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Analysis of recent trends and variability of temperature and relative humidity over Sri Lanka

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सार – **दुनिया जलवायु परिवर्तन और जलवायु प्रणाली में बदलाव के प्रतिकूल परिणामों का सामना कर रही है। अतः मौसम विज्ञानी, जलवायु विज्ञानी, कृषि विज्ञानी और जलविज्ञानी सहित कई पक्षों के लिए मौसम परिवर्ती की प्रवृत्तित्र और प्रतिरूपों का अध्ययन करना बहुत महत्वपूर्ण है। हालांकि कई शोधकर्ताओं ने ऐतिहासिक वर्षा की प्रवृत्तियों और प्रतिरूपों की जांच की है परंतु केवल कुछ ने ही वायुमंडलीय तापमान की प्रवृत्तियों की जांच की है। उल्लेखनीय है कि पिछले अध्ययनों में से किसी ने भी श्रीलंका में सापेक्ष आर्द्रता के रुझानों की जांच करने का प्रयास नहीं किया है। इसलिए, इसका अध्ययन करने के लिए इस शोध पत्र में श्रीलंका के वायुमंडलीय तापमान और सापेक्ष आर्द्रता की प्रवृत्ति् और परिवर्तिता विश्लेषण प्रस्तुत किया गया है। श्रीलंका में** 1990 **से** 2019 **तक** 30 **वर्षों के लिए तीन जलवायु क्षेत्रों नामतः शुष्क क्षेत्र, मध्यवर्ती क्षेत्र और आर्द्र क्षेत्र में वितरित** 18 **स्टेशनों पर न्यूनतम और अधिकतम तापमान तथा सापेक्ष आर्द्रता रिकॉर्ड की दीर्घकालिक विविधताओं के रिकॉर्ड की जांच की गई। मान केंडल परीक्षण** (MK), **सेन की ढलान और स्पीयरमैन के आरएचओ परीक्षण सहित गैर-प्राचलिक सांख्यिकीय परीक्षणों का उपयोग करके वार्षिक और मासिक प्रवृत्तिएयों का मूल्यांकन किया गया, जबकि तापमान और आर्द्रता के बदलते बिंदुओं को पेटिट परीक्षण का उपयोग करके निर्धारित किया गया। इसके अलावा, विविधता के गुणांक** (CoV) **का उपयोग करके जलवायु मापदंडों की परिवर्तिता का अनुमान लगाया गया। प्रस्तुत विश्लेषण से रोचक और उत्साहजनक परिणाम प्राप्त हुए हैं। मध्यवर्ती जलवायु क्षेत्र में बडुल्ला की पहचान अप्रत्याशित घटती तापमान प्रवृत्तियों के साथ की गई, जबकि कई अन्य क्षेत्रों की पहचान प्रत्याशित बढ़ते तापमान और सापेक्ष आर्द्रता प्रवृत्तियों के साथ की गई। इन परिणामों के आधार पर अनुकूलन कार्यों को देश के लिए सतत विकास लक्ष्यों को प्राप्त करने में शामिल करना दिलचस्प होगा।**

ABSTRACT. The world is experiencing adverse consequences of climate change and shifts in climate regimes. Hence, studying the trends and patterns of meteorological variables is of major importance for many parties, including meteorologists, climatologists, agriculturists and hydrologists. Although several researchers have examined the trends and patterns in historical rainfall, only a few have examined the trends in atmospheric temperature. Noteworthy none of the previous studies have attempted to investigate trends in relative humidity over Sri Lanka. Therefore, identifying this existing research gap, this present paper presents a trends and variability analysis of atmospheric temperature and relative humidity of Sri Lanka. The long-term variations of minimum and maximum temperature and relative humidity records at 18 stations distributed in the three climatic zones namely, the dry zone, the intermediate zone and the wet zone in Sri Lanka were investigated for 30 years from 1990 to 2019. Annual and monthly trends were assessed using non-parametric statistical tests, including the Mann Kendall test (MK), Sen's slope and Spearman's rho test, while the changing points of temperature and humidity were determined using the Pettit test. In addition, the variability of climate parameters was estimated using the Coefficient of Variation (CoV). Interesting and encouraging results were obtained from the present analysis. Badulla in the intermediate climatic zone was identified with unexpected decreasing temperature trends, while several other areas were identified with expected increasing temperature and relative humidity trends. The adaptation practices based on these results would be interesting to incorporate in achieving sustainable development goals for the country.

Key words – Long-term trends, Non-parametric tests, Relative humidity, Temperature, Variability.

1. Introduction

Climate change and weather patterns changes have been recorded in many regions (Alexander & Arblaster, 2017; Ayugi *et al*., 2020; Bartels *et al*., 2019; Ghimire *et al*., 2019; Irannezhad *et al*., 2016; Khattak *et al*., 2011). Beingan island, Sri Lanka has also been severely affected by climate changes and weather pattern changes. Noteworthy, Sri Lanka was among the top ten countries affected by climate change and extreme climatic events in 2020 [Eckstein *et al*., 2020]. Increases in the frequency of erratic rainfall events, increases in temperature, occurrences of prolonged drought events, etc. in different parts of the country are prevalent in Sri Lanka. The dramatic land-use changes that happened in Sri Lanka during the past few decades due to deforestation for agriculture, expansion of human settlements cannot be ruled out as major reasons for the changes experienced in local climates (Naveendrakumar *et al*., 2018; Samarasinghe *et al*., 2022).

