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# Analyzing Relationships Between Rainfall and Paddy Harvest using Artificial Neural Network (ANN) Approach: Case Studies from North-Western and North-Central Provinces, Sri Lanka

**Thilini Ranasinghe[1], Gayantha Gunawardena[1], Eranga M. Wimalasiri[2*] and Upaka Rathnayake[1]**

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## ABSTRACT

***Purpose:*** *Food and agriculture are frequently affected from on-going climate change. A significant percentage of annual harvest is lost due to extreme climatic conditions in different parts of the world. Sri Lanka is considered as a country which is vulnerable to climate change. Therefore, this research presents a detailed analysis to find out the non-linear relationships between the rainfall and paddy harvest in two major provinces of Sri Lanka.*

***Research Method:*** *North-central and North-western provinces as two major agricultural areas were selected for the study. Rainfall trends were identified using non-parametric Mann-Kendall and Sen's slope estimator tests. The artificial neural network (ANN) approach was used to establish non-linear relationships between rainfall and paddy yield.*

***Findings:*** *There was no significant ($p > 0.05$) linear correlation between rainfall amount and the rainfed paddy yield in tested locations. However, no clear relationship between the rainfall and rain fed yield were found in the 14 predefined functions (polynomial, logarithmic, exponential and trigonometric) derived using ANN where the calculated coefficients of determination were less than 0.3.*

***Research Limitations:*** *Due to lack of other climate variables such as temperatures, a significant relationship was not observed in this study.*

***Originality/value:*** *We have shown that non-linear artificial neural network approach can be used to study the impact of climate on agricultural production in Sri Lanka.*

**Keywords:** *ANN, linear and non-linear correlations, Maha season, rainfall trends, rice yield, Yala season*

## INTRODUCTION

Climate change and the associated variability are two major constraints to agriculture across the world (IPCC, 2013). In Sri Lanka, climate change is evident in terms of increased temperature, rainfall variability and increased extreme weather events (De Costa, 2008; De Zoysa and Inoue, 2014; Esham and Garforth, 2012). Other than the agriculture, climate change has resulted many critical issues that includes increase of sea level, extinction of species, unbalanced ecosystem, health issues and natural disasters (IPCC, 2013). With the climate change, yields of staple crops such as rice and maize are expected to decline in tropical region of the world (Karunaratne and Wheeler, 2015). Therefore, proper understanding of the climate variability and their impact to the agriculture is important.

The climatic parameters, specially, rainfall has a significant impact on global food production. Both droughts and floods have damaged a

[1] *Department of Civil Engineering, Faculty of Engineering, Sri Lanka Institute of Information Technology, Malabe, Sri Lanka*
[2*] *Department of Export Agriculture, Faculty of Agricultural Sciences, Sabaragamuwa University of Sri Lanka, Belihuloya, Sri Lanka*
*eranga@agri.sab.ac.lk*
*https://orcid.org/0000-0002-2527-7650*

significant percentage of the annual harvest of food production (Joardder and Hasan Masud, 2019; Stella, 2019; Wakiyama *et al.*, 2019). Changes in the rainfall seasons, extreme low and high temperatures and increase and decrease of water availability to crops can result the poor quality of agricultural products as well as the reduction of yield (Chandrasiri *et al.*, 2020; Kang *et al.*, 2009). Not only the amount of harvest but also the food quality also reduced due to the variation of the climatic factors (Campbell *et al.*, 2016; Ceccarelli *et al*., 2010; Kang *et al.*, 2009). The impact of climate change is quite significant to Sri Lanka, therefore, the economy and the development of the country can adversely be impacted (Kottawa-Arachchi and Wijeratne, 2017).

Sri Lanka is a small tropical island (coordinates - 7.8731° N, 80.7718° E) in the Indian Ocean with an year-round warm weather. Seasonal temperature variation is not significantly observed in the country; therefore, the amount and pattern of rainfall distribution play an important role in the agro-climatology in Sri Lanka (Chandrasiri *et al.,* 2020; Chithranayana and Punyawardena, 2008). The country receives rainfall from two major monsoons and two inter monsoons to different parts of the country in different times of the year. The first inter monsoon (FIM) is activated from March to May, while south west monsoon (SWM), second inter monsoon (SIM) and north east monsoon (NEM) are activated from May/June to September, from October to November and from December to February, respectively (Suppiah, 1996). These four monsoons are assigned into two growing seasons; *Yala* or minor growing season (FIM and SWM) and *Maha* or major season (SIM and NEM).

