2003 and the highest (82.41%) in 1977 (Choudhury et al., 2014). Similarly in their analysis of 20 years (1995–2014) of humidity data from southeastern Nigeria, reported minor fluctuations, with a minimum of 66.09% in 2011 and a maximum of 87.33% in 2007 (Ogbonna and Urhibo, 2022). They also noted that although the variations in relative humidity were not significant, it is important for concerned personnel to remain vigilant, as changes in humidity could negatively impact crop growth.

3.2 Relationship between Years and Relative Humidity

The analysis of the relationship between monthly average relative humidity (%) and years revealed a slight but insignificant declining trend ($y = -0.0823x + 245.86$, $R^2 = 0.0646$) (Fig. 2), indicating a small decrease in average monthly relative humidity over the study period. Although the total reduction in mean monthly relative humidity was 1.23% (with a yearly decline of 0.0823%), the low R^2 value of 0.0646 suggests that the relationship between relative humidity and time is complex and not well represented by a simple linear model. These findings align with who reported an annual reduction of 0.0366% in mean relative humidity for Khulna from 1981 to 2020, indicating a general declining trend in the region (Islam et al., 2024). Similarly, Syeda (2020) documented a negative growth rate in annual average relative humidity for Dhaka, Bangladesh. Another study also found a decrease in annual relative humidity in northeastern Bangladesh. That research using regression analysis on data from 1974 to 2020 for six stations in southwestern Bangladesh, observed a declining trend in wet season humidity and an increasing trend in dry season humidity for Khulna (Hasan and Hoque, 2022). Likewise, researches conducted a trend analysis of annual relative humidity for two stations (Al Ain and Western Region) in the UAE over a 31-year period (1979–2010). Their results showed a statistically non-significant declining trend ($p > 0.05$) at both stations.

3.3 Variation in Monthly Relative Humidity

The analysis of monthly relative humidity trends over time has provided a detailed understanding of humidity distribution in Khulna. January, the first month of the year, had an average relative humidity of 79.47% (Table 3). In February, there was a slight decline, with an average humidity of 74.40%. March saw a further decrease, averaging 71.70% - the lowest relative humidity recorded during the study period (2007–2021). In April, the mean relative humidity rose slightly to 72.67%, beginning to impact the region's ecosystems. Over the 15-year period, Khulna experienced a little higher humidity in May, with an average of 76.20%, indicating a noticeable climate shift due to increased precipitation. Humidity continued to rise in June, reaching an average of 83.33%, suggesting significant rainfall during this month. July recorded the highest relative humidity in Khulna, with an average of 87.27%, highlighting the climatic instability and signaling the onset of the monsoon season. August followed closely with an average relative humidity of 86.06%, nearly matching September's 86.07%, indicating the gradual end of the rainy season. In October, the average relative humidity dropped to 83.07%, marking the conclusion of the monsoon. November saw a further decrease to 79.40%, while December recorded 81.80% relative humidity. These findings align with who analyzed humidity data from Khulna (1984–2013) and reported a maximum average relative humidity in July (86.3%) and a minimum in March (70.40%) (Acharjee et al., 2020). Similarly, others observed that for Bangladesh between 1976 and 2015, July had the highest average relative humidity (86.67%) and March the lowest (68.16%) (Islam et al., 2018). The study noted that average relative humidity in Aceh Besar, Indonesia (2011–2020), ranged between 72% and 85% over months of the year (Chairani, 2022).

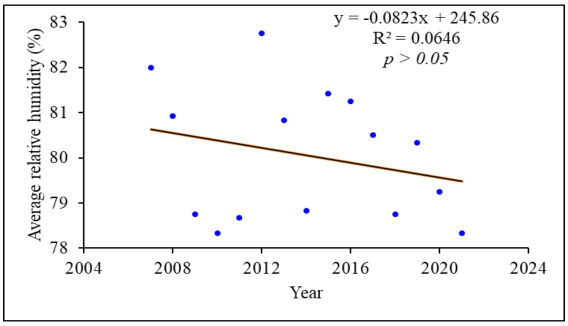


Figure 2: Functional relationship between years and average relative humidity (%).

