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TREND ANALYSIS OF RELATIVE HUMIDITY IN THE AGRO CLIMATIC ZONES (ZONES II &IIIA) OF BIHAR

1. Climate change is one of the most serious environmental issues for humankind in the present world. India is still a part of this wave. The most obvious effects of climate change in India, aside from a few minor difficulties, are changes in agricultural production and forest cover (Balasubramanian and Birundha, 2012; Nageswara rao *et al*., 2018). In recent years, India has experienced severe weather conditions, which have resulted in irregular weather patterns, reduced agricultural productivity and ultimately sluggish economic growth (Shah and Srivastava, 2017). In the context of crop production, RH has a direct impact on plant water relations and an indirect impact on leaf growth, photosynthesis, pollination, disease occurrence and economic yield. RH plays an important role in climate impact studies and has the potential to be a very insightful tool for climate research. Understanding climatic patterns is critical because climate change is linked to several global challenges such as food insecurity, water scarcity, biodiversity loss and health issues. According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2013), the global mean surface temperature is increasing quasi-linearly with cumulative greenhouse gas emission. As a result, assessing the characteristics of climatic elements is critical for understanding temporal and spatial variability at local, regional and global scales. Trend analysis has become the most commonly used technique for identifying regional and local climatic variability (Amadi *et al*., 2014). It is a method for extracting underline pattern of behaviour in time series data, as well as the science of studying changes in pattern in a time series.

Recently, there are many studies have been conducted to investigate trends in various climatic parameters especially in temperature and precipitation in India (Das *et al*., 2020; Chakma and Biswas, 2022; Datta *et al*., 2022; Singh and Kumar, 2022; Sarkar and Kumar, 2023), but very few study have been done on relative humidity data. Rao *et al*. (2004) studied in annual mean relative humidity at 15 urban sites and observed substantial increasing trend at most the locations. In northwest and central India, Singh *et al*. (2008) observed increasing at six river basins and decreasing trend pattern in three river basins. Jaswal and Koppar, (2011) shown evidence of significant increase in atmospheric moisture content with trends in annual mean specific humidity and relative humidity showing increase at 89% and 75% IMD stations, respectively. In Western Rajasthan, Kundu *et al*.

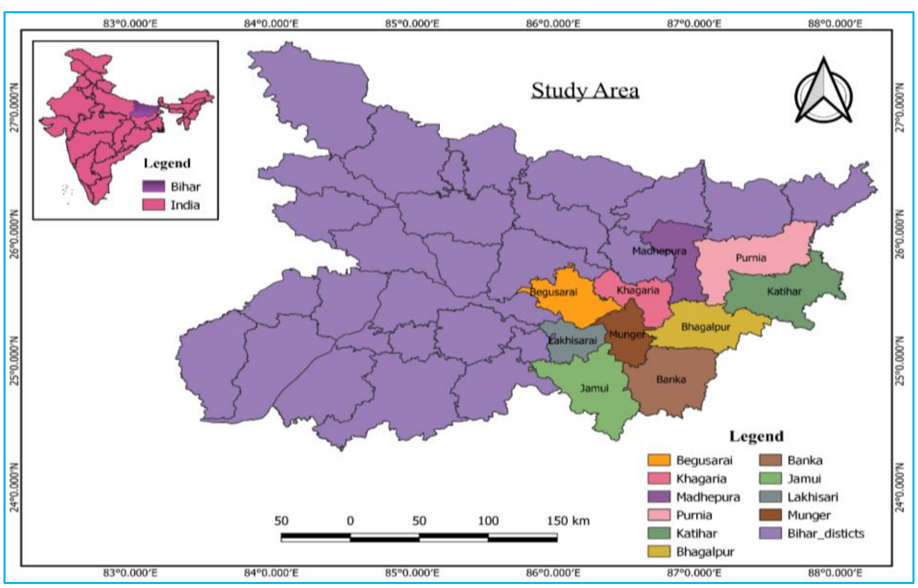

Fig. 1. Geographical map of study area

TABLE 1

Lat. and Long. coordinates of study area

Location	Lat.	Long.
Begusarai	25.4988° N	86.122° E
Bhaglpur	25.2446° N	86.9717° E
Jamui	24.9225° N	86.2256° E
Kathihar	25.5571° N	87.5568° E
Khagaria	25.511° N	86.4724° E
Lakhisarai	25.1676° N	86.0953° E
Madhepura	25.9163° N	86.7934° E
Munger	25.3657° N	86.4878° E
Purnia	25.7768° N	87.4743° E
Banka	24.8854° N	86.924° E

(2015) found the decreasing trends patterns. Furthermore, Farooq and Kumar (2021) also reported that spatial and temporal changes in relative humidity and found the no statistically significant trends on a monthly, annual and seasonal relative humidity in Srinagar. However, in Ranichauri, statistically significant increasing trend were detected on monthly, annual as well as seasonal relative humidity

The ongoing above discussion makes it clear that understanding RH changes is critical to human comfort, climate change, and other contemporary environmental issues. Understanding the uncertainties associated with RH patterns will provide a foundation for better managing of climate change, and other environmental hazards. As a result, the study's objectives are to examine the RH patterns in Bihar State with the goal of raising awareness about changes in humidity, which are useful information in developing strategies to mitigate the impact on climate change, and other related environmental problems.

2. *Data and methodology - Study Area* - Bihar is located in the Indo-Gangetic plains, between latitude 24°-27° N and longitude 82°-88° E and has a total geographical area of 94,163 square kilometres. The climate is subtropical and classified into three agro-climatic zones: Zone-I (North-West Alluvial Plains), Zone-II (North-East Alluvial Plains), and Zone-III (South Alluvial Plains). The average temperature ranges from 10 °C in the winter to 34 °C in the summer, with a weighted average annual rainfall of 1170 mm. Between July and September, the RH is generally high. It is roughly 70% in June and increases to about 80% in July, August and September. Summer afternoons have the lowest RH, which is around 45 percent. In the current study, total ten districts of two agro-climatic zones (Zone-II and Zone-IIIA) of Bihar, *viz*., Begusarai, Bhagalpur, Lakhisari, Jamui, Banka, Munger, Khagaria, Kathihar, Madhepura and Purnia have been considered and shown in Fig. 1.

Study Data - Historical (1981- 2021) monthly RH (%) datasets have been retrieved from the National Aeronautics and Space Administration (NASA) organization “Prediction of Worldwide Energy Resource" (https://power.larc.nasa.gov/data-access-viewer/) on a grid of 0.5° Lat. × 0.625° Long. spatial resolution. For each location, Lat. and Long. coordinates have been reported in Table 1. Furthermore, the time series datasets have been segregated into five data sets, *viz*., annual, and seasonal as characterized by the Indian Meteorological Department (IMD) guidelines: Winter (January and February), Pre-monsoon (March - May), Monsoon (June - September) and Post-monsoon (October – December).

Methodology used for determination of trend in relative humidity - In this study, the non-parametric tests such as Mann-Kendall test, Sen's slope estimator and Pettitt Mann-Whitney (PMW) test, have been used for the trend analysis in relative humidity and whole procedures have been carried out on *R* packages.