The country's annual rainfall spatially varies from 800 mm to 5000+ mm (Chithranayana and Punyawardena, 2008). Therefore, the country can be sub-divided into three major climatic zones namely, dry zone (annual rainfall < 1700 mm/year), wet zone (annual rainfall > 2500 mm/year) and intermediate zone (annual rainfalls in between 1750-2500 mm/year). More than 87% of the country accounts for the dry and the intermediate zones on which rainfall plays a crucial role in agriculture (Nisansala *et al.,* 2019). However, the altitude, annual rainfall and other physical characteristics have been used to further divide the country into 46 agro-ecological zones.

Sri Lanka does not emit a considerable amount of greenhouse gases to the environment; however, the island is not safe from the consequences of on-going climate change (De Costa, 2008; De Zoysa and Inoue, 2014; Yamane, 2009). Not only reductions of rainfall but also increments were observed in different parts of the country (Jayawardene *et al.,* 2005). Therefore, the agricultural sector in the country is negatively affected by climate shocks (Zubair *et al.*, 2005; Zubair, 2002). The country is also ranked to the 2$^{nd}$ place in global Climate Risk Index (CRI) in 2019, which calculates the extent of climate-related losses such as storms, floods, heat waves to the economy (Eckstein *et al*., 2019). Statistics have revealed that around 26% of the population in the country involves in agricultural activities as their major livelihood (Central bank Sri Lanka, 2017). Therefore, any climate associated damage to agriculture has directly affected the livelihood of the society, food system and the economy.

Different crops and crop combination are cultivated in the country under many agro-climatic scenarios. Out of several crops, rice is the major cereal of the country that occupies 18.18% of total and 35.71% of agricultural lands (AgroStat, 2019). Sri Lanka is almost self-sufficient in its rice demand; however, climate associated risks make a severe impact on the production. The paddy production in the country declined by 21.9% in 2016 Yala compared to that of 2015 as a reason of flooding due to a severe tropical storm. The extreme rainfall delayed paddy cultivation of the minor growing season and necessitated re-sowing in major growing areas (Central bank Sri Lanka, 2016). Adverse weather has continued from 2016 due to the failure of rainfalls in NEM and SWM in 2017, which created severe drought conditions lasting 9 months, reduced the production of paddy by 46.1% marking the lowest paddy production over the last decade (Central bank Sri Lanka, 2017). Therefore, understanding of the relationship between rainfall amount and paddy production is important in Sri Lanka.

The relationship between climatic parameters and crop yield can be studied using different approaches such as crop modeling, linear and nonlinear regression on which they have different advantages and disadvantages. Crop models need several inputs that include weather, soil and crop parameters that hinder their applications (Wimalasiri *et al.,* 2020). The non-linear method, which is the mostly used method in Sri Lanka consists of several drawbacks including missing the impact/ relationship of other covariates while most of the relationships are not linear. Therefore, the non-linear regression approach which facilitates the relationship using the same input dataset for linear regressions is gaining popularity. The impact of rainfall and climate change on crop yield was previously studied for major crops such as paddy (De Silva *et al.,* 2007; Dharmarathna *et al.,* 2012), maize (Karunaratne and Wheeler, 2015) and plantation crops (Peiris *et al.,* 2007; Wijeratne *et al.*, 2007) in different geographic locations and timescales in Sri Lanka. However, a detailed analysis among climatic factors and the paddy yield has not been carried out.

However, Fujihara *et al.* (2008) state that critical scarcities would not occur in water requirements for future crops, if a significant increase in the demand is not there in the future. Nevertheless, it is well predicted that the demand for food is in an increasing phase. Therefore, it is highly essential to analyze the impact of climate change on food production in the world, then, to predict and develop some adaptation strategies. Similar to many other countries, the food demand in Sri Lanka has been increased with population growth and with improved living styles. However, a detailed analysis on the paddy yield with respect to the climatic parameters is yet to be showcased in the context of Sri Lanka.

Therefore, as an initial study, the objective of the paper is to analyse the impact of climate change on paddy harvest in Sri Lanka for two of the main provinces (namely North-central and North-western provinces) using non-linear regression which were developed using artificial neural network (ANN) approach. Initial assessment was carried out for identifying the relationships in between the rainfall to a particular location and the corresponding harvest. Rainfalls were assessed for the trends and then, the correlation was tested for the rainfalls and the paddy yield. Linear analyses were famous among many researchers; however, non-linear regression analyses and artificial neural network analysis were carried out in this research to assess the impact of rainfall on paddy yield as a novel approach.