Fernando and Chandrapala, 1992; Fernando, 1997; De Costa, 2008; Chandrapala, 1996; Naveendrakumar *et al*., 2018; Amaraweera, 2014; Zubair *et al*., 2005 and Sujeewa, 2011) have clearly demonstrated that the atmospheric temperature levels have increased across many areas of Sri Lanka. In addition, fluctuations in rainfall levels have been observed in different parts of the country by many researchers, including Ratnayake and Herath, 2005; Jayatillake *et al*., 2005; Dissanayake and Rajapakse, 2019; Shantha and Jayasundara, 2005; Meegahakotuwa and Nianthi, 2018; Rathnayake, 2019; Perera *et al*., 2020; Alahacoon and Edirisinghe, 2021; Amarasinghe, 2020). It is noteworthy to state that Sri Lanka is an agricultural country of which 30% of its people are engaged in agriculture related activities contributing to 7.8% of the Gross Domestic Product (Ministry of Agriculture. Sri Lanka Council for Agriculture Research Policy, NARPS, 2018). Therefore, understanding of historical climates of Sri Lanka is crucial for decision making and policy formulations for different sectors not only for agriculture but also for other sectors including water resources, disaster management, etc.

The relative humidity is the ratio of actual water vapor in the air to the saturation vapor pressure of water at the same temperature. Therefore, it plays a crucial role in the formation of clouds, smog, fogs (Elliott & Angell, 1997; Van Wijngaarden & Vincent, 2005) and precipitation mechanisms [Willett *et al*., 2007), etc. In addition, water vapor plays a critical role as a greenhouse gas, regardless of its small proportion ($1/10000^{th}$) in the atmosphere (Abu-Taleb *et al*., 2007).

The relative humidity depends on atmospheric temperature and absolute water vapor present in the atmosphere (Willett *et al*., 2007). The water holding capacity of the atmosphere increases with increasing temperature, according to the Clausius-Clapeyron equation (Brown, 1951). The warm air has the ability to hold and redistribute more moisture, which causes a change in atmospheric circulation (Allen & Ingram, 2002; Bates *et al*., 2008; Durack *et al*., 2012; Wentz *et al*., 2007; Ye *et al*., 2013). Therefore, surface air temperature and humidity can seriously impact the hydrological cycle and the surface energy budget. Besides all of these, humidity and temperature affect human comfort.

Many studies provide sound evidence for increasing atmospheric temperature. These increases are attributed mainly due to anthropogenic reasons such as extensive use of fossil fuels, deforestation, urbanization, etc. However, one should also not undermine the natural variabilities of the earth caused due to El-Nino Southern Oscillation, La-Nina phenomena, etc. (Vassoler & Zebende, 2012). The El-Nino and La-Nina phenomena are strongly linked to global climates. Anomalously warm sea surface temperatures in the equatorial Eastern Pacific are referred to as the El Nino phase and its cold analogue is referred to as La Nina (Zubair, 2002; Zubair & Ropelewski, 2006).The shift in the location of tropical rainfall disrupts the atmospheric circulation patterns that connect the tropics with the middle latitudes, which in turn modifies the mid-latitude jet streams. By modifying the jet streams, El Niño and La Niña can affect the global climate systems including temperature and humidity levels in many parts of the world (NOAA, 2021).

These natural phenomena have accelerated warming far more when compared to the pre-industrial time periods (IPCC, 2007). Future temperature projections also confirm that temperature levels would steadily increase, with significant variations in different regions of the world. IPCC reports stated that Southeast Asia may have an increasing phase in atmospheric temperature. Therefore, Sri Lanka may also face the same impacts on atmospheric temperature (CCKP, 2020).

Previous studies carried out in different regions experiencing different climates of the world have investigated the trends of relative humidity (Abu-Taleb *et al*., 2007; Van Wijngaarden & Vincent, 2003; Kousari *et al*., 2010; Kousari & Asadi Zarch, 2010; Bleej, 2020). For instance, Van Wijngaarden & Vincent, 2003, studied trends in relative humidity over Canada experiencing a humid continental climate. Among others,Abu-Taleb *et al*., (2007); Kousari *et al*., (2010); Kousari & Asadi, (2010); Bleej, (2020) have carried out similar studies in the arid and semi-arid climatic zones such as Iran, Iraq and Jordan. Hence, it would be interesting to examine the trends in relative humidity over tropical Sri Lanka.

However, up to date, to the best knowledge of the authors of this paper, none of the previous studies in Sri Lanka has focused on examining the trends of relative humidity. This is also the case for the global scale, where the amount of studies related to relative humidity is a handful when compared to the vast amount of studies carried out related to rainfall and temperature. Therefore, to address the identified research gap, this research work examines the trends of relative humidity at 18 meteorological stations operated by the Meteorological Department of Sri Lanka.