2.1. *Mann-Kendall (MK) test* - Mann Kendall test (Mann, 1945 and Kendall, 1975) has been used for the identifying trends in the time series data. It is a statistical non-parametric test widely used in trend analysis for climatological studies. The advantage of non-parametric test over parametric test, it does not require the data to be normally distributed. The MK test statistics (S) for rainfall can be computed as follows.

Null hypothesis (H_0) : There is no trend

Alternative hypothesis (H_1) : There is presence of trend

The Mann-Kendall test statistic (S) :

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(Y_j - Y_k) \tag{1}$$

where n is the number of the data points, Y_j is the observed value at time j and Y_k is the observed value at time K. The value of sgn ($Y_j - Y_k$) is computed as follow:

$$\operatorname{sgn}(Y_j - Y_k) = \begin{cases} +1, & (Y_j - Y_k) > 0 \\ 0, & (Y_j - Y_k) = 0 \\ -1, & (Y_j - Y_k) < 0 \end{cases} \tag{2}$$

For large samples (n >10), the test is conducted using a normal approximation (Z statistics) with the mean and the variance as follows:

$$E(S) = 0 \tag{3}$$

$$\operatorname{Var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \tag{4}$$

where q is the number of tied (zero difference between compared values) groups and t_p is the number of data values in the p^{th} group. Test statistic Z as follows:

$$Z = \begin{cases} \dfrac{S-1}{\operatorname{Var}(S)} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\operatorname{Var}(S)} & \text{if } S < 0 \end{cases} \tag{5}$$

A statistically significant trend is evaluated using the Z value which positive value of Z indicates an increasing trend and its negative value a decreasing trend. Null hypothesis (H_0) is tested at 5% level of significance ($Z_{0.05}$ = 1.96).

2.2. *Sen's slope estimator*

To estimate the true slope of an existing trend (as change per year) the Sen's nonparametric method has been used. The Sen's method (Sen, 1968 and Pingale *et al.*, 2014) can be used in cases where the trend can be assumed to be linear.

$$Q = \operatorname{Median}\left(\frac{Y_j - Y_k}{j - k}\right) \tag{6}$$

where Y_j is the observed value at time j and Y_k is the observed value at time K. Q is a magnitude of trend estimate. Sen's slope indicates an increasing trend for positive value and a decreasing trend for negative value in the time series data.

2.3. *Pettitt Mann-Whitney (PMW) test*

The PMW test (Pettitt, 1979) distinguishes the most likely change year in the yearly time series sequence. The PMW test statistics can be computed as follows;

Assume a time series $\{Y_1, Y_2, ..., Y_n\}$ with a length n and where t is the time of the most likely change point. Two samples, $\{Y_1, Y_2, ..., Y_t\}$ and $\{Y_{t+1}, Y_{t+2}, ..., Y_n\}$, can then be derived by dividing the time series at time t. An index, U_t, is derived as:

$$U_t = \sum_{i=1}^{t} \sum_{j=1}^{n} \operatorname{sgn}(Y_i - Y_j) \tag{7}$$

$$\operatorname{sgn}(Y_i - Y_j) = \begin{cases} +1, & \text{if } (Y_i - Y_j) > 0 \\ 0, & \text{if } (Y_i - Y_j) = 0 \\ -1, & \text{if } (Y_i - Y_j) < 0 \end{cases} \tag{8}$$

TABLE 2

Statistical parameters of RH for Bhagalpur and Jamui districts

Seasons	Bhagalpur			Jamui		
	Mean (%)	Standard Deviation	CV (%)	Mean (%)	Standard Deviation	CV (%)
Annual	58.45	5.31	9.09	57.38	4.57	7.98
Winter	47.79	7.96	16.66	48.74	7.09	14.56
Pre-monsoon	34.41	6.52	18.96	31.92	5.69	17.83
Monsoon	78.08	4.04	5.18	76.42	3.90	5.01
Post-monsoon	70.45	8.38	11.89	69.75	8.37	12.01

TABLE 3

Statistical parameters of RH for Kathihar and Khagaria districts

Seasons	Kathihar			Khagaria		
	Mean (%)	Standard Deviation	CV (%)	Mean (%)	Standard Deviation	CV (%)
Annual	59.43	6.52	10.90	56.17	4.86	8.66
Winter	49.09	8.74	17.81	47.40	7.07	14.92
Pre-monsoon	37.29	6.86	18.39	31.51	5.80	18.43
Monsoon	77.92	5.36	6.88	75.30	4.34	5.76
Post-monsoon	70.44	9.87	14.03	67.31	8.78	13.04

TABLE 4

Statistical parameters of RH for Lakhisari and Purnia districts

Seasons	Lakhisari			Purnia		
	Mean (%)	Standard Deviation	CV (%)	Mean (%)	Standard Deviation	CV (%)
Annual	57.38	4.57	7.98	59.37	6.46	10.88
Winter	48.74	7.09	14.56	48.17	9.03	18.75
Pre-monsoon	31.92	5.69	17.83	36.75	5.5	19.53
Monsoon	76.42	3.88	5.10	78.96	7.18	5.97
Post-monsoon	69.75	8.37	12.01	70.13	10.04	14.31

TABLE 5

Statistical parameters of RH for Madhepura and Munger districts

Seasons	Madhepura			Munger		
	Mean (%)	Standard Deviation	CV (%)	Mean (%)	Standard Deviation	CV (%)
Annual	57.28	6.29	10.98	57.28	4.86	8.66
Winter	47.15	8.48	17.99	47.15	7.07	14.92
Pre-monsoon	33.97	6.99	20.58	33.97	5.80	18.43
Monsoon	76.72	4.91	6.40	75.30	4.31	5.76
Post-monsoon	67.78	9.94	14.67	67.31	8.78	13.04

TABLE 6

Statistical parameters of RH for Banka and Begusarai districts

Seasons	Banka			Begusarai		
	Mean (%)	Standard Deviation	CV (%)	Mean (%)	Standard Deviation	CV (%)
Annual	58.45	5.31	9.09	56.17	4.86	8.66
Winter	47.79	7.96	16.66	47.40	7.07	14.92
Pre-monsoon	34.41	6.52	18.96	31.51	5.80	18.43
Monsoon	78.08	4.04	5.18	75.30	4.34	5.76
Post-monsoon	70.45	8.38	11.89	67.31	8.78	13.04

TABLE 7

Statistical test results of RH for Bhagalpur and Jamui districts

Seasons	Bhagalpur			Jamui		
	MK test (Z value)	Sen's slope estimate	PMW test (K)	MK test (Z value)	Sen's slope estimate	PMW test (K)
Annual	4.684*	0.299	2001	3.797*	0.207	1997
Winter	4.201*	0.476	2002	3.482*	0.337	2001
Pre-monsoon	3.448*	0.290	2001	3.077*	0.245	2001
Monsoon	3.055*	0.169	1997	1.909NS	0.112	1995
Post-monsoon	3.515*	0.411	1996	2.853*	0.355	1996