Table 3: Monthly average relative humidity (%) in Khulna over years (2007-2021)

Month	Average relative humidity (%)	Range (%)	Standard deviation (%)	CV (%)
January	79.47	75-84	2.32	2.93
February	74.40	71-78	2.20	2.95
March	71.60	68-75	2.80	3.91
April	72.67	65-78	3.52	4.84
May	76.20	72-81	2.81	3.68
June	83.13	80-86	1.92	2.31
July	87.27	84-91	2.09	2.39
August	86.07	84-91	1.83	2.13
September	86.07	81-91	2.55	2.96
October	83.07	76-87	3.49	4.03

November	79.40	76-87	2.92	3.68
December	81.80	76-86	3.25	3.98

The standard deviation (SD) and coefficient of variation (CV) for average monthly relative humidity in Khulna were the highest in April (3.52% and 4.84%), indicating greater variability, and the lowest in August (1.83% and 2.13%), suggesting more stability during that month. These results are consistent with who found a higher SD of 3.50% in March and a lower SD of 1.60% in July for Khulna (Acharjee et al., 2020). By contrast, reported minimal variation in relative humidity in Southeast Nigeria, with an SD and CV of 0.48% and 0.06%, respectively, over the period 1995–2014 (Ogbonna and Urhibo, 2022). The researcher monthly relative humidity in Aceh Besar, Indonesia, finding the highest SD and CV in August (5% and 0.067%) and the lowest in March and November (2% and 0.028%) (Chairani, 2022).

The monthly trends in average relative humidity in Khulna from 2007 to 2021 showed a tri-modal distribution pattern, with peaks in July, August, and September, followed closely by October. The smallest peak occurred in April (Fig. 3), followed by March.

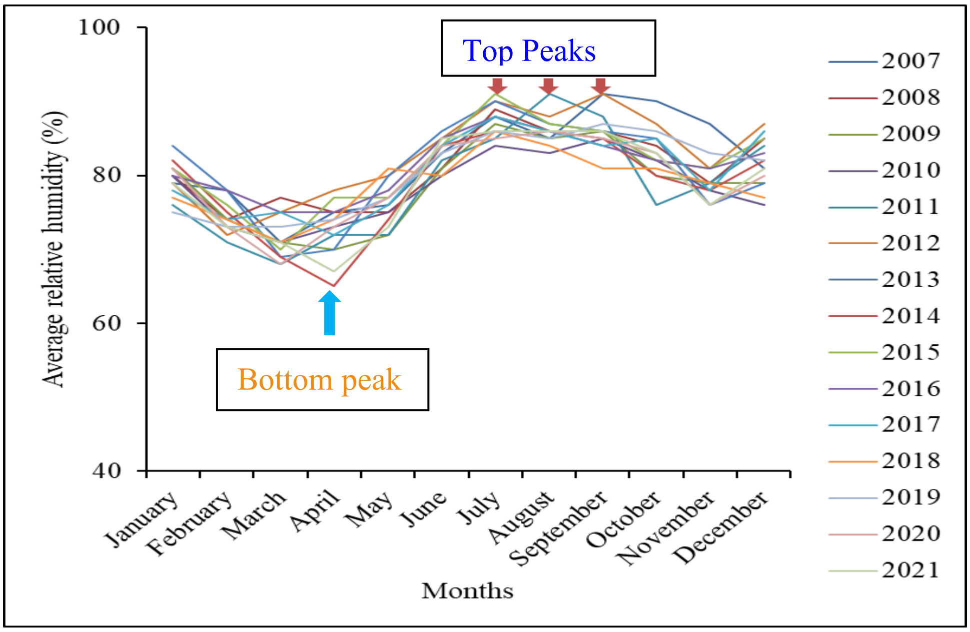


Figure 3: Monthly trends in average relative humidity (%) in Khulna over 15 years.

3.4 Trend Analysis of Monthly Mean Relative Humidity

The trends in mean monthly relative humidity from 2007 to 2021 were analyzed using linear regression. The regression models, along with their respective equations and coefficients of determination (R^2), for each month from January to December, are presented in Fig. 4 (a) and Fig. (b), and summarized in Table 4. As shown in these figures, mean monthly relative humidity increased only in May and June, while it declined in all other months. In Khulna, the largest increase in mean monthly relative humidity occurred in June, with a 2.46% rise over the past 15 years. Conversely, the most significant reduction was seen in September, with a 4.17% decrease during the same period. These findings contrast with study, which observed an increasing trend in relative humidity for all months in Barishal, Bangladesh, between 1961 and 2018 (Salman and Ahmed's, 2015). In Barishal City, the highest increase in relative humidity was in December (0.8256%) and the smallest in September (0.1186%) per year, with overall increases of 47.88% in December and 6.88% in September.