## MATERIALS AND METHODS

### *Statistical Analysis of Climate Trends*

Mann Kendall test combined with Sen's slope is frequently used to investigate the trends in climates (Ahmad *et al.*, 2015; Bossa *et al.*, 2020; Chen *et al.*, 2016; Loua *et al.,* 2019; Yue and Pilon, 2004). Mann Kendall test analyzes the monotonically increase and decrease patterns of the climate data series with respect to the time whereas Sen's slope gives the gradient of the trend in Mann Kendall test results. Mann Kendall test can be mathematically expressed in the following equations (1-4) (Kendall, 1957; Mann, 1945).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(X_j - X_i) \tag{1}$$

$$sgn(X_j - X_i) = \begin{cases} +1 & if(X_j - X_i) > 0 \\ 0 & if(X_j - X_i) = 0 \\ -1 & if(X_j - X_i) < 0 \end{cases} \tag{2}$$

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p\,(t_p - 1)(2t_p + 5)\right] \tag{3}$$

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} & if S > 0 \\ 0 & if S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}} & if S > 0 \end{cases} \tag{4}$$

where $X_i$ and $X_j$ are the rainfall time series observations in sequential order, *n* is the length of the rainfall time series, $t_p$ is the number of ties for the $p^{th}$ value and $q$ is the number of tied values. *“”sgn”* in equation 1 is explained in equation 2. The variance of $S$ is given in equation 3. Positive $Z$ values suggest a positive trend whereas negative $Z$ values suggest a negative trend where the null hypothesis can be neglected.

Mann Kendall test is a non-parametric test. Therefore, it can be used for any distribution. However, in this analysis, it was used to observe the rainfall trends. Serial correlations are not usually analyzed using non-parametric tests as they can be easily assessed using linear regression. The test has few drawbacks too. It can identify alternative upward and downward trends in the same data series. In addition, multiple data points for one time period are not accepTable 0to the test. Therefore, a mean value should be considered. However, when it comes to rainfall, it is the sum of the rainfall over a particular time period and that is usually over a month or season or year.

Sen’s slope estimator can be given in the following equations (5-6) (Sen, 1968).

$$T_i = \frac{x_j - x_k}{j - k} \quad (5)$$

$$Q_i = \begin{cases} T_{\frac{(N+1)}{2}} & N \text{ is odd} \\ \frac{1}{2} T_{N/2} + T_{(N+2)/2} & N \text{ is even} \end{cases} \quad (6)$$

where positive $Q_i$ values suggest that there is an increasing (upward) trend in climatic data series, while negative values suggest the opposite. Sen’s slope estimator test evaluates the magnitude of the trend. However, the test produces the magnitude of the trend along a straight line. It is not capable of handling variable trend magnitudes over the time. Therefore, these two non-parametric tests are linear results-oriented tests. More details of these two tests are given in Khaniya *et al.* (2019).

Rainfall time series can be tested for its correlation to the other time series (yield with respect to the time) using linear and non-linear correlation tests. Linear correlation measures the linear relationship between the two time series; rainfall and corresponding yield. More information on the linear correlation analysis can be found in Perera and Rathnayake (2019). However, most of the real-world scenarios do not follow linear relationships. The relationships are usually behaved in a non-linear manner. Nevertheless, not only finding a non-linear relationship among rainfall and corresponding paddy yield is difficult but also its mathematical presentation is highly challenging. Therefore, non-linear analyses are used rarely in the context of Sri Lanka. Therefore, a set of pre-defined nonlinear functions were used to identify the non-linear correlation of rainfall and paddy yield.

Even though these correlation tests are challenging, they are computationally less expensive. Therefore, they can be used without much difficulty in the computational power. The impact of rainfall on the paddy yield was analyzed by combining the Mann Kendall test to the correlation analysis. Rainfall time series was initially tested for the potential trends and a trend has been identified initially. Then, the same rainfall time series was correlated to the paddy yield time series. If they have a good correlation, that would imply the influence of rainfall to the corresponding paddy yield. It was assumed herein that the rainfall trends due to on-going climate change have an impact to the paddy yield if the rainfall and yield are correlated together either by linear or non-linear relationships.

### *Artificial Neural Network (ANN) Models in Non-Linear Relationships*

Artificial neural networks are famous in search of non-linear relationships among real world problems. ANNs are structured based on human brain neural networks to compute the relationships where they are difficult to obtain from direct human brains. Therefore, non-linear complex engineering problems usually seek the attention of ANNs for good and accepTable 0solutions. There are three important layers in ANN; input layer, hidden layer and output layer. Independent variables are fed to the input layer and output layer produces results of the problems. More information on artificial neural networks can be found in Graype (2019).