* = Significant at 95% confidence level, NS = non-significant

TABLE 8

Statistical test results of RH for Kathihar and Khagaria districts

Seasons	Kathihar			Khagaria		
	MK test (Z value)	Sen's slope estimate	PMW test (K)	MK test (Z value)	Sen's slope estimate	PMW test (K)
Annual	4.414*	0.362	2001	3.866*	0.235	2001
Winter	4.504*	0.518	2001	3.493*	0.354	2001
Pre-monsoon	3.066*	0.340	1997	3.088*	0.262	2001
Monsoon	3.830*	0.244	1997	2.033*	0.117	1994
Post-monsoon	4.301*	0.462	1997	3.178*	0.432	2005

* = Significant at 95% confidence level, NS = non-significant

TABLE 9

Statistical test results of RH for Lakhisari and Purnia districts

Seasons	Lakhisari			Purnia		
	MK test (Z value)	Sen's slope estimate	PMW test (K)	MK test (Z value)	Sen's slope estimate	PMW test (K)
Annual	3.797*	0.207	1997	4.225*	0.343	2001
Winter	3.482*	0.337	2002	4.054*	0.524	2002
Pre-monsoon	3.077*	0.245	2001	3.403*	0.370	2001
Monsoon	1.909NS	0.112	1995	3.493*	0.207	1997
Post-monsoon	2.853*	0.355	1996	4.077*	0.462	1997

* = Significant at 95% confidence level, NS = non-significant

TABLE 10

Statistical test results of RH for Madhepura and Munger districts

Seasons	Madhepura			Munger		
	MK test (Z value)	Sen's slope estimate	PMW test (K)	MK test (Z value)	Sen's slope estimate	PMW test (K)
Annual	4.583*	0.363	2001	3.866*	0.235	2001
Winter	4.122*	0.480	2001	3.493*	0.354	2001
Pre-monsoon	3.650*	0.334	2001	3.088*	0.262	2001
Monsoon	3.425*	0.205	2002	2.033*	0.117	1994
Post-monsoon	4.178*	0.541	2002	3.178*	0.432	2005

* = Significant at 95% confidence level, NS = non-significant

TABLE 11

Statistical test results of RH for Banka and Begusarai districts

Seasons	Banka			Begusarai		
	MK test (Z value)	Sen's slope estimate	PMW test (K)	MK test (Z value)	Sen's slope estimate	PMW test (K)
Annual	4.684*	0.299	1997	3.867*	0.235	2001
Winter	4.167*	0.471	2001	3.493*	0.354	2001
Pre-monsoon	3.156*	0.301	1999	3.008*	0.262	2001
Monsoon	3.055*	0.169	1997	2.033*	0.117	1994
Post-monsoon	3.515*	0.411	1996	3.178*	0.432	2005

* = Significant at 95% confidence level, NS = non-significant

A plot of U_t against t for a time series with no change point would result in a continually increasing value of U_t. However, if there is a change point (even a local change point) then U_t would increase up to the change point and then begin to decrease. This increase followed by a decrease may occur several times in a time series, indicating several local change points. So there is still the question of determining the most significant change point. We can identify the most significant change point K_t where the value of $| U_t |$ is maximum.

$$K_t = \max_{1 \le t \le T} |U_t| \tag{9}$$

The approximated significance probability *P(t)* for a change point is given as:

$$P = 1 - \exp\left(\frac{-6K_t^2}{n^3 + n^2}\right) \tag{10}$$

The change point is statistically significant at the time t with a significance level of α when probability $P(t)$ exceeds $1 - \alpha$.

3. *Results and discussions* - *Relative humidity variability* - Relative humidity variability patterns over 1981 to 2021 for ten districts in Bihar using coefficient of variation (*CV*) indicated that the moderate variations observed in the winter and pre-monsoon RH, whereas, annual, monsoon and post-monsoon RH were observed low variations for all the tens locations (Tables 2 to 6). The maximum amount of mean relative humidity recorded for annual, winter, pre-monsoon, monsoon, and post-monsoon are 59.43%, 49.09%, 37.29%, 78.96% and 70.45%, respectively. In monsoon and post-monsoon seasons, the RH is generally exceeding 70% because of mostly rainfall period occurred. The minimum RH is occurred in winter season due to air contains low temperature, so that RH is lower in this season.

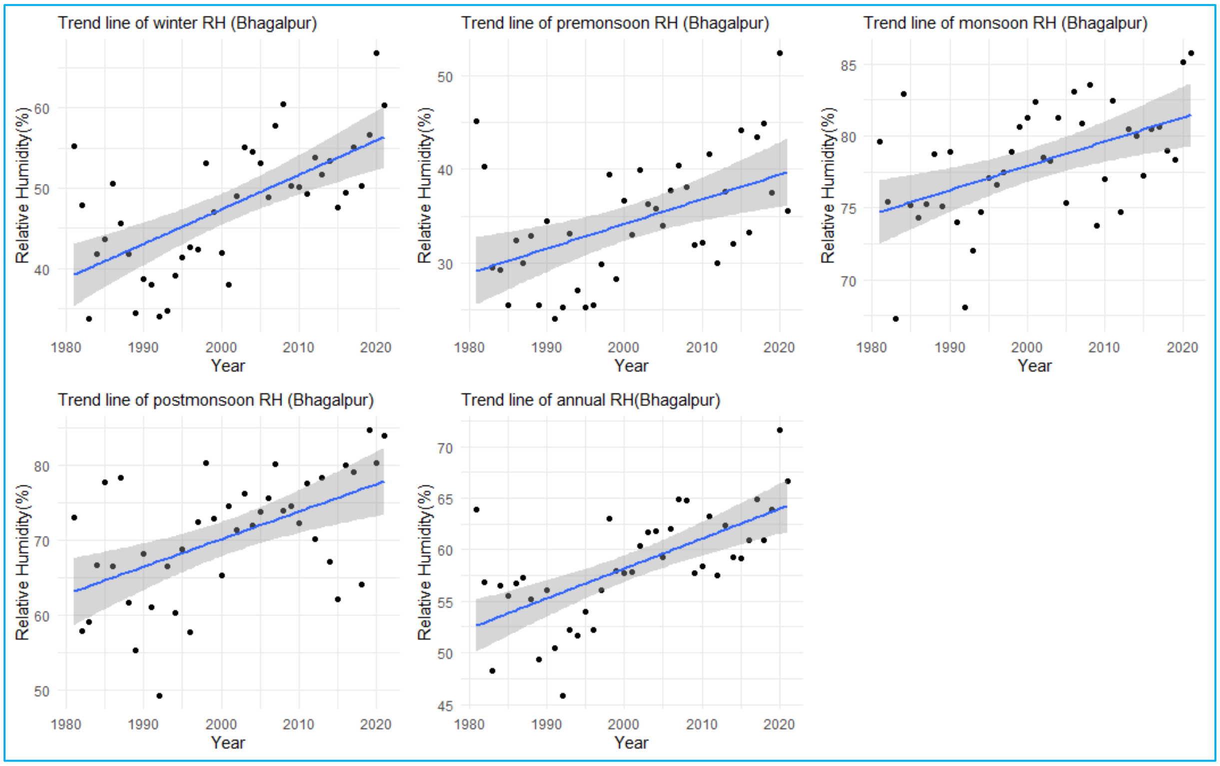

Fig. 2. Trend plots of RH in Bhagalpur district

Non-parametric trend analysis - The trend analysis of RH, non-parametric test such as MK test, Sen's slope estimator and PMW test have been used. Significance of the trend is determined by the MK test. The magnitude is evaluated by Sen's slope estimator and significant changing point is evaluated by PMW test. In this study, gridded data of monthly RH (%) during 1981 to 2021 are used for the trend analysis. The value of tests result on annual and seasonal basis of the tens locations is summarized in Tables 7 to 11.