The stations selected in this study are located in the three climatic zones (the dry zone, the intermediate zone and the wet zone) and distributed in all nine (Central, Northern, Uva, Sabaragamuwa, etc.) administrative regions of Sri Lanka. Understanding historical trends of temperature are vital to formulating adaptation strategies to cope up with future climate. In addition, the understanding of past trends will essentially serve in decision making and planning in different sectors including agriculture, water resources, tourism, etc. It was found that in South Asia by 2050 changes in temperature, rainfall, wind speed, RH, etc will reduce the production of rice, wheat and maize by 14%, 44% to 49% and 9% to 19% (Nelson *et al*., 2009). Future climate projections up to 2050s in Sri Lanka from two population and greenhouse gas emission scenarios (GHG) (A2 and B2 scenarios) revealed that during the wet season, average rainfall decreases by 17% (A2) and 9% (B2), with rains ending earlier and potential evapotranspiration increasing by 3.5% (A2) and 3% (B2). Consequently, the average paddy irrigation water requirement increases by 23% (A2) and 13% (B2) (De Silva *et al*., 2007). It is also expected that under the high GHG emission scenario a decline in tea production of 12% is predicted in Sri Lanka (Gunathilaka *et al*., 2019). Another study revealed that climate change would impact the country's economy in both beneficial and harmful ways. This study projected that increases in rainfall would benefit the economy while temperature increases will be harmful (Seo *et al*., 2005). The study by Wijeratne *et al*., 2007 indicated that a reduction of monthly rainfall by 100 mm could reduce the productivity by 30-80 kg of 'made' tea per hectare.The previous conducted studies clearly show that the changes in climates will adversely impact many sectors in the island. More importantly, Sri Lanka being an agricultural country, the recommendations based on the present study will assist in research related to the potential shifting of crop calendars, introducing new crop varieties that can also tolerate temperature fluctuations.

2. Study area and data collection

Sri Lanka is an island in the Indian Ocean located between the latitudes 5 to 10° N and longitudes 79 to 82° E. The climate of the island is tropical and influenced by two main monsoon seasons. In addition, the teleconnections influence the climate of the country, mainly by the El-Nino Southern Oscillation (Zubair *et al*., 2008). The mean temperature of the country is 27 °C in the coastal areas ad 16° C in the central mountains. The two main monsoon seasons of the country are the northeast monsoon (December to February) and the southwest monsoon (SWM) (May to September). However, there are two intermediate monsoon seasons, namely the 1st inter-monsoon season (March to April) and the 2nd inter-monsoon season (October to November). The rainfall for the northeast monsoon and southwest monsoon is brought by tropical cyclones and slow-moving tropical flows in the Bay of Bengal.

Sri Lanka owns a total geographical area of 65,610 km² comprising 62,705 km² area of land and 2,905 km² area of water. The country is occupied by nearly 21 million people (Satyanarayana *et al*., 2017). Main meteorological stations in 18 major areas spanning in all the three climatic zones of the country (the dry zone, the intermediate zone and the wet zone) were selected for this study. These locations are depicted in Fig. 1.

These meteorological stations considered in this study are located in the 9 provinces of Sri Lanka including Colombo and Katunayake stations from the Western province, Rathnapura from Sabaragamuwa province, Anuradhapura from the North Central province, Pottuvil, Batticaloa and Trincomalee from the Eastern province, Mannar, Vavuniya and Jaffna from the Northern province, Katugastota and Nuwara-Eliya from the Central province, Bandarawela and Badulla from the Uva province, Galle and Hambantota from the Southern province and Kurunegala and Puttalam from the North-Western province.

The Department of Meteorology of Sri Lanka maintains 22 main meteorological stations across the country. However, 18 main stations among these 22 were selected for this study based on the availability of continuous data sets of atmospheric temperature and relative humidity. The locations of these 18 stations are given in Table 1. The data were purchased from available stations for 30 years period from 1990 to 2019 for the maximum temperature, minimum temperature, maximum relative humidity and minimum relative humidity. The nearest neighbour approach was used in XLSTAT (https://www.xlstat.com/en/solutions/features/missing-data) software under the missing data of preparing data to fill the missing data in the data series (Eskelson *et al*., 2009).

3. Materials and method

3.1. *Mann Kendall test (MK test)*

Trend detection methods that are used in hydro-meteorological variables can be divided into two types. They are parametric and non-parametric methods. Among them, trend analysis using a non-parametric test is frequent in climate studies. The past data are analyzed to check the trends in the climatic data series. Mann-Kendall (MK) test is one of the most commonly used non-parametric tests to detect the significance of trends in time series data sets (Rathnayake, 2019; Perera *et al*., 2020; Kamal & Pachauri, 2019; Panda & Sahu, 2019).

The null hypothesis, H_0, indicates that there is no trend in the data series while hypothesis, H_A means that the timeseries follows an increasing/decreasing trend. The equations of the MK test are given below (refer to Eqns. 1 to 4).

The Mann-Kendall test statistic S (Mann, 1945) is calculated as,

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \tag{1}$$

where, n is the number of data points and x_i and x_j are the values of data in time series i and j (j>i), respectively. The sgn ($x_j - x_i$), is the function of sign and expressed in Eqn. 2.