Table 4: Regression equations for all the months in a year (2007-2021) of mean monthly relative humidity (%) in Khulna

Month	Regression equation	R^2	p value
January	$y = -0.1107x + 302.45$	0.0453	0.306
February	$y = -0.0821x + 239.84$	0.0279	0.391
March	$y = -0.0786x + 229.84$	0.0158	0.519
April	$y = -0.1536x + 381.96$	0.0381	0.392
May	$y = 0.1607x - 247.48$	0.0655	0.478
June	$y = 0.1643x - 247.74$	0.1461	0.284
July	$y = -0.1036x + 295.86$	0.0493	0.265
August	$y = -0.0286x + 143.61$	0.0049	0.540
September	$y = -0.2786x + 647.11$	0.2390	0.036^{**}
October	$y = -0.0536x + 109.96$	0.0051	0.654
November	$y = -0.2464x + 575.71$	0.1422	0.112
December	$y = -0.0250x + 132.15$	0.0012	0.750

** Significant at 5% level

This difference in relative humidity trends between Khulna and Barishal could be attributed to locational variations and different data sets. The geographic position of the area selected for the study, the magnitude to which it is influenced by solar radiation, and the characteristics features of the atmosphere for this site, all these conditions have impact on the climatic elements. Two possible reasons for the rising trend in humidity are linked to increasing temperatures and greater land surface moisture (Hasan and Hoque, 2022).

As study suggest, if water vapor levels remain constant and temperatures drop, relative humidity increases (Salman and Ahmed, 2020). The data analysis also conducted a trend analysis of yearly relative humidity for two stations (Al Ain and Western Region) in Abu Dhabi from 1979 to 2010 (George et al., 2016). Their analysis showed a statistically significant decreasing trend for Al Ain in March, April, and August, while the Western Region experienced significant decreases in February, March, April, June, October, and December.

3.5 Relationship between Relative humidity, Temperature and Rainfall

When plotted against average monthly temperature, mean monthly relative humidity produced a straight line, revealing a negative but significant relationship between the two climate variables (Fig. 5). The resulting regression equation was $y = -1.0028x + 107.01$, indicating that for each degree Celsius increase in temperature, relative humidity decreased by 1%. The R^2 value of 0.0409 suggests that over 4% of the variation in relative humidity can be explained by changes in temperature. Additionally, a positive, linear and significant association was found between mean monthly relative humidity and average monthly rainfall (Fig. 6). The regression equation derived was $y = 0.0215x + 76.779$, with an R^2 value of 0.1991. This indicates that for each millimeter increase in precipitation, there is a corresponding increase of 0.0215% in relative humidity. The R^2 value suggests that about 20% of the variation in relative humidity can be attributed to fluctuations in rainfall. The researcher in their study on the impact of climatological factors on relative humidity in the Yangtze River Delta of Iran, identified temperature as the most significant factor affecting relative humidity, noting that rising temperatures led to decreased humidity (Yao et al., 2021). Examined the potential influence of variations in air temperature over land and sea surfaces on changes in relative humidity (Vicente-Serrano et al., 2018). Their results indicated that reductions in relative humidity are linked to increases in global temperatures or a decrease in water supply due to evapotranspiration. Higher temperatures play a critical role in increasing dryness in tropical regions, which could severely impact agricultural productivity and food security (Hadipour et al., 2020).

