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Seasonal Trend Analysis of Humidity using Multi-Method Detection Techniques of Silchar, Assam (1986-2022)

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ABSTRACT

This study explores the extended form of methodologies for trend detection in meteorological time series, focusing on one of the critical climatic variables, Humidity, which is collected from Silchar station of Assam, India. To assess the presence and magnitude of trends, a comprehensive approach is adopted, employing the Mann-Kendall (M-K) test, its modified version, and Sen's slope estimation, alongside the Innovative Trend Analysis (ITA) technique. These methods together offer a robust framework for detecting and quantifying trends in the dataset. The monthly data of 37 years from 1986-2022 at 3 pm and at12 pm has been processed to find out the variability of humidity for which M-K test, modified M-K test and ITA method with trend magnitude and slopes is adopted to check the seasonal variation of humidity at 3 pm and 12 pm. Based on the statistical outcomes derived from the three trend detection methods and their corresponding visualizations, the analysis reveals both increasing and decreasing trends in humidity across different seasons includes a significant trend in humidity measurements has been identified during the winter, monsoon, and post-monsoon seasons at 3 PM, with a corresponding pattern similarly apparent in the monsoon season 12 PM observations. These variations are observed in the humidity values recorded at both 3 pm and 12 pm, highlighting a seasonal divergence in humidity patterns, with certain periods exhibiting rising rates, while others demonstrate declining or no trends.

Keywords: Meteorology, Humidity, Trend Detection, Mann-Kendall test, Sen's slope, Innovative trend analysis, Modified M-K test.

1 Introduction

Trend detection in meteorological time series is crucial for understanding long-term environmental changes in a given area. There are various statistical parametric and non-parametric tests to detect trends across different subjects. Long-term examination of trends is crucial in respect of socioeconomic development and climate change. There are of various extended form in the methodologies of trend analysis. Although the parametric tests are more influential than non-parametric but there is an assumption that all data points are independent and normally distributed. One of the most widely used non-parametric test to observe trend is Mann-Kendall test, proposed by Mann, 1945 and Kendall, 1955, in this test Hamed and Rao (1998) evaluate the correlation between the rank order of the observed values and their order in time is considered. Hirsch & Slack (1984) have described about the extension of Mann Kendall (M-K) test and its characteristics elaborately. Hamed and Rao (1998) have proposed a modified non-parametric trend test in presence of auto-correlation in data set, which is more advanced than original Mann-Kendall test. Yue and Wang (2004) have discussed elaborately the elimination of serial correlation on Mann Kendall (M-K) test to check it significance on trend analysis. Shi et al. (2011) have studied detection of trend on high temperature, high humidity, sultry weather in the warm season of China from 1961 to 2004. Mondal et al. (2012) have discussed monthly trend by M-K test and modified M-K test with the Sen's slope estimation on rainfall in Orissa. Liu et al. (2012) have studied the annual and seasonal trend analysis of rainfall by adopting Mann-Kendall (M-K) test in China for the period of 1956-2000. Ali & Abubaker (2019) have studied trend analysis elaborately in the Yangtze river basin using the M-K test, Sen's slope and Innovative trend analysis (ITA). Agarwal et al. (2021) have discussed the daily and seasonal trend pattern of rainfall data collected from the India Meteorological Department (IMD) for the period of 1981-2016 for various locations of Andhra Pradesh using the M-K test and Sen's slope estimation process. Alashan (2020) has explained about the logarithmic scale on Innovative trend analysis. Alifujiang et al. (2020) have described elaborately the advantages of graphical representation and trend identification of innovative analysis on precipitation of lakes in the Issyk-Kul Basin. Serinaldi et al. (2020) have explained some very significant characteristics with proper evidence of the Innovative Trend Analysis (ITA) method on temporal dependence. Pastagia and Mehta (2022) have discussed innovative trend analysis on rainfall data in Rajasthan state in India. Eşit (2023) has presented a new graphical approach, i.e. Innovative Polygon Trend Analysis (IPTA), besides the Mann-Kendall (M-K) test and Innovative Trend Analysis (ITA). Kliengchuay et al. (2024) have studied trends of temperature, precipitation, and relative humidity by the M-K test and ITA method.

From these collected reports, it is clearly observed that besides the M-K test, there are some other variants by which it is possible to get more operated results about trends from the modified M-K test and innovative trend analysis also. Analyzing a significant region to understand its historical trends and future projections offers insights that extend beyond agriculture, contributing to advancements in economics, communication, and other critical sectors.