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} +1, & \text{if } (x_i - x_j) > 0 \\ 0, & \text{if } (x_i - x_j) = 0 \\ -1, & \text{if } (x_i - x_j) < 0 \end{cases} \tag{2}$$

The variance can be calculated as,

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \tag{3}$$

where, m is the number of tied groups and t_i is the extent tie numbers. Tied group is a sample set, which has the same value when the sample size n > 10. Next, the standard normal test statistics Z_s can be calculated as below.

$$Z_s = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}, & \text{if } S > 0 \\ 0 & \\ \dfrac{S+1}{\sqrt{Var(S)}}, & \text{if } S < 0 \end{cases} \tag{4}$$

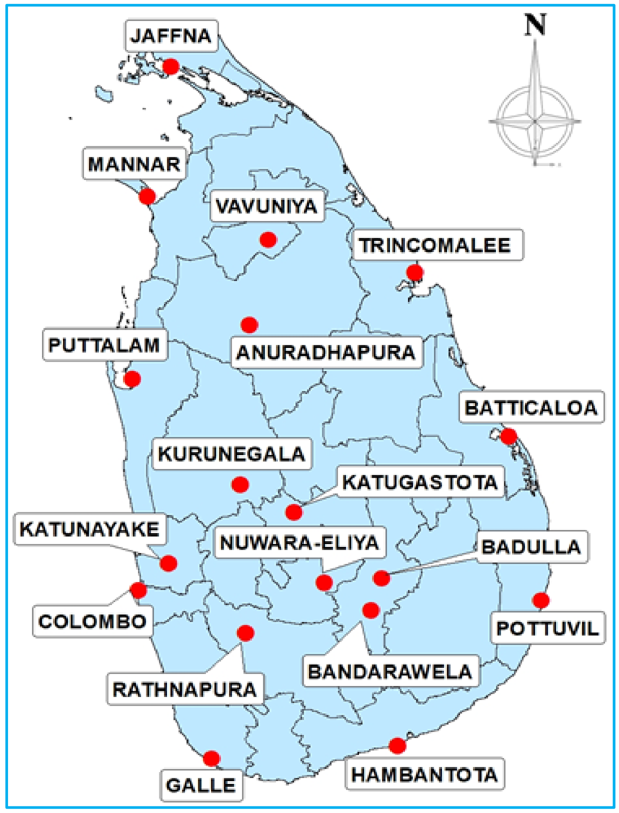


Fig. 1. Location map of meteorological stations used in the current study

When Z_s shows positive values, the trend is an increasing trend, while Z_s shows negative values the trend detects as a decreasing trend. Testing of trends is carried out at the specific significance level of α. When (Z_s) > Z_1 – α/2, the null hypothesis is rejected and the significant trend exists in the time series (Gocic & Trajkovic, 2013).

3.2. *Sen's Slope Estimator test*

Sen (1968) has developed the non-parametric procedure for estimating the slopes of trends in time series data sets. The median of slope for all data set can be computed as Eqn. 5.

$$Q_i = \frac{x_i - x_k}{j-k}, \qquad \text{for } i = 1, 2 \ldots, N \tag{5}$$

where, the x_i and x_k are the values of data at times j and k (j>k), respectively. If there is only one datum in respective time period, then the $N = \frac{n(n-1)}{2}$, n represents the number of time periods. However, if there are multiple observation sets in one or more than one time period, the $N < \frac{n(n-1)}{2}$, n represents the total number of observations.

TABLE 1

Description of meteorological stations used in this study

Climatic zone	Station	Latitude (°)	Longitude (°)	Province
Dry zone	Anuradhapura	8.3114	80.4037	North Central
	Pottuvil	6.8753	81.8306	Eastern
	Batticaloa	7.7310	81.6747	Eastern
	Mannar	8.9810	79.9044	Northern
	Trincomalee	8.5874	81.2152	Eastern
	Vavuniya	8.7542	80.4982	Northern
	Jaffna	9.6600	80.0200	Northern
	Puttalam	8.0300	79.8300	North Western
	Hambantota	6.1200	81.1300	Southern
Intermediate zone	Nuwara-Eliya	6.9700	80.7700	Central
	Kurunegala	7.4814	80.3609	Northwestern
	Badulla	6.9900	81.0500	Uva
Wet zone	Katunayake	7.0700	80.0100	Western
	Colombo	6.9271	79.8612	Western
	Rathnapura	6.7056	80.3847	Sabaragamuwa
	Katugastota	7.3360	80.6214	Central
	Bandarawela	6.8259	80.9982	Uva
	Galle	6.0535	80.2210	Southern

The median of slope or Sen's slope estimator calculated as shown in Eqn. 6.

$$Q_{med} = \begin{cases} Q\left[N + 1/2\right], & \text{if } N \text{ is odd} \\ \dfrac{Q\left[N/2\right] + Q\left[N + 2/2\right]}{2}, & \text{if } N \text{ is even} \end{cases} \quad (6)$$

The Q_{med} sign shows the reflection of trend, while the numerical value indicates the steepness of the trend. The value of the median slope should be found that it is statistically different from zero, for that it should attain the confidence interval of Q_{med} at a specific probability.

3.3. *Spearman's rho test*

The Spearman's rho test (Spearman, 1904) is another method with uniform power for linear and non-linear trends and is commonly used to verify the absence of trends. Spearman's rho test is used to detect monotonic hydrological time-series trends and showed that both are equally strong for long-term data. The null hypothesis (H_o) of the test tells that all the data in the time series are independent and identically distributed, while the alternative hypothesis (H_1) showcases the existence of increasing or decreasing trends. Positive values of standardized test statistics indicate upward trends, while negative standardized test statistics indicate downward trends in the time series.