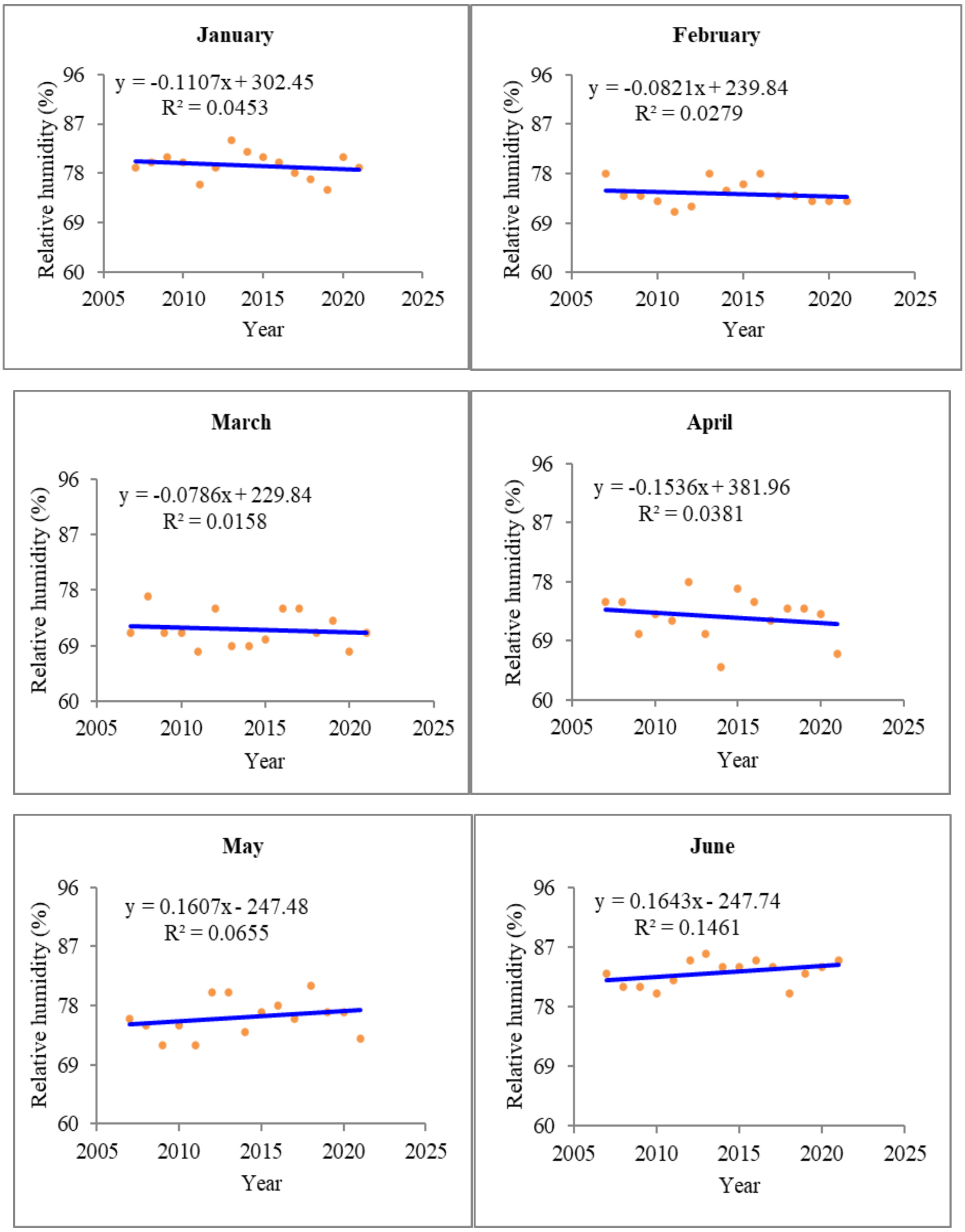
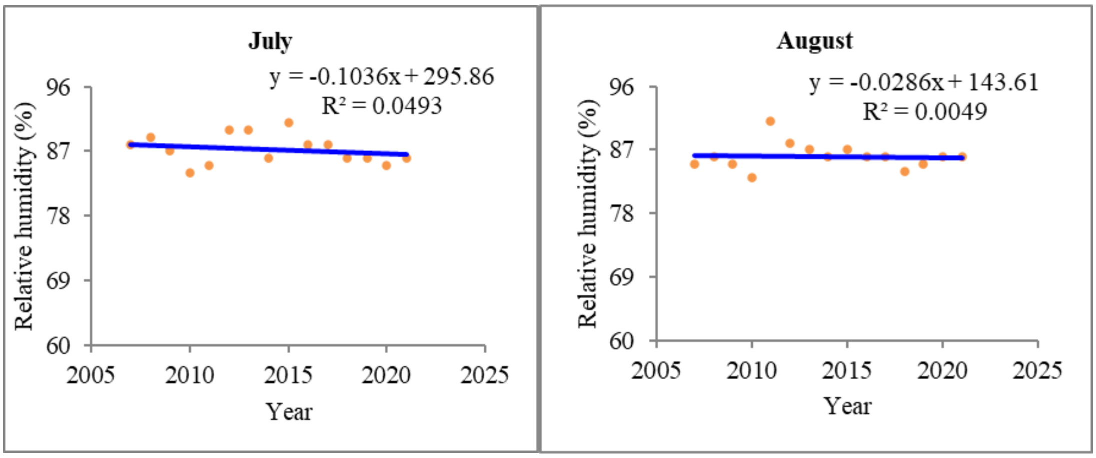


Fig. 4 (a).