Research from previous studies indicates that the trend detection can be applied in numerous dimensions for various meteorological parameters and it is a very important statistical test to check the long-term change in presence and absence of serial correlation in the time series data points and visualization (ITA) representation. Davis et al. (2016) have discussed among the various meteorological parameter, Humidity has very significant effects on the association between weather and human health. This study elaborates the various generalized form of trend detection on Humidity in Silchar station as it is a vital hub of the Barak Valley, excelling in socio-economic development, education, tea cultivation, fisheries, and numerous other domains. Gupta and Biswas (2010) have mentioned it is located in Barak Valley zone within the North-East Region at 92°51′ East (E) longitude and 24°5′ North (N) latitude and at a height of 114.68 m above the sea level.

2 Methodology

2.1 Data Sources

The data is collected from National Data Centre (NDC), India Meteorological Department (IMD), Pune for the period of 1986-2022, which is a monthly data i.e. the average of daily humidity observations for all 30 or 31 days within a particular month provides the monthly humidity measurement for that month, either at 3 pm or 12 pm. For the analysis, the humidity data is arranged season wise, namely Winter (January, February), Pre-Monsoon (March, April, May), Monsoon (June, July, August, September) and Post-Monsoon (October, November and December).

2.2 Mann-Kendall (M-K) test

The non parametric Mann-Kendall (M-K) test (Mann, 1945; Kendall,1975) is most commonly used to study the monotonic increasing or decreasing trend in meteorological time series data with the assumption that there is no autocorrelation in data points, which is not satisfying the normality criterion. The M-K test statistic is

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign}(T_j - T_i) \tag{1}$$

and

$$\text{sign}(T_j - T_i) = \begin{cases} -1 & \text{if } (T_j - T_i) < 0, \\ 0 & \text{if } (T_j - T_i) = 0, \\ 1 & \text{if } (T_j - T_i) > 0, \end{cases} \tag{2}$$

where n is length of the data set,T_j and T_i are the sequential assessments of the information at times j and i j > i, respectively (Motiee & McBean, 2009). The positive value of S indicates the upward trend and negative value of S infers downward trend in the data set. The value of |S| is compared directly to the theoretical distribution of S derived by Mann and Kendall when . The statistic S is approximately normally distributed when with the mean and variance as follows (Ali & Abubaker, 2019):

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

and

$$V(S) = \frac{n(n-1)(2n+5) - \sum t_i(i)(i-1)(2i+5)}{18}. \tag{4}$$

In which t_i denotes the number of ties to extent i. The summation term in the numerator is used only if the data series contains tied values. The standard test statistic Z_α is calculated as follows:

$$Z_\alpha = \begin{cases} \frac{S-1}{\sigma} & \text{if } S > 0, \\ 0 & \text{if } S = 0, \\ \frac{S+1}{\sigma} & \text{if } S < 0. \end{cases} \tag{5}$$

2.3 Sen's Slope estimation

Sen's slope test is a non-parametric test, which estimates the magnitude of a trend in the data predicted by Sen's estimator. If T_i is the slope of all data pairs then can be calculated as (Sen, 1968),

$$T_i = \frac{x_j - x_k}{j - k},\ i = 1, 2, \ldots, N \tag{6}$$

and

$$Q_i = \begin{cases} T_{\frac{N+1}{2}} & \text{if } N \text{ is odd}, \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+1}{2}}\right) & \text{if } N \text{ is even}, \end{cases} \tag{7}$$

where X_j and X_k denote the values of data at the j^{th} and k^{th} time, respectively, where time j is after time k ($k \leq j$). Sen's estimator is given as

$$Q_{\text{med}} = \begin{cases} T_{\frac{N+1}{2}}, & \text{if } N \text{ is odd,} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+1}{2}}\right), & \text{if } N \text{ is even.} \end{cases} \tag{8}$$

The positive value of Q_{med} indicates an increasing trend, while the negative value of Q_{med} refers to a decreasing trend in the particular time period (Mondal et al., 2012).