3.4. *Pettit test (PT)*

The Pettit test is a non-parametric test used to detect the change point in a time series (Pettitt, 1979). Therefore, abrupt changes in temperature and relative humidity can be identified from this test. The null hypothesis of the test, H_o indicates the homogeneous data set, while the alternative hypothesis, H_1 represents failure occurrence in the considered time series. If the calculated *p*-value (probability of obtaining results) is less than α or a significance level of 0.05 (5%), then this change point is considered to be statistically significant. The Pettit test was widely used in hydrological studies. Nevertheless, more details on the Pettit test can be found in Pettit, 1979.

TABLE 2

Annual trends of temperature and relative humidity from 1990 to 2019

Station	T_{min}	T_{max}	RH_{min}	RH_{max}
Puttalam	NST	NST	NST	NST
Hambantota	0.03 °C	0.025 °C	0.08%	0.1%
Nuwara-Eliya	NST	0.02 °C	NST	NST
Colombo	0.03 °C	NST	NST	-0.07%
Anuradhapura	0.02 °C	NST	NST	-0.05%
Katugasthota	NST	0.02 °C	NST	NST
Rathnapura	NST	NST	NST	NST
Trincomalee	NST	NST	NST	NST
Bandarawela	NST	NST	NST	NST
Katunayake	0.02 °C	NST	NST	NST
Jaffna	NST	0.03 °C	NST	NST
Badulla	-0.02 °C	-0.06 °C	NST	-0.25%
Mannar	NST	0.02 °C	NST	0.22%
Vavuniya	NST	NST	NST	NST
Batticaloa	0.03 °C	0.02 °C	NST	NST
Pottuvil	0.05 °C	NST	0.15%	NST
Kurunegala	NST	0.03 °C	NST	-0.13%
Galle	0.02 °C	NST	NST	NST
Legend	T_{min} - Minimum temperature T_{max} - Maximum temperature RH_{min} - Minimum Relative Humidity RH_{max} - Maximum Relative Humidity NST – No Significant Trends			

3.5. *Coefficient of Variation (CoV)*

Variability analysis provides a quantitative measure of the variation of the data sets from their average value. In simple terms, the coefficient of variation (CoV) provides the variation within a sample data set. This can be mathematically presented in Eqn. 7.

$$\text{CoV} = \frac{\sigma}{\mu} \tag{7}$$

where, μ and σ are the mean and the standard deviation of the data set, respectively. The higher the value of CoV indicates a larger variability. Moreover, some researchers have presented the degree of variability in mathematically. For instance, if CoV is less than 20 (CoV < 20), then, the sample data sets shows a low variability. If CoV is between 20 and 30 (20 < CoV < 30), then, the sample poses inherits a moderate variability, while if it is greater than 30 (CoV > 30) it shows high variability (Niyongendako *et al*., 2020).

3.6. *Overall methodology*

Initially, the obtained observed temperature and relative humidity data sets were purchased from the meteorological department and the missing data were filled. The annual and monthly trends of temperature and relative humidity were examined using the Mann-Kendall test, while the magnitude of trends were obtained from the Sen's Slope estimator test. In addition, the Spearman's rho test, Pettit's test and Coefficient of Variation were checked to detect the significance of trends, abrupt changes in trends and variability of the data series. The results obtained from these tests are presented in the next section.

4. Results and discussion

4.1. *Temperature and relative humidity trends*

4.1.1. *Annual trends*

Trend results of annual temperature (maximum and minimum) and humidity (maximum and minimum) are demonstrated in Table 2. Pottuvil demonstrates the highest increase in the minimum temperature among all 18 stations and that is 0.05 °C per year. However, this station is located in the dry zone of the country. In addition, Anuradhapura, Batticaloa and Hambantota from dry zones, Colombo, Katunayake and Galle from wet zones show increasing trends of minimum temperatures in the orders of 0.02-0.03 °C per year. Nevertheless, Badulla in the intermediate zone showcased a significant decrease of (0.02 °C per year) in minimum temperature. This might affect the tea cultivation and production in the area. This observation can also be seen in the maximum temperature trend for Badulla. The temperature has a significant decreasing trend of 0.06 °C per year. Therefore, this can be a critical factor for the agricultural activities in the region. Thus, an in-depth analysis of the impact of climate change on agriculture should be a futuristic study. In addition, increasing annual maximum temperature can be observed in Hambanthota, Jaffna, Batticaloa, Kurunegala, Katugasthota and Nuwara-Eliya. Hambanthota is interesting as the area is being heavily developed for various industrial activities, which can increase the near surface atmospheric CO_2 concentration levels. Therefore, the temperature increase would be interesting to further investigate in relation to the development activities. Furthermore, Nuwara-Eliya is world-renowned as one of the main tourism centers in the country. Hence studying the impact would be interesting to investigate with the tourism industry.

The relative humidity has several increasing trends in its both minimum and maximum values. Hambanthota has increasing trends in both minimum and maximum; however, a notable increasing trend can be seen in Mannar in the maximum relative humidity (0.22%). Both Hambanthota and Mannar are in the dry zone of the country and would be interesting to understand the comfortability of living in these regions with temperature and relative humidity increases. Nevertheless, interesting observations of negative trends can be observed in Colombo, Anuradhapura, Badulla and Pottuvil.