Trend analysis of annual RH - The MK test results (*Z* value) showed the statistically significant increasing trends for all the locations under consideration. A sharp increasing trend can be easily visualised through trend plots of the annual RH (Figs. 2-11). Annual RH increased at rates of 0.207% year^{-1} to 0.363% year^{-1} during 1981 to 2021. The highest increasing rate was observed in the Madhepura district, while the lowest increasing rate was observed in the Jamui and Lakhisari district. The most probable year of change in the observed annual RH was shifted between 1997 to 2001. Majority of the districts like Bhagalpur, Kathihar, Khagaria, Purnia, and Madhepura, the most probable of year of change point was observed in 2001.

Trend analysis of winter RH - In winter RH, significant increasing trend observed in all tens locations for the period of 1981 to 2021. It can also be easily visualised through the trend plots of winter RH (Figs. 2-11). Positive magnitude of significant trend was increased at the rate of 0.337% year^{-1} to 0.524% year^{-1}. The highest increasing rate of winter RH was observed in the Purnia district, while the lowest increasing rate was observed in the Jamui and Lakhisari district. The most probable year of change in the observed winter RH was shifted between 2001 and 2002.

Trend analysis of pre-monsoon RH - The pre-monsoon RH was showed significant increasing trend for all tens locations. The significant increasing can be also seen in trend plots of pre-monsoon season (Figs. 2-11). The estimated magnitude of increasing trend was 0.245 to 0.370% year^{-1} during 1981 to 2021. At spatial scale, the highest increasing rate of change of pre-monsoon RH was observed in the Purnia district while the lowest was observed in the Jamui and Lakhisari district. The PMW test indicated as the most probable change point in the pre-monsoon season was shifted between 1997 to 2001. However, majority of the districts like Bhahalpur, Jamui, Khagaria, Lakhisari, Purnia, Madhepura, Munger and Begusarai were shifted in 2001.