2.4 Modified M-K test

Time series with serial correlation will make it more difficult for the test to accurately determine a significant trend. In order to remove the influence of serial correlation on the M-K test, the variance of test statistic of M-K test is modified. This modified M-K test is more robust than original M-K test, when it is about the trend analysis in presence of serial correlation (Hamed & Ramachandra Rao, 1998). To reduce the effect of serial correlation on the MK test, effective sample size (ESS) has been proposed to modify the MK statistic, in which the modified variance of S is given by (Yue & Wang, 2004),

$$V^*(S) = V(S)\frac{n}{n^*} \tag{9}$$

Where V(S) is mentioned in equation no. 4, n is the actual number of independent sample (ASS), n* is the effective number of independent samples, and $\frac{n}{n^*}$ is the correction factor.

2.5 Innovative Trend Analysis (ITA)

The ITA method for trend analysis is developed by Sen in meteorological time series data, 2012. At first the hydro-meteorological time series data must be divided into two equal sub-series and ranked separately in ascending order. The method is based on the fact that the plotting two equal time series data against one another produces a dispersion of points along the 1:1 (45°) line in the grid point system. This type of graphic provides a first visual assessment of the patterns in a time series data. From the graphical representation of the scattering points of supplied data, it may be concluded that the monotonic increasing or decreasing trend. If the data points are lied in the triangular area below the 1:1 line, shows that there is a decreasing trend present in the time series. The trend indicator of ITA method may be created by multiplying 10 at the 10 % significance level to offer a scale equivalent to the MK test and

Sen's slope estimator test and the equation is

$$B = \frac{1}{n} \sum_{i=1}^{n} \frac{10(X_i - X_j)}{\mu} \tag{10}$$

Where B is the trend indicator, n is the length of each sub-series, $X_i, i = 1, 2, \ldots, \frac{n}{2}$ (the first half) and $X_j, j = \frac{n}{2}+1, \frac{n}{2}+2, \ldots, n$ (the second half) are two observed values from each sub-series, and μ is the mean of the first sub-series. The positive value of B indicates an increasing trend, while a negative value explains a decreasing trend (Ali & Abubaker, 2019).

3 Results and Discussion

The main objective of this paper is to study various dimensions of trend analysis. To execute this objective, three types of non-parametric statistical analysis have been adopted: the Mann-Kendall (M-K) test, the modified Mann-Kendall (M-K) test, and Innovative trend analysis (ITA) to check the pattern or trend in the Humidity of Silchar at 3 pm and 12 pm.

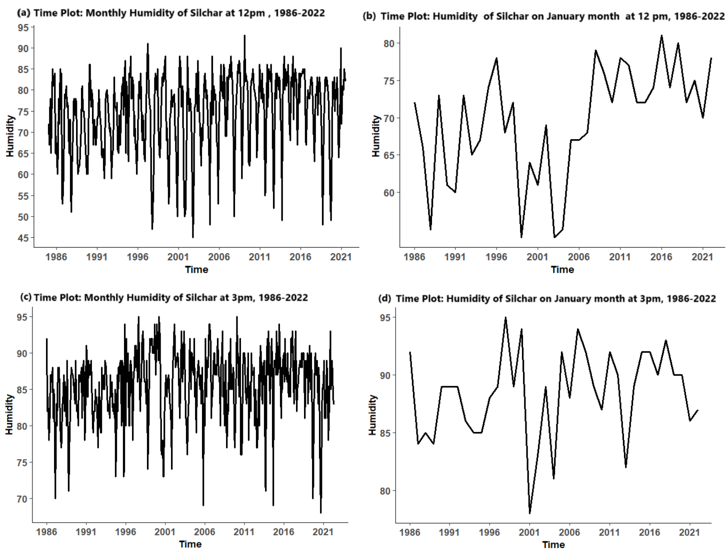

Fig. 1: Time series plot of monthly humidity at 3 pm and 12 pm, 1986-2022.

From Fig 1, it is clearly observed that there is a significant variation in humidity measurements at both 3 PM and 12 PM. (a) and (c) display the complete monthly dataset for each year from 1986 to 2022, while (b) and (d) focus solely on January's data for the same years.