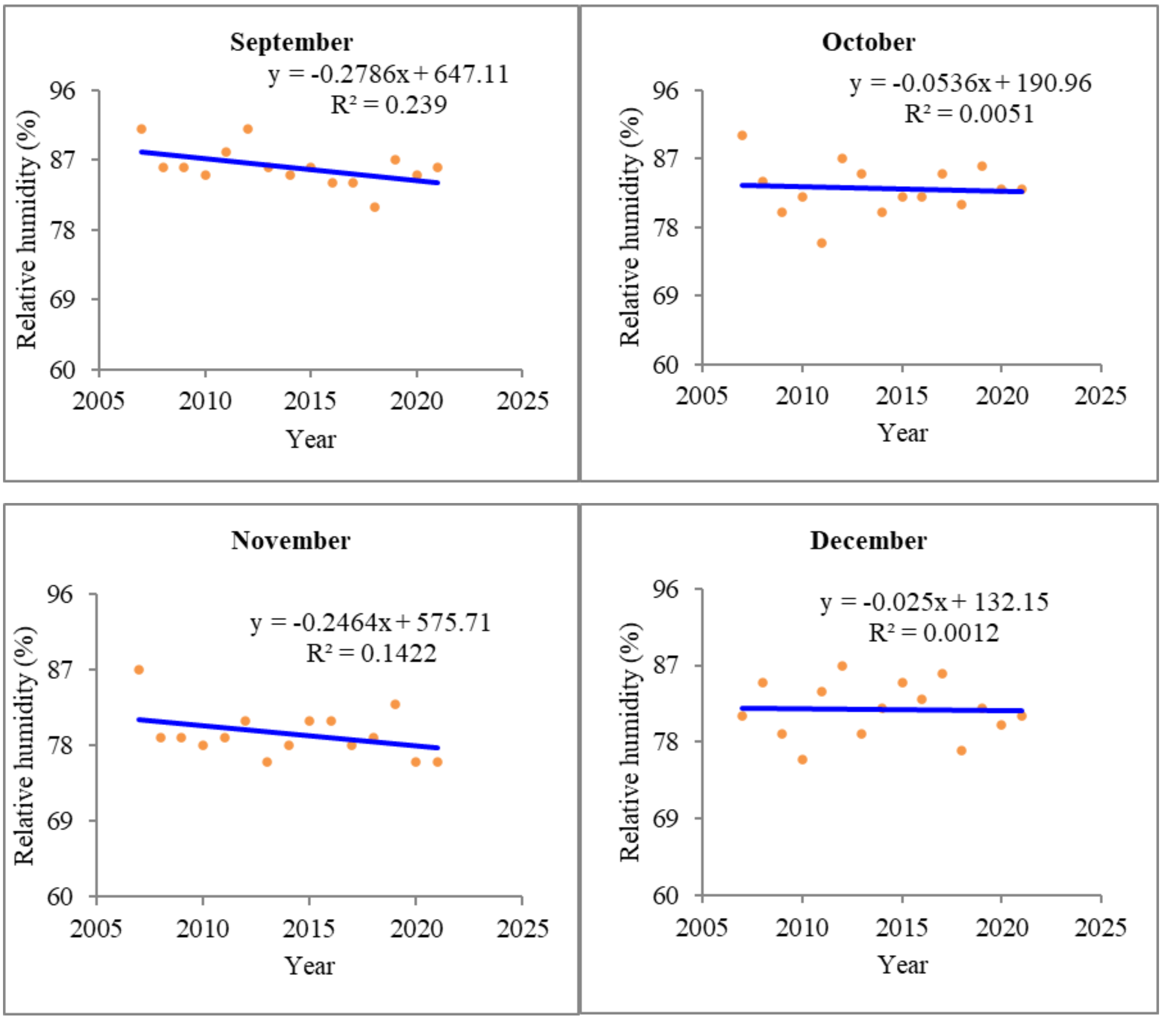


Fig. 4 (b).

Figure 4: (a), and 4 (b). Trend analyses of mean monthly relative humidity (%) in Khulna over years.