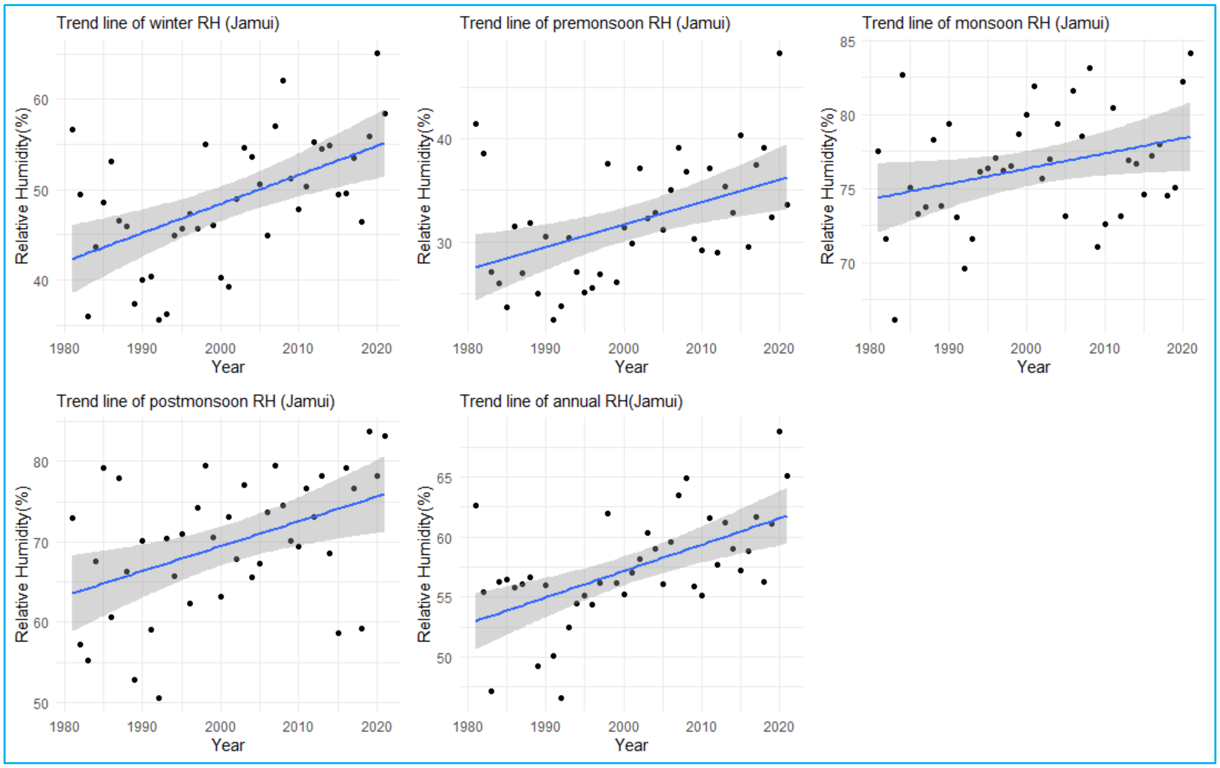

Fig. 3. Trend plots of RH in Jamui district

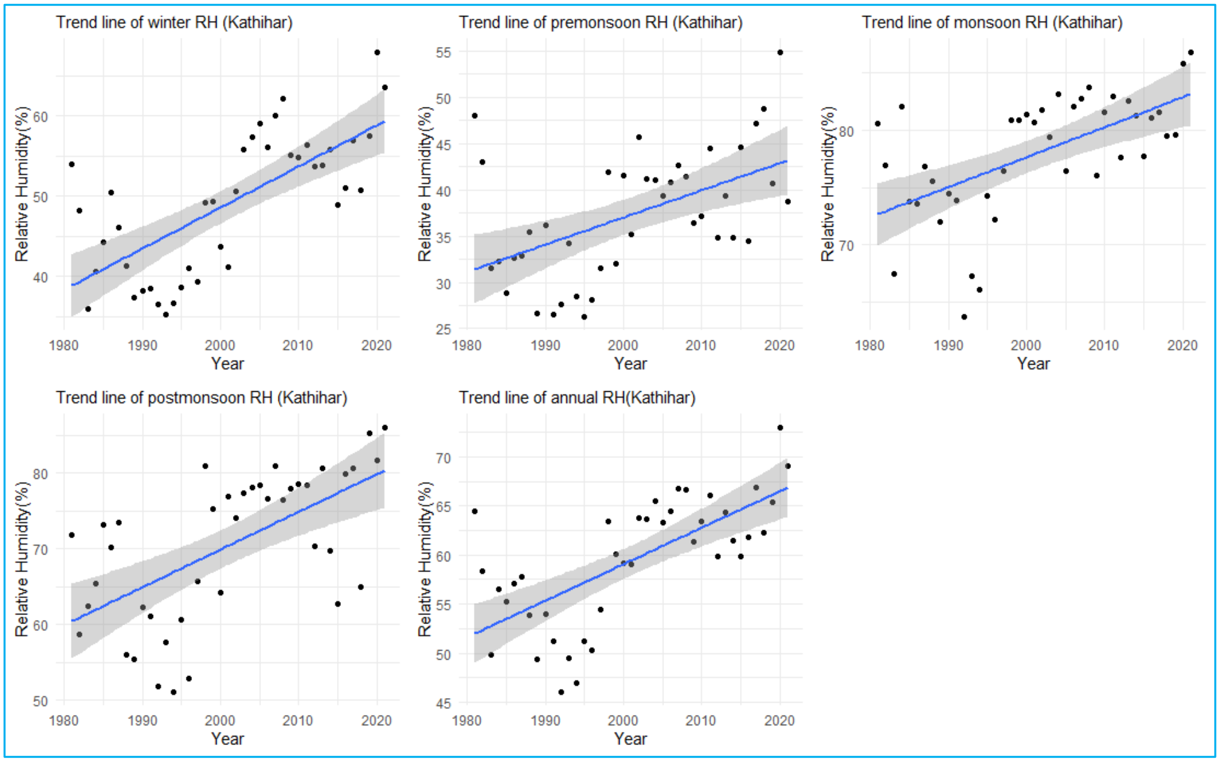

Fig. 4. Trend plots of RH in Kathihar district

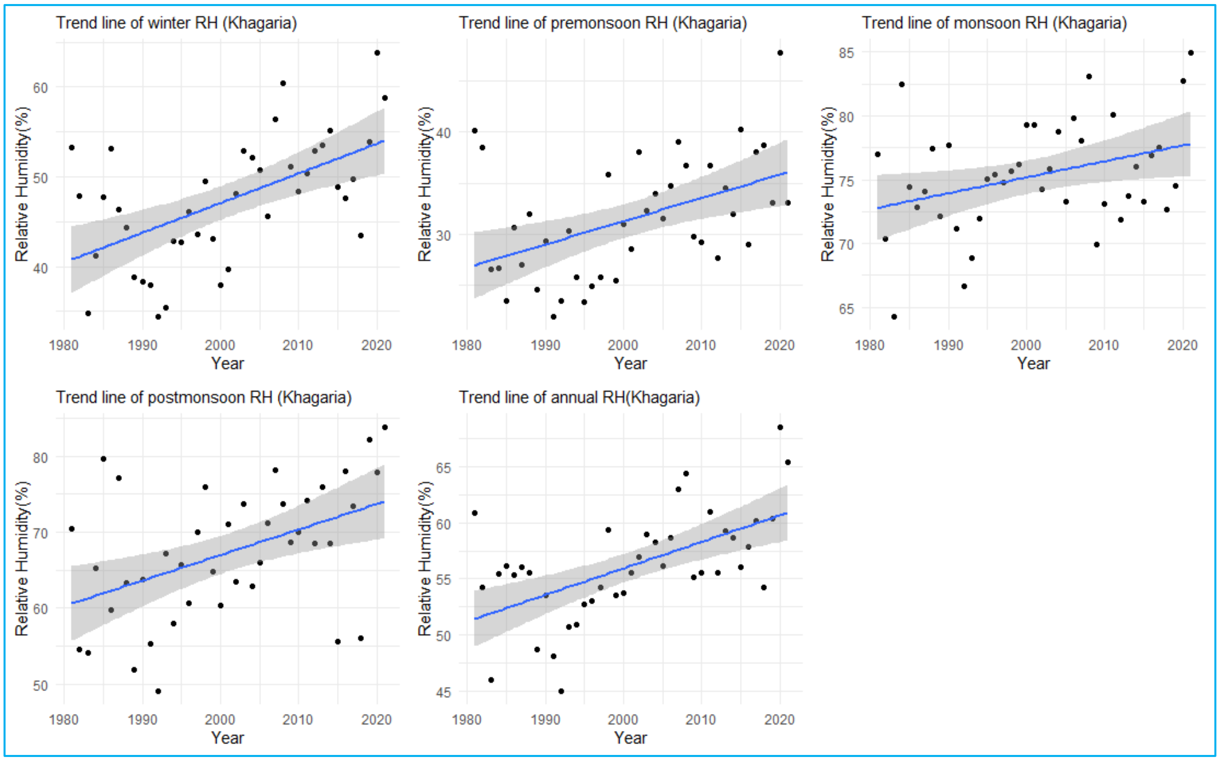

Fig. 5. Trend plots of RH in Khagaria district

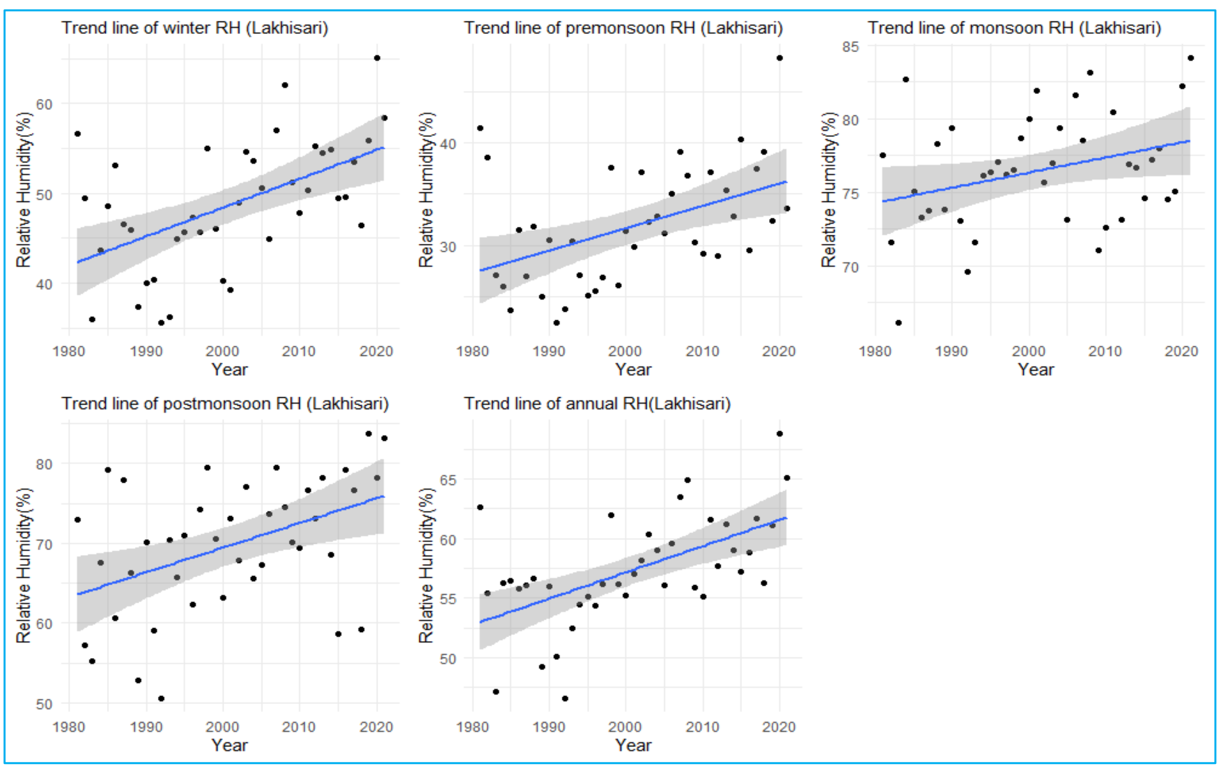

Fig. 6. Trend plots of RH in Lakhisari district

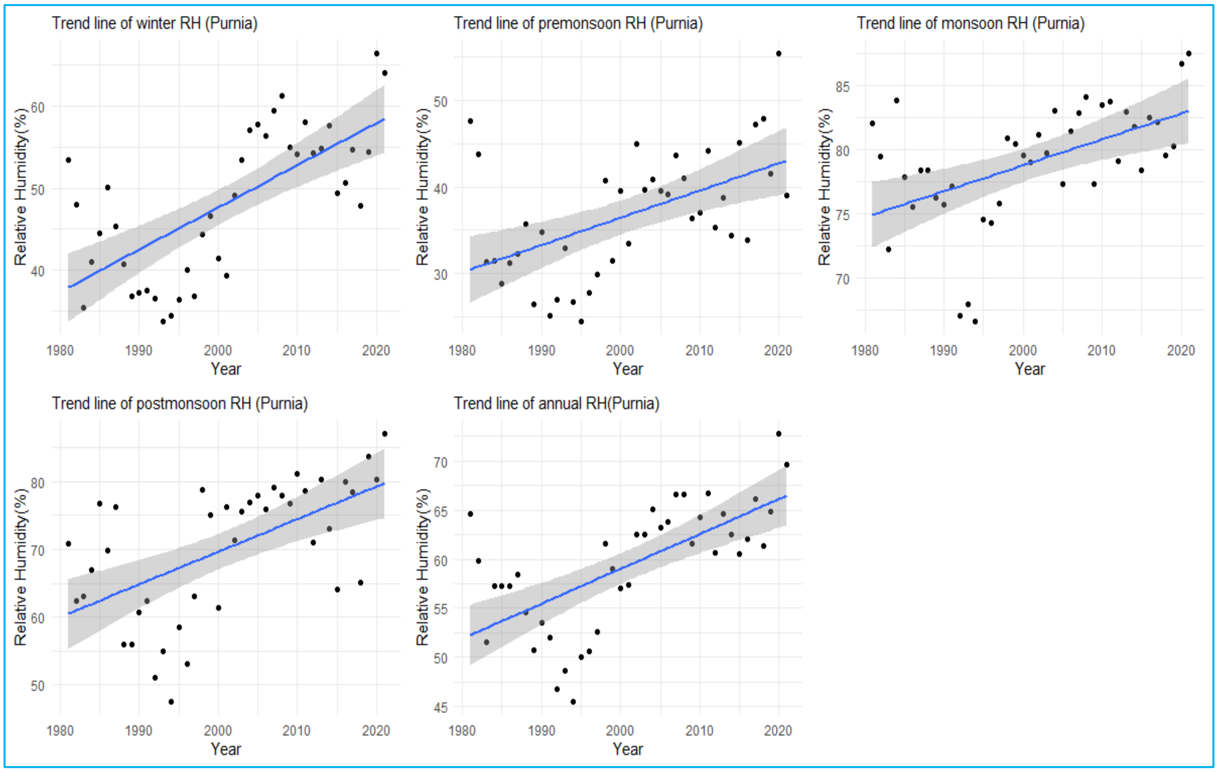

Fig. 7. Trend plots of RH in Purnia district

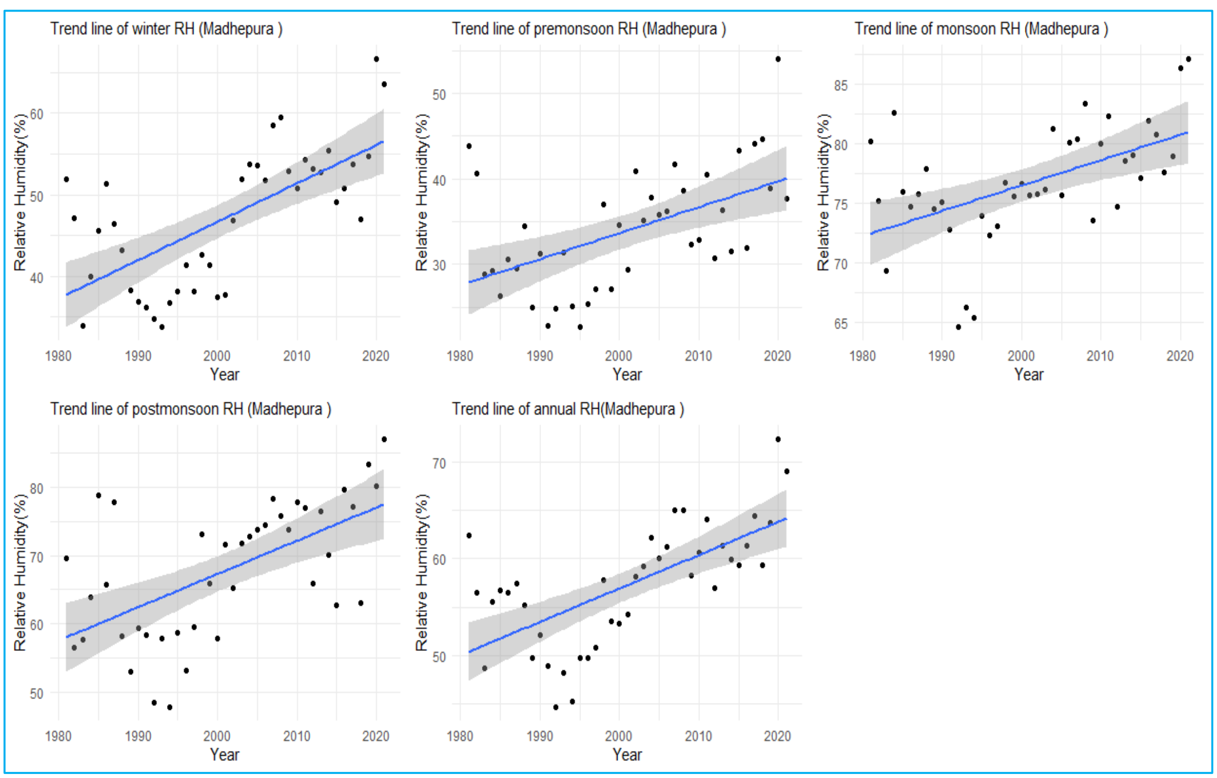

Fig. 8. Trend plots of RH in Madhepura district

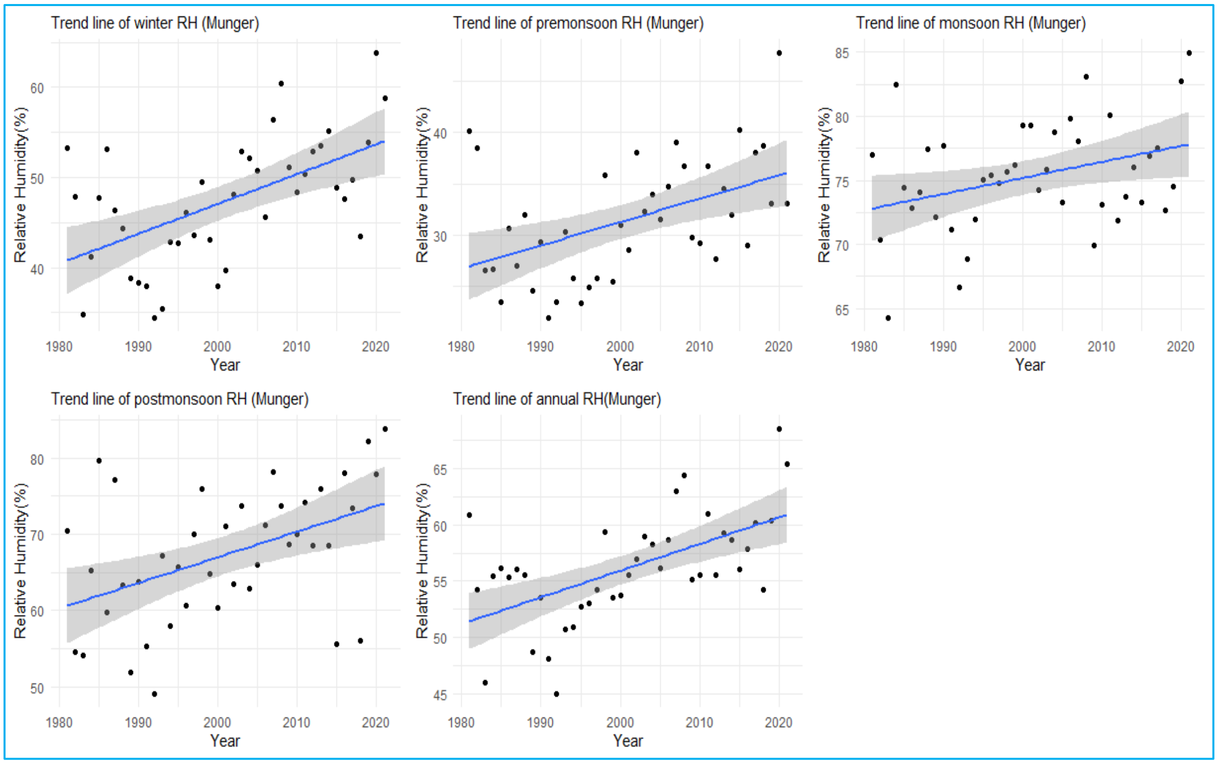

Fig. 9. Trend plots of RH in Munger district

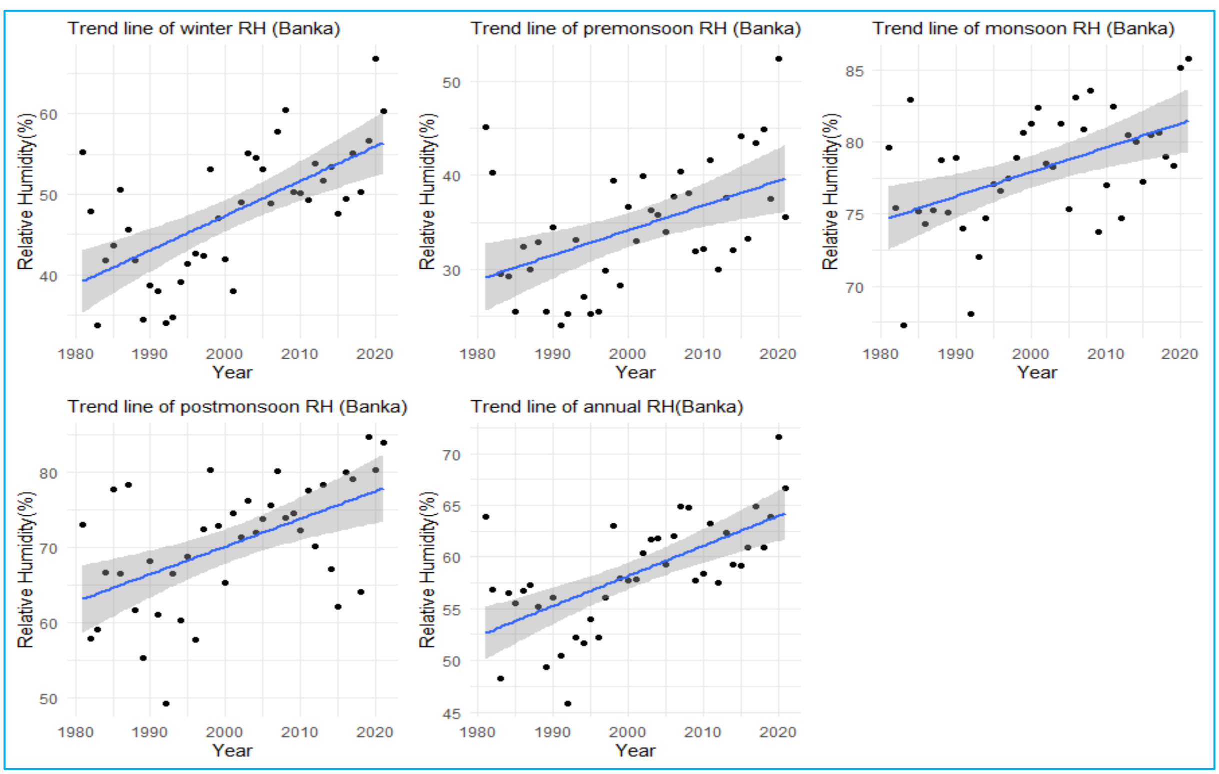

Fig. 10. Trend plots of RH in Banka district

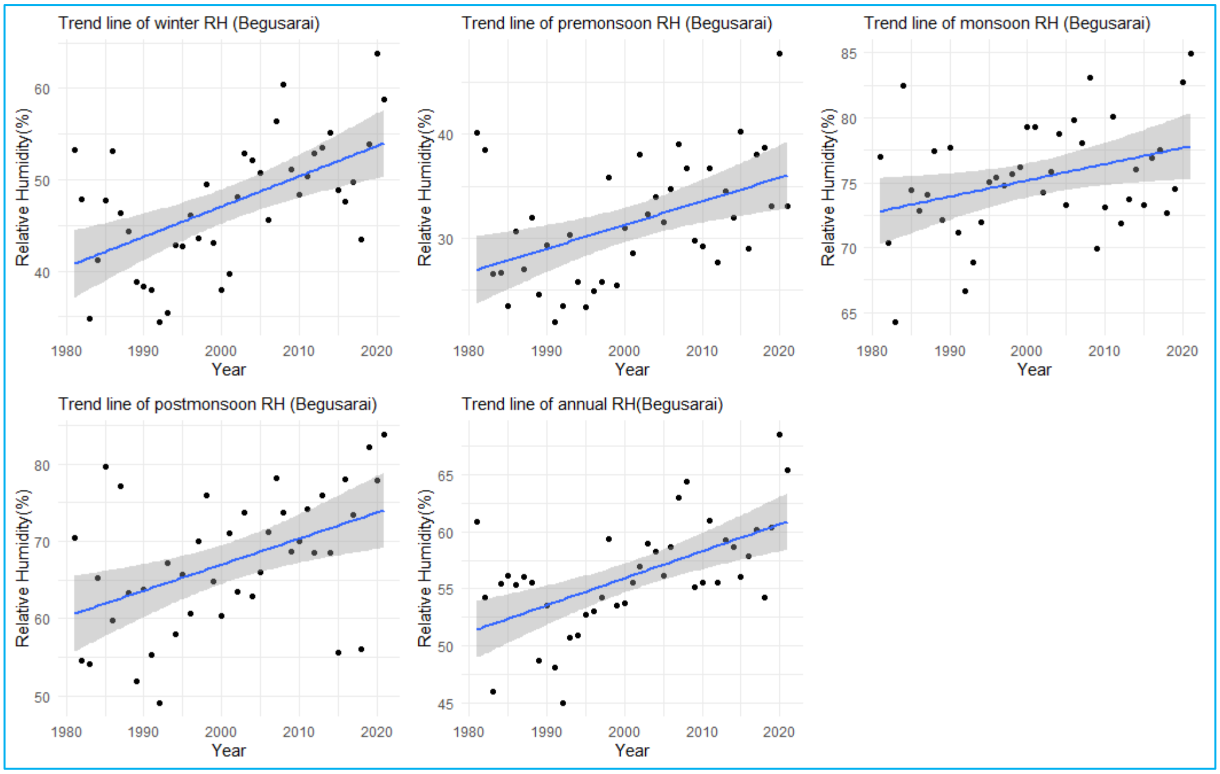

Fig. 11. Trend plots of RH in Begusarai district

Trend analysis of monsoon RH - In monsoon RH, significant increasing trends were observed over the study regions except Jamui and Lakhisari districts. It can be easily visualised through the trend plots of the monsoon season during 1981 to 2021 (Figs. 2-11). The magnitude of estimated increasing rate of change of monsoon RH was 0.112 to 0.244% year^{-1}. The highest increasing rate of change was observed in the Kathihar district, while the lowest was observed in the Jamui and Lakhisarai districts. The most probable year of change in the monsoon season was shifted between 1994 to 2002.