From Table 1, it is clearly observed that January, November, and December month have less than 0.05 p-value, which is significant at the 5% level

Table 1: Table for mann-Kendall (M-K) test of Humidity at 12 pm monthly

Months	z statistic	n	p-value	Sen's slope	tau value
January	3.0721	37	**0.0021**	**0.3333**	**0.3608**
February	1.3390	37	0.1806	0.1026	0.1581
March	-1.0235	37	0.3061	-0.1250	-0.1213
April	-0.1311	37	0.8957	0.0000	-0.0168
May	1.7479	37	0.0805	0.1633	0.2072
June	1.3308	37	0.1833	0.0863	0.1592
July	-0.1982	37	0.8429	0.0000	-0.0252
August	1.3578	37	0.1745	0.1053	0.1634
September	1.8185	37	0.0690	0.1111	0.2246
October	3.0415	37	**0.0024**	**0.1914**	**0.3661**
November	0.9896	37	0.3224	0.0500	0.1237
December	4.4774	37	**0.0000**	**0.5238**	**0.5344**

of significance, i.e. there is a trend in those months. Sen's Slope estimation allows one to find whether data would have an upward trend or a downward trend. Except March, the remaining months are showing upward regression according to the observed results presented in the above table for the period of 1986-2022. The positive tau value indicates the direct association between month and observed values of Humidity at 12 pm for that month and vice versa for the period of 1986-2022.

Similarly, in Table 2, only June and August show a significant trend since their p-values, 0.0368 and 0.0261, are less than 0.05 at the level of significance of 5%, respectively.

Table 3 represents the results of M-K test season wise Humidity at 12 pm, in which winter, monsoon and post-monsoon season has significant trend at 5 % level of confidence interval since they have smaller p-value. All seasons are showing upward trend which is indicated from Sen's slope estimated values and from tau values it is reflected that there is a positive association between the seasons and observed data from those seasons.

Table 4 shows only monsoon season is showing significant trend (0.0153 p value) with positive Sen's slope and tau value.

Analysis of Tables 1 through 4 reveals that monthly humidity data recorded at both 3 pm and 12 pm generally lack significant trends, as per the result of M-K test. However, the seasonal data demonstrates notable trends at both time points for the Silchar station. Therefore, the subsequent trend analysis will utilize the modified M-K test and ITA, focusing exclusively on seasonal data at 3 pm and 12 pm.

Table 2: Table for Mann-Kendall (M-K) test of Humidity at 3 pm monthly

Months	z statistic	n	p-value	Sen's slope	tau value
January	1.5318	37	0.1256	0.0646	0.1837
February	1.0762	37	0.2818	0.0833	0.1276
March	-0.9324	37	0.3511	-0.0625	-0.1110
April	0.7755	37	0.4380	0.0541	0.0929
May	1.8871	37	0.0591	0.1026	0.2263
June	2.0876	37	**0.0368**	**0.0863**	**0.2509**
July	1.3126	37	0.1893	0.0400	0.1598
August	2.2242	37	**0.0261**	**0.1111**	**0.2650**
September	0.3012	37	0.7632	0.0000	0.0389
October	0.1512	37	0.8799	0.0000	0.0200
November	0.9896	37	0.3224	0.0500	0.1237
December	1.2623	37	0.2068	0.0702	0.1537

Table 3: Table for Mann-Kendall (M-K) test of Humidity at 12 pm season wise

Season	z statistic	n	p-value	Sen's slope	tau value
Winter	2.7303	74	**0.0063**	**0.1162**	**0.2205**
Pre-Mon	0.5943	111	0.5523	0.0163	0.0388
Monsoon	2.2049	146	**0.0274**	**0.0169**	**0.1273**
Post-Mon	6.9476	111	$\mathbf{3.716 \times 10^{-11}}$	**0.1466**	**0.4642**

Table 4: Table for Mann-Kendall (M-K) test of Humidity at 3 pm season wise

Season	z statistic	n	p-value	Sen's slope	tau value
Winter	1.3151	74	0.1885	0.0357	0.1071
Pre-Mon	1.1370	111	0.2555	0.0151	0.07509
Monsoon	2.9066	146	**0.0036**	**0.0153**	**0.1659**
Post-Mon	1.4075	111	0.1593	0.0121	0.0959

Table 5 represents the characteristics of modified M-K test, in which two extra features are there, namely corrected z and new p-value than classical M-K test. The old p-value for winter, monsoon and post-monsoon have significant p-value i.e. less 0.05, which are examined based on assumption that there is no auto-correlation in data points and new-p values are found in presence of auto-correlation. From both old p-value and new p-value, it is observed that there is a significant trend in winter, monsoon and post-monsoon season. The

Table 5: Table for Modified Mann-Kendall (M-K) test of Humidity at 12 pm season wise

Season	**Original z**	**Corrected z**	**n**	**Old p-value**
Winter	2.7303	4.8021	74	**0.0063**
Pre-Mon	0.5943	0.4662	111	0.5523
Monsoon	2.2049	2.1885	146	**0.0274**
Post-Mon	6.9476	4.0098	111	$\mathbf{3.716 \times 10^{-11}}$
	New p-value	**Sen's slope**	**Tau value**	
Winter	$\mathbf{1.57 \times 10^{-6}}$	**0.1162**	**0.2165**	
Pre-Mon	0.641	0.0163	0.0383	
Monsoon	**0.0286**	**0.0169**	**0.1227**	
Post-Mon	$\mathbf{6.08 \times 10^{-5}}$	0.1466	**0.4544**	

Sen's slope estimation and tau values show that there is an increasing pattern and positive association in between seasons and humidity data at 12 pm.