Several researchers have reported a trend of rising temperatures and declining relative humidity in various parts of Iran, particularly in the northern regions. Studies have documented increasing trends in both minimum and mean temperatures, alongside decreasing average relative humidity in arid and semi-arid areas of Iran (Kosari and Zarch, 2010; Karimi et al., 2020; Bahrami and Mahmoudi, 2022).The research established that higher temperatures correlate with lower relative humidity, adding that the drying rate of materials is faster, and moist air reduces evaporation (Ajadi and Sanusi, 2013). However, the relationship between temperature and humidity can vary by region. The study noted that inconsistencies in relative humidity affect expected precipitation, with heavy rainfall occurring when relative humidity exceeds 80% (Mawonike and Mandonga, 2017). Furthermore, found a strong negative correlation between mean monthly relative humidity and average monthly temperature in a 10-year climate study (2011–2020) in Aceh Besar District, Indonesia, while also documenting a moderate positive correlation between mean annual rainfall and average relative humidity during the same period (Chairani, 2022).Tried to draw relationship between temperature and relative humidity in three governorates of Baghdad, Mosul and Muthanna, Iraq taking two years climate data (2012 and 2013) (Al-Saadi and Jaber, 2023). Their results indicated an inverse relationship between the temperature as a whole and the relative humidity, as well evident from the negative values of the correlation coefficient (r) between temperature and relative humidity for most of the months in the year.

3.6 Temperature-humidity index (THI)

Table 5 presents the annual characteristics of the Temperature-Humidity Index (THI) in Khulna, Bangladesh, over the past 15 years. The THI values ranged narrowly from 77.12 to 78.93, with an average of 77.91. The highest THI was recorded in 2016, while the lowest occurred in 2011, although the variations were not statistically significant. The years that reported THI values below the mean were 2007 (77.19), 2008 (77.57), 2011 (77.12), 2013 (77.65), 2014 (77.70), 2018 (77.59), and 2020 (77.65).

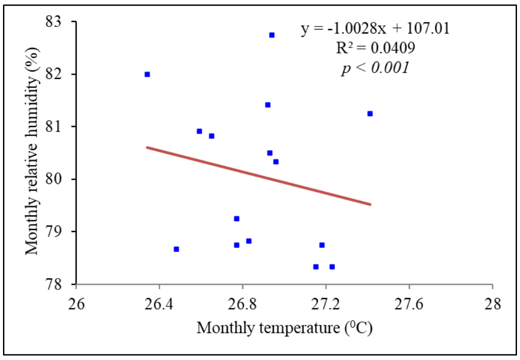


Figure 5: Functional association between mean monthly relative humidity (%) and mean monthly temperature (^{0}C) in Khulna over time (2007-2021).

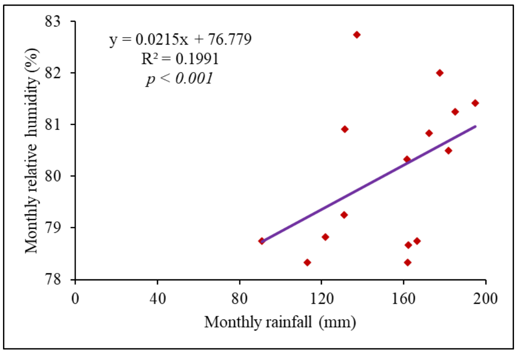


Figure 6: Functional relationship between mean monthly relative humidity (%) and mean monthly rainfall (mm) during 2007-2021 in Khulna.

In contrast, the years with THI values above the average included 2009 (78.24), 2009 (78.27), 2012 (78.36), 2015 (78.16), 2016 (78.93), 2017 (78.06), 2019 (78.09), and 2021 (78.14). The results of this study suggest that the THI levels may be perceived as uncomfortable for the human body. The study reported in their study from China that annual THIs ranged from 49.71-54.77 over 60 years (Yao et al., 2021).

Table 5: Yearly temperature-humidity index (THI) category values of Khulna in Bangladesh.