As a combination of trends in temperature and relative humidity, it is interesting to understand the country's agriculture, tourism and human comfortability. Previous research studies show cased that a 0.1-0.5 °C increase in temperature can reduce rice yield approximately by 1-6% (Vidanage & Abeygunawardane, 1994). In addition, some researchers predicted that the climate change would affect Sri Lanka's Forest distribution, with increases in tropical very dry forest areas (5%) and tropical dry forest areas (7%) and a decrease in tropical wet forest areas (11%) (Somaratne & Dhanapala, 1996). Therefore, scientists attribute this warming trend, seen throughout the country, possibly due to both enhanced greenhouse effect and local heat island effect caused by rapid urbanization (Basnayake, 2008; Basnayake & Punyawardena Vithanage, 2003).

Decreasing of the minimum temperature to Badulla means that the temperatures recorded in the early morning are decreasing. Therefore, nights are getting colder in Badulla. However, for many other places, the day times and night times are becoming warmer. Overall it is clear that most of the stations located in the dry zone of the country are experiencing warming trends. Increased temperature trends will definitely cause increased evaporation in tanks and reservoirs, which are the major storage facilities of water resources in the dry zone. The higher evaporation rates will result in higher water vapor contents; thus, lead to heavy precipitation events and sometimes to increasing tropical cyclonic activity (De Costa, 2008). Some studies have also demonstrated that this can also lead to increased salinity in lower altitudes (Zubair, 2002).

4.1.2. *Monthly trends*

Table 3 presents the trend analysis results for monthly minimum temperature analysis. Only selected areas with significant temperature trends are presented in the table. Significant increasing temperature trends for minimum temperatures are detected in Hambanthota, Colombo, Anuradhapura, Batticaloa and Galle areas. However, notably, significant decreasing trends can be seen in Badulla. Therefore, these monthly trend analyses validate the annual trends in temperature variations.

Similarly, decreasing trends can be found in the maximum temperatures for the Badulla area. The trends are varying between 0.04 and 0.08 °C per month in a year. Therefore, 1.2-2.4 °C temperature difference may have been observed for the Badulla area over the last 30 years for some of the months. This is highly important along the lines of discussion on the agricultural activities in the area.

The temperature trends in minimum and maximum temperatures can be further graphically illustrated in Fig. 2 for three important areas. They are in the wet zone (Colombo), intermediate zone (Badulla) and dry zone (Hambanthota). Clear positive trends can be seen for both wet and dry zones, while negative trends can be observed in the intermediate zone of Sri Lanka.

TABLE 3

Monthly trends of minimum temperature in selected areas (in °C)

Month	Hambantota	Colombo	Anuradhapura	Badulla	Batticaloa	Galle
January	0.02	0.03	-	-	-	-
February	0.03	0.04	-	-	0.03	0.03
March	0.04	0.04	0.03	-	0.04	0.03
April	-	-	0.02	-	0.03	-
May	0.02	0.03	-	-0.03	0.03	-
June	0.04	0.02	0.02	-	0.05	0.03
July	0.04	0.04	0.03	-0.02	0.04	0.03
August	0.02	-	0.01	-	0.03	-
September	-	-	-	-	0.03	-
October	0.04	0.04	0.02	-	0.02	-
November	0.03	0.03	0.02	-0.03	0.02	0.02
December	0.04	0.05	0.03	-	0.02	0.03

Similarly, De Costa, 2008 and De Silva and Sonnadara, 2009) also found increasing trends in temperature in Sri Lanka. The increasing temperature trends observed in most of the regions of the country can well be due to deforestation. These increases in temperature will affect the species habitats causing negative consequences on the biodiversity of Sri Lanka. Previous studies have also demonstrated that an increase in temperature will lead to the occurrence of heat waves. The negative consequences of heatwaves can be intense to the population of Sri Lanka especially the adult population.

4.2. *Change point detection in temperature and relative humidity*

4.2.1. *Change points in annual scales*

The change point detection was carried out by the Pettit test for annual minimum and maximum temperatures and relative humidity, which are given in Table 4. Significant trends identified from MK test are only included in Table 4.

Recent changing points can be seen in Hambanthota (2009); Colombo (2008); Badulla (2007) and Batticaloa (2008) for minimum temperatures. Therefore, Hambanthota, Colombo and Batticaloa might have experienced a minimum temperature rise in the respective years. However, according to the MK test results, Badulla may have experienced a temperature reduction in its minimum temperature in the year 2007. This extended to the maximum temperature reduction for Badulla in year 2006. Nevertheless, Nuwara Eliya (2007),

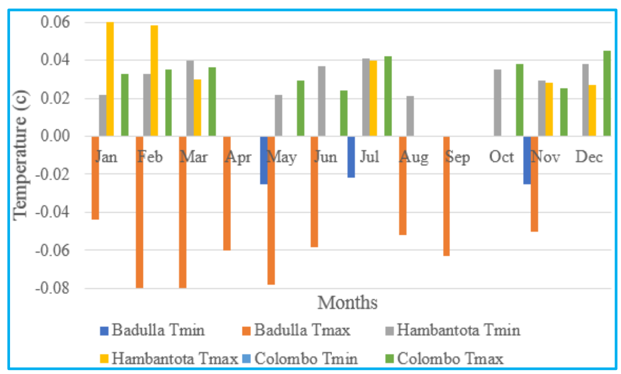


Fig. 2. Monthly trends in minimum and maximum temperatures

Katugasthota (2013), Jaffna (2013) and Kurunegala (2008) have experienced a temperature rise in their maximum temperatures. Nevertheless, some minor fluctuations in relative humidity occurred in Hambanthota, Colombo, Anuradhapura, Badulla, Mannar, Pottuvil and Kurunegala areas.