Table 6: Table for Modified Mann-Kendall (M-K) test of Humidity at 3 pm season wise

Season	**original z**	**corrected z**	**n**	**old p-value**
Winter	1.3151	6.2076	74	**0.1885**
Pre-Mon	1.1370	0.6180	111	0.2555
Monsoon	2.9066	1.8015	146	**0.0036**
Post-Mon	1.4075	1.4074	111	0.1593
	new p-value	**Sen's slope**	**tau value**	
Winter	$\mathbf{5.379 \times 10^{-10}}$	**0.0357**	**0.1044**	
Pre-Mon	0.5365	0.0151	0.0730	
Monsoon	**0.0716**	**0.0153**	**0.1613**	
Post-Mon	0.1592	0.0121	0.0918	

From Table 6, it is observed that monsoon shows significant trend according to old p-value but from new p-value, it is found that winter shows significant trend i.e. in presence of auto-correlation in data points with upward trend.

Fig. 2 gives idea about the characteristics of humidity at 12 pm for the period of 1986-2022, where QQ 5% line gives the visualization of upper bound and lower bound of data points at 95% confidence interval presented above and below the no trend line and QQ 10% gives idea about the limit of humidity at 90% confidence interval. If points lie on the no trend line indicates

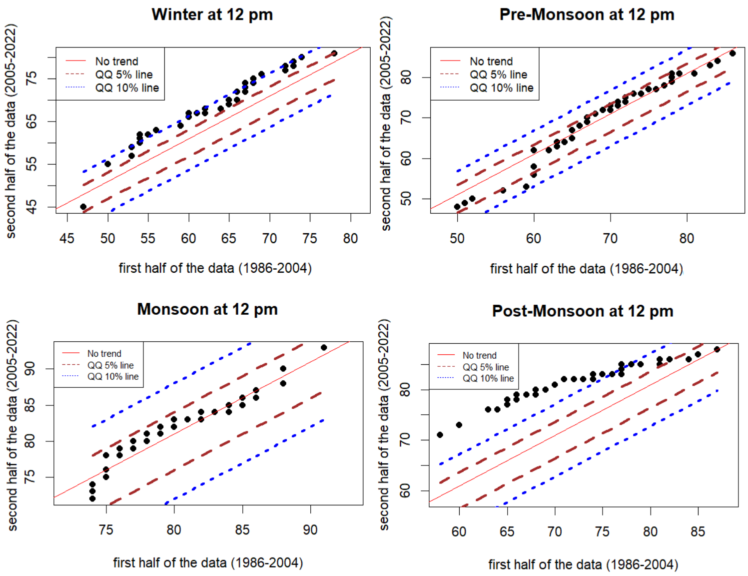

Fig. 2: Plot of Innovative trends season wise of Humidity at 12 pm for the period of 1986-2022.

that there is no trend, above the no trend line shows increasing trend and below the no trend line shows decreasing trend. Since most of points lie above the no trend line in case of winter, monsoon and post-monsoon season shows there is a positive trend but in case of pre-monsoon season, maximum points are lied on or near by the no trend line shows there is a very less chance of getting linear pattern in that season. Similarly, Fig. 3 represents the pattern of quantitative values of humidity at 3 pm.

Table 7 represents the trend indicator, slope, upper confidence level (UCL) and lower confidence level (LCL) of ITA for humidity at 3 pm and 12 pm. From the above table it can be depicted that except pre-monsoon season at 3 pm, the remaining seasons are showing increasing trend since they have positive slope and indicator.