Year	THI value	Human sensation	Symbol	Comfort class
2007	77.19	Sultry	D	Uncomfortable
2008	77.57	Sultry	D	Uncomfortable
2009	78.24	Sultry	D	Uncomfortable
2010	78.27	Sultry	D	Uncomfortable
2011	77.12	Sultry	D	Uncomfortable
2012	78.36	Sultry	D	Uncomfortable
2013	77.65	Sultry	D	Uncomfortable
2014	77.70	Sultry	D	Uncomfortable
2015	78.16	Sultry	D	Uncomfortable
2016	78.93	Sultry	D	Uncomfortable
2017	78.06	Sultry	D	Uncomfortable
2018	77.59	Sultry	D	Uncomfortable
2019	78.09	Sultry	D	Uncomfortable
2020	77.65	Sultry	D	Uncomfortable
2021	78.14	Sultry	D	Uncomfortable
Mean	77.91	Sultry	D	Uncomfortable

The monthly THI values for Khulna were calculated for the period from 2007 to 2021 and have been presented in Table 6. Monthly THI values ranged from 65.30 in January to 83.72 in August, with an average of 77.94. The hotter months of the year, associated with the highest levels of heat stress and discomfort, include April, May, June, July, August, September, and October. March was also identified as a month of discomfort, while December, January, and February were classified as sub-comfortable based on human sensation. November was categorized as less comfortable.

Table 6: Monthly temperature-humidity index (THI) category values in Khulna, Bangladesh.

Month	THI value	Human sensation	Symbol	Comfort class
January	65.30	Warm	B	Sub-comfort
February	69.92	Warm	B	Sub-comfort
March	77.30	Sultry	D	Uncomfortable
April	81.95	Extremely stuffy	E	Extremely uncomfortable
May	83.24	Extremely stuffy	E	Extremely uncomfortable
June	83.17	Extremely stuffy	E	Extremely uncomfortable
July	83.47	Extremely stuffy	E	Extremely uncomfortable
August	83.72	Extremely stuffy	E	Extremely uncomfortable
September	83.16	Extremely stuffy	E	Extremely uncomfortable
October	80.81	Extremely stuffy	E	Extremely uncomfortable
November	74.69	Hotter	C	Less comfortable
December	68.62	Warm	B	Sub-comfort
Mean	77.94	Sultry	D	Uncomfortable

The increase in THI values above the mean was particularly evident from April and continued through October. Overall, the data indicate high thermal stress during the summer and monsoon months, characterized by elevated THI values, while lower values were observed in December and January. These findings align with those of who identified June, July, and August as the hottest months of the year in northern Iran, marked by significant heat stress and discomfort (Solaimani et al., 2023). They similarly recognized December, January, and February as the cold months of the year, mirroring our results. The research reported comparable findings in China after analyzing monthly THI data over a 60-year period (1960–2010) (Yao et al., 2021). They found that THI values were lower in December, January, and February, with a slight increase in November, and higher values during the remaining months. According to their study, monthly THI values ranged from 29.24 to 68.57, with the lowest in January and the highest in July.

4. CONCLUSION

This study was conducted to inspect unevenness in relative humidity in Khulna of Bangladesh by means of historic data from 2007 to 2021. The analysis of annual relative humidity revealed narrow fluctuations, with the highest relative humidity of 82.75% recorded in 2012 and the least relative humidity of 78.33% in 2010 and 2021. The average monthly relative humidity was obtained the maximum in July, while the lowermost relative humidity was found in March. Yet again, the seasonal trends in mean relative humidity in Khulna over the years (2007-2021) showed a tri-modal distribution array, with July, August and September being the peak months. The study also denoted that average monthly relative humidity amplified only in May and June, while it shrank in the rest ten months of the year. Over the study period, the annual average relative humidity decreased by 1.23%. The most significant decrease was realized in September; with a 4.17% reduction during 2007-2021. Moreover, the average relative humidity was inversely and directly linked to average temperature and average rainfall, respectively. The THI across months suggested that most of them bear humidity that is uncomfortable for human skin. The present study offers important insights and a new point of view for decision makers, allowing them to initiate useful activities in response to climate change. The findings of the present study are also helpful in choosing climate resilient options for different parts of Bangladesh, as well as for directing climatology studies and evaluating the consequence of climate modification across the country. If climate alterations progress in the forthcoming days, they will possibly create substantial negative impacts on the climate of Khulna as well as on Bangladesh. Based on the study's outcomes, it is important to focus that water resources encounter serious threats in the perspective of a changing climate. Therefore, future innovative studies need to be carried out with to study climate change in Bangladesh and its waves on the global level.

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Cite The Article: Md. Sarwar Jahan (2024). Trend Analysis of Relative Humidity in Khulna of Bangladesh from Historical Data. *Geological Behaviour 8(2): 155-163.*