4.3. *Variability of temperature and relative humidity*

4.3.1. *Inter-annual variability of temperature and relative humidity*

The variability analysis results of annual minimum, maximum temperature and relative humidity during 30 years from 1990 to 2019 are shown in Table 5. In general, it was observed that the CoVs in annual minimum and maximum temperatures were comparatively low during the 30 years of analysis. Rathnapura recorded the lowest

TABLE 4

Year of change point in temperature and relative humidity

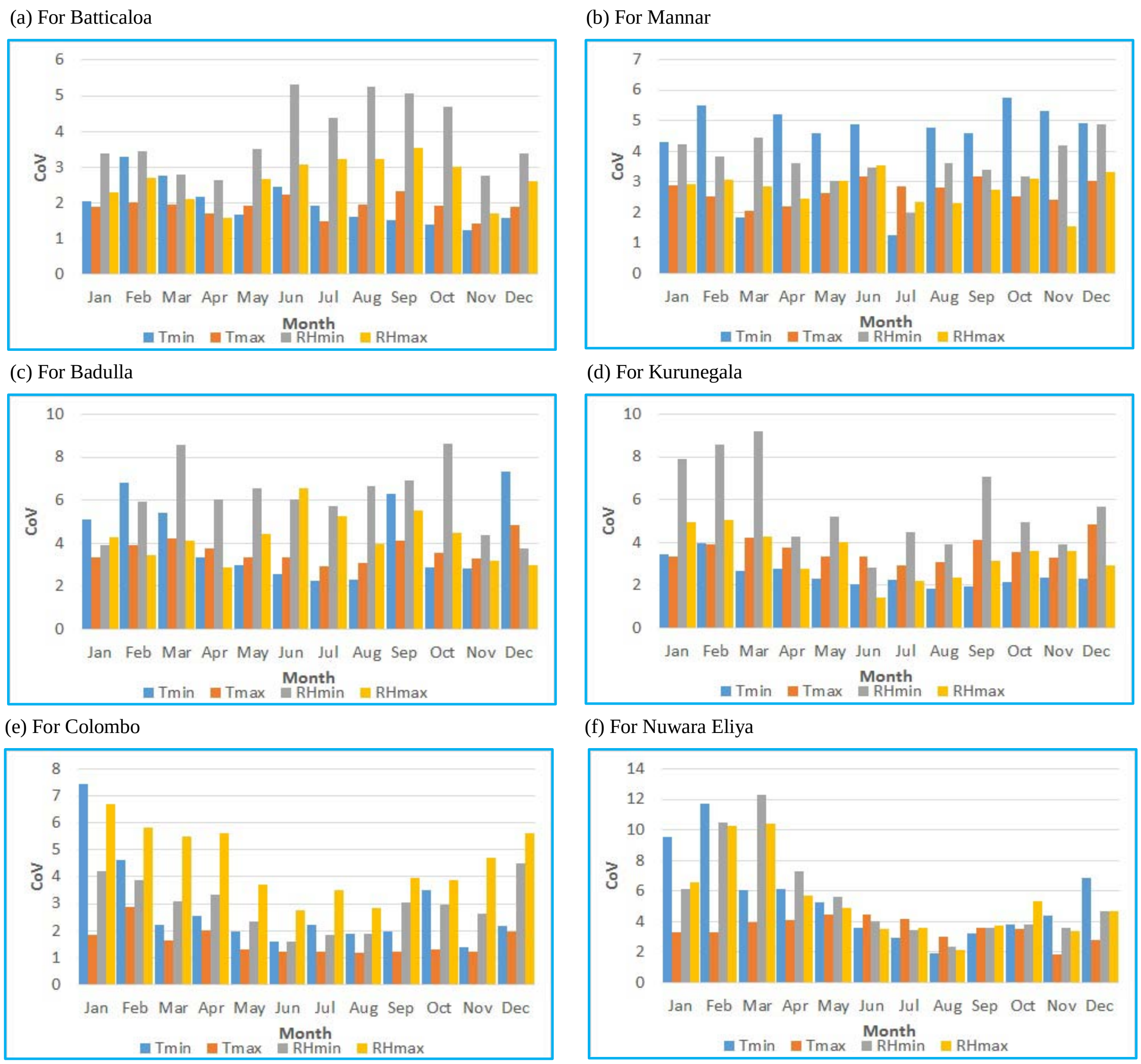
Station	T_{min}	T_{max}	RH_{min}	RH_{max}
Hamabanthota	2009	2000	2003	2004
Nuwara Eliya	-	2007	-	-
Colombo	2008	-	-	2006
Anuradhapura	1997	-	-	2008
Katugasthota	-	2013	-	-
Katunayake	1997	-	-	-
Jaffna	-	2013	-	-
Badulla	2007	2006	-	2006
Mannar	-	2000	-	2008
Batticaloa	2008	2000	-	-
Potuvil	1998	-	2003	-
Kurunegala	-	2008	-	2000
Galle	1997	-	-	-