4 Conclusion

This paper provides a detailed statistical and visual analysis of humidity trends at both 12 pm and 3 pm for the Silchar station, across different seasons. For the 12 pm observations, all seasons except the pre-monsoon period exhibit significant trends (p-value < 0.05) according to both the Mann-Kendall test and modified its modified Mann-Kendall test. With the assumption of no auto-correlation and auto-correlation in the time series data points i.e. in M-K test and modified M-K test respectively, the Season of winter, monsoon and post-monsoon is showing significant trend with positive tau and Sen's slope value, which clearly indicates that there is an increasing trend with a positive associ-

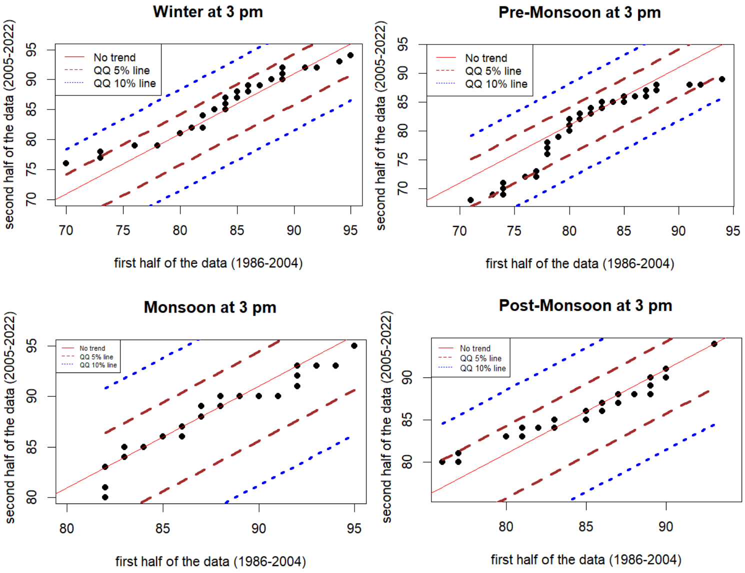

Fig. 3: Plot of Innovative trends season wise of Humidity at 12 pm for the period of 1986-2022.

ation between season and data points of humidity at 12 pm. The interpretation of these mentioned statistics at 12 pm can be visualized also by ITA method, the same characteristics of data points in winter, monsoon and post-monsoon season. Since the maximum of the observations lie above the red colored no trend line in winter, monsoon and post-monsoon, explains increasing trend of humidity in Silchar at 12 pm in Fig. 2. Similarly, in case of 3 pm observations of humidity, considering with no auto correlation assumption for M-K test, only the monsoon season is showing significant trend (p-value<0.05) with positive tau and Sen's slope value and although the remaining seasons are not having significant trend but has positive association between the observations of that season and time according to their tau value and Sen's slope. But if it is about modified M-K test, then the insignificant p-value of winter season is tended to significant trend value having auto-correlation assumption and remain characteristics of other seasons are same as of the interpretation of M-K test. Similarly, the graphical representation of statistics of humidity at 3 pm is explained in Fig. 3 and also there is a brief quantitative description about the idea of characteristics of humidity at 3 pm and 12 pm. The examination of trend indicators and slope values reveals a prominent increasing pattern in humidity levels at 3 pm. Conversely, for the observations at 12 pm during the pre-monsoon season display a declining pattern. Apart from this deviation, all other observations consistently show an upward pattern, as indicated by their corresponding trend and slope metrics.

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Table 7: Season wise trend indicator, trend slope, Upper and lower confidence level of ITA for humidity at 12 pm and 3pm

Season	**Time**	**Trend Indicator**		**Trend Slope**	
winter	12 pm	0.1483		0.8720	
	3 pm	0.0541		0.2376	
Pre-Mon	12 pm	0.0167		0.1344	
	3 pm	-0.0092		-0.0621	
Monsoon	12 pm	0.0208		0.1894	
	3 pm	0.0088		0.0733	
Post-Mon	12 pm	0.1739		1.2913	
	3 pm	0.0222		0.1393	
		LCL at 90%	**UCL at 90%**	**LCL at 95%**	**UCL at 95%**
winter	12 pm	-0.0091	0.0091	-0.0108	0.0108
	3 pm	-0.0064	0.0064	-0.0076	0.0076
Pre-Mon	12 pm	-0.0018	0.0018	-0.0021	0.0021
	3 pm	-0.0061	0.0061	-0.0073	0.0073
Monsoon	12 pm	-0.0020	0.0020	-0.0024	0.0024
	3 pm	-0.0029	0.0029	-0.0035	0.0035
Post-Mon	12 pm	-0.0051	0.0051	-0.0061	0.0061
	3 pm	-0.0024	0.0024	-0.0028	0.0028

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