Hidden layer has one section to train various algorithms. Among many algorithms, Levenberg-Marquardt (LM) algorithm is significantly used in the literature. It is noted herein that many researchers have concluded that LM algorithm outperforms most of the other training algorithms. More information on LM training algorithm can be found in Du and Stephanus (2018).

The artificial neural network analyses were carried out in the MATLAB Deep Learning Toolbox and the relationship (Equation 7) was modeled.

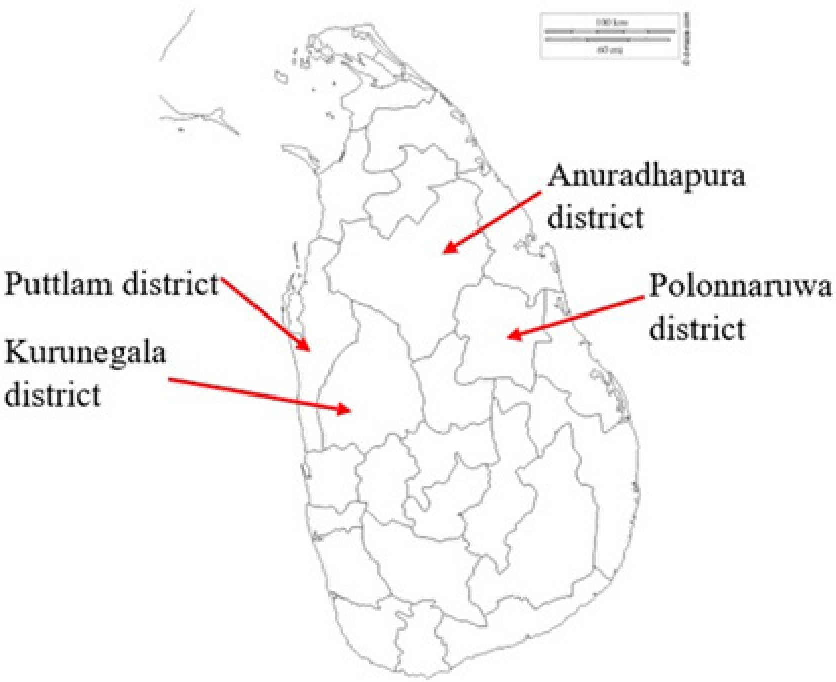
*Paddy yield=Function (Rainfall)* (7)

### *Case Study Application to North West and North Central Provinces*

Two important districts in Sri Lanka were considered for this analysis. They are the North-western and North-central provinces of Sri Lanka (Figure 01). These two provinces have two districts each in it. Puttalam district and Kurunegala district are in the North-western province whereas Anuradhapura and Polonnaruwa districts are in the North-central province. These two provinces give a significant contribution to the total paddy harvest in the country. Therefore, it would be interesting to observe the climate change impacts on the paddy harvest over the time.

Trend analyses were carried out to the seasonal rainfalls in these four districts using the monthly rainfall data obtained from the Department of Meteorology, Sri Lanka. The trends of the rainfalls and their magnitude were understood from the non-parametric tests. After that, the relationship between rainfall and the yield was tested using both linear and non-linear methods. The paddy yield data were obtained from the Department of Census, Sri Lanka. Correlation between seasonal rainfall and seasonal yield was tested from the linear analysis; however, pre-defined functions were used to test the non-linear relationships. 14 pre-defined functions varying from polynomial, exponential, logarithmic and trigonometric were selected for non-linear analysis.

Artificial neural network analyses were carried as per the Equation 7 using the LM training algorithm. 15 minimum random runs were carried out for each district for each yielding season. The best results presenting the better correlation coefficients with minimum computational time (epochs) and minimum mean square error were selected.




*Source: www.d-maps.com*

**Figure 01: Map of study locations**

## RESULTS AND DISCUSSION

Figs. 02 a-d presents the rainfall variations for *Yala* and *Maha* seasons for Anuradhapura, Polonnaruwa, Puttalam and Kurunegala areas. As it is a well-known fact, *Maha* season receives more rainfall than the *Yala* season in Sri Lanka. Therefore, less stress on irrigational water can be observed during the higher rainfall periods. However, *Yala* season in the country receives less rainfall and therefore, channelized water from tanks is necessary to continue the agricultural activities. Usually, the total land areas are not cultivated during the *Yala* season mainly due to the water shortage.