No trend identified by MK test

TABLE 5

CoV of annual temperature and relative humidity from 1990 to 2019

Station	T_{min}	T_{max}	RH_{min}	RH_{max}
Colombo	1.46	0.75	0.99	3.99
Trincomalee	1.01	0.93	2.13	1.21
Anuradhapura	1.47	1.82	2.08	6.11
Katugastota	1.82	1.34	1.59	5.94
Rathnapura	0.87	1.10	1.68	4.78
Bandarawela	1.40	1.16	2.75	1.78
Mannar	3.94	2.17	1.80	1.79
Vavuniya	3.17	1.10	3.90	1.28
Batticaloa	1.40	1.09	1.76	1.26
Pottuvil	5.54	0.90	2.26	2.30
Kurunegala	2.24	1.40	2.17	1.92
Galle	1.31	0.86	1.56	1.24
Puttalam	1.38	1.28	1.74	1.02
Jaffna	0.90	1.00	1.39	1.97
Hamabantota	1.31	1.19	1.99	3.53
Badulla	2.30	2.60	2.63	2.72
Nuwara Eliya	2.36	1.59	2.19	3.45
Katunayake	1.10	0.80	1.18	0.91



Figs. 3(a-f). CoV results

variability among all stations in minimum temperature, which was 0.87. However, Pottuvil has the highest (5.54). Badulla recorded the highest variability in maximum temperature (2.6) and that is understood as Badulla was experiencing regular negative temperature trends. This area also has regular variability in relative humidity too. Therefore, as it was discussed in previous sections, it is very important to understand the climate change impacts on agriculture, forest cover and human comfortability.

However, Kurunegala is found as the area with the lowest variability in terms of maximum temperature. However, Anuradhapura shows high variability in relative humidity. Therefore, further analysis on these climatic factors would be interesting and thus investigate their impact on society.

4.3.2. *Variability of monthly temperature and relative humidity*

Some of the results from the CoV test of monthly minimum and maximum temperature and relative humidity are shown in Fig. 3. Only several selected, including Batticaloa and Mannar from the dry zone, Badulla and Kurunegala from the intermediate zone and Colombo and Nuwara Eliya from the wet zone are presented here. However, the variability of all climate zones was low during the 30 years from 1990 to 2019. Among all areas, Pottuvil has shown the highest variability (8.39) in January for maximum temperature, while Batticaloa has shown the lowest variability (1.42) in November for the dry zone. In addition, Pottuvil was recorded with the highest variability in January as 11.63 in minimum temperature, while Trincomalee was shown the lowest variability of 1.15 in July during 30 years. Similarly, variabilities can be seen for intermediate and wet zones for minimum and maximum temperatures and relative humidities. Therefore, the impact of the change of the temperature and relative humidity is interesting to understand along lines of human comfortability.

5. Conclusions

This study was performed to find out the trends and the variability of the temperature and relative humidity in Sri Lanka by considering 18 areas across Sri Lanka. The analysis was done using observed data of minimum and maximum temperature and minimum and maximum relative humidity parameters. Results from the trend analysis inannual and monthly scales showcase increasing temperature trends for several areas in all climatic zones with observations of increasing trends in relative humidity. The minimum and maximum temperatures were found with increasing trends in most of the stations. In addition, the maximum relative humidity shows similar trends in most of the stations. These results were discussed in the context of agriculture. The direction of trends in different regions can vary such as the decreasing temperature patterns observed for Badulla located in the intermediate zone. This might be because the temperature changes depend on many factors including latitude, elevation, surface cover, land use type, etc. as explained by (Karl *et al*., 2006). However, further analysis in studying the impact of these changes on other activities is recommended. The change point detection results showcased that these changes might have happened from 2006 to 2007. Therefore, critical analysis of these years is further recommended. In addition, Hambanthota area is facing increasing trends in temperatures. This could critically affect the recent development activities in the area. The area is noted to be a relatively drier partin Sri Lanka and further increasing temperatures can lead to arid climates. This can even result in soil moisture deficiencies and thus causing a negative impact on crop growth. Therefore, it can ultimately affect crop production. Therefore, these climate changes alarm all the stakeholders and thus plan the adaptation processes immediately.

The increasing temperature trends of temperature will essentially increase the evapotranspiration of water bodies. Hence, it is recommended that the suitability of rainwater harvesting techniques should be investigated, especially in the dry zones of the country for increased water security. Renovating the existing tanks in the dry and intermediate zones to store excess rainfall during the SWM season and devising methods to store and transfer excess rainfall in the wet zone to the dry zone are other available alternatives to increase water security as well.

Thus, this research along with the trends of other climatic parameters like rainfall can be effectively used in adaptation practices in climate change. That can lead to enhance the sustainable goals in food production, comfortable living, etc. in long term. Further studies are recommended to explore the relationship between CO_2 concentrations and increasing temperature rates to obtain a clear and broad picture of food security and sustainability. The increasing trends of temperature which is mainly attributed to human-induced causes including green house gas emissions should be reduced while promoting sustainable methods to safeguard the planet earth. Hence, alternative renewable energy methods including solar, wind power should be promoted. Promoting electric cars and limiting fossil fuels is also another possible alternative.

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