Trend analysis of post-monsoon RH - The MK test results showed that statistically significant increasing trends for all tens locations which can be also seen through the trend plots of the post-monsoon seasons. Post-monsoon RH increased at rates of 0.355 to 0.541% year^{-1} during 1981 to 2021 and at the highest rate was observed in the Madhepura district while the lowest rate was observed in the Lakhisari and Jamui districts. The most probable year of change in the observed post-monsoon RH was shifted between 1996 to 2005.

In this study, annual and seasonal relative humidity showed significant increasing trend during 1981 to 2021 for agro climatic zones (Zone-II and Zone-IIIA) of Bihar. Similar results are found in the pieces of work of Pandey and Pandey (2012) found the significant increasing trends was observed in annual air temperature (maximum, minimum, mean and dew point temperature) and relative humidity in Tons River Basin in Central India. Jaswal and Koppar (2011) showed that evidence of an increase in air moisture content over India during 1969-2007 with more than 90% stations showing increasing trends in specific humidity. And, reported by Dai (2006) the increasing trends in RH over India are consistent with trends.

4. *Conclusions* - The present study evaluated the observation of annual and seasonal RH trends at the agro climatic zones (Zone-II and Zone-IIIA) of Bihar from 1981 to 2021. The nonparametric test such as MK test, Sen's slop estimator and PMW test, have been used for trend detection in relative humidity. The descriptive results of the winter, and pre-monsoon seasons were found the highest variation in relative humidity as compared to other seasons. Due to presence of rainfall period, relative humidity of monsoon and pre-monsoon seasons were observed above 70%. The nonparametric test results showed increasing trends in the annual and seasonal RH at all the locations. Annually, the magnitude of increasing

trend varied from 0.363% year^{-1} in Madhepura to 0.207% year^{-1} Jamui and Lakhisari. In case of winter RH, the magnitude of increasing trend varied from 0.337% year^{-1} in Purnia to 0.524% year^{-1} in Jamui and Lakhisari. During pre-monsoon, the highest increasing trend at Purnia (0.0.370% year^{-1}) and the lowest at Jamui and Lakhisari (0.245% year^{-1}). In case of monsoon season, the magnitude of increasing trend varied from 0.244 % year^{-1} in Kathihar to 0.112% year^{-1} in Jamui and Lakhisarai. During post-monsoon season, the rate of change of increasing trend was varied from 0.541% year^{-1} in Madhepura to 0.355% year^{-1} in Lakhisari and Jamui. The most probable year of change in the observed RH was observed in 1996 to 2005. However, majority of the locations shifted in the year 2001 to 2002.The increasing moisture content in the environment may cause of the thundershowers and isolated rainfall in study areas. The changing trend in RH can lead to a serious concern for human comfort, agriculture and hydrological cycle.

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Ethical approval: The authors confirm that this work is original and has not been published elsewhere nor is it currently under consideration for publication elsewhere.

Author's Contributions

Ravi Ranjan Kumar and Kader Ali Sarkar: The data analysis and the initial drafting of the manuscript, Interpreting the results and organizing the presentation of findings.

Digvijay Singh Dhakre and Debasis Bhattacharya: Refinement of the study and methodology, In-depth interpretation of analytical outputs and critical revisions of the manuscript.

Disclaimer: The contents and views presented in this research article/paper/letter are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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@RAVI RANJAN KUMAR
*KADER ALI SARKAR
#DIGVIJAY SINGH DHAKRE
$DEBASIS BHATTACHARYA

Department of Agricultural Statistics, Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal, India

(@tan2ravi@gmail.com)
(#dhakreds@gmail.com)
($debasis_us@yahoo.com)

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***Corresponding author's email: kader804@gmail.com**