Averages and the standard deviations of the rainfall and yield data are presented in Figs. 03 and Table 01. The Figure 03 illustrates the statistics of rainfalls in the monthly resolution. Distribution of mean monthly rainfall showed clear bimodal patterns in all the locations with two peak rainy periods (Figure 03). Being located at the intermediate zone in the North-western part of the country, Kurunegala receives a comparatively higher rainfall throughout the year (Annual average rainfalls in these districts are given here. Kurunegala – 1778 mm/year, Puttalam– 1174 mm/year, Polonnaruwa - 1678 mm/yearand Anuradhapura – 1368 mm/year)

As it is presented in Table 01, average rainfall values for *Yala* season are much lower than those of the *Maha* season for all four districts. Therefore, these average rainfall values clearly present the irrigational water requirement during the *Yala* season for the full harvest of paddy from the total paddy fields. There is a clear difference between the rain-fed yield and the total yield. Total yield includes the harvested paddy due to the irrigational water from tanks in addition to the rain fed irrigation.

Results from student t test showcase the *Maha* season rainfall was significantly ($p < 0.05$) higher than the *Yala* season rainfall for all four stations. The highest difference between *Maha* and *Yala* season rainfall was reported from Polonnaruwa (1287 mm) followed by Anuradhapura (855 mm) and Kurunegala (676 mm). The least difference between two seasons as, was from Puttalam (633 mm).

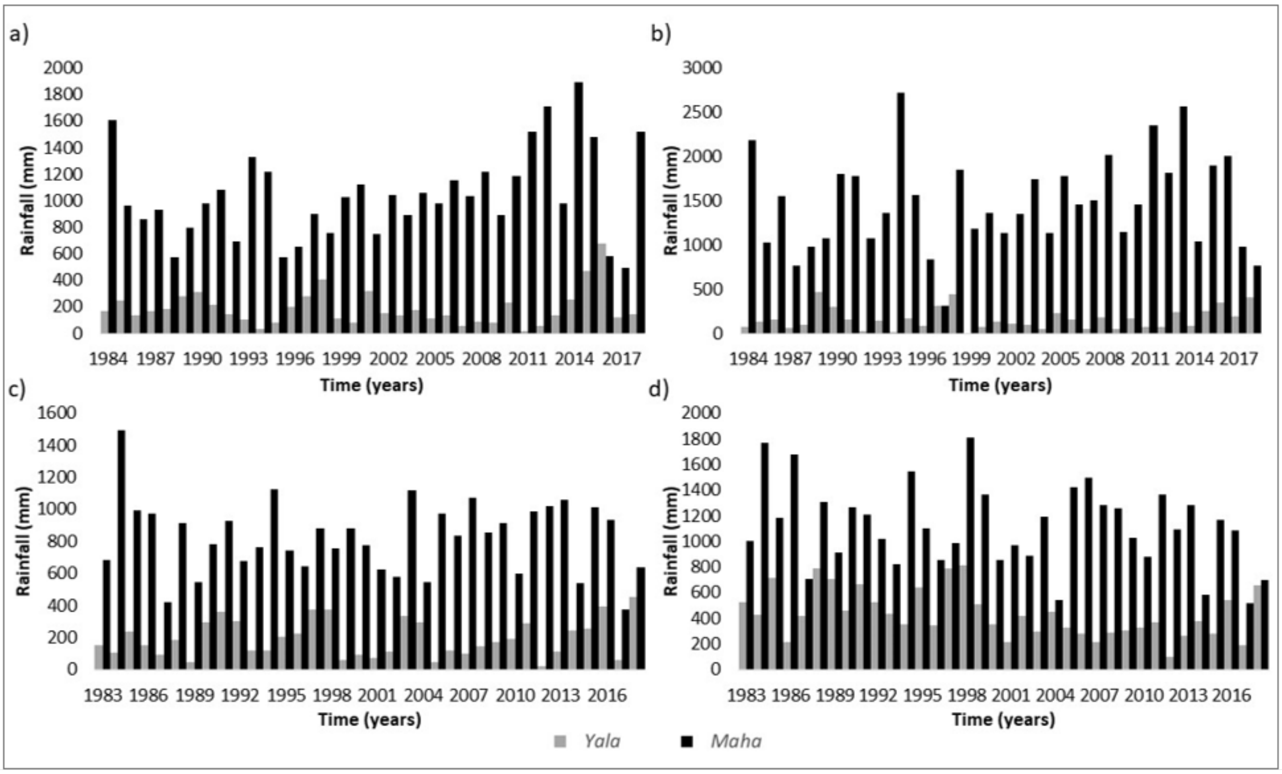



**Figure 02: Rainfall variations for *Yala* and *Maha* seasons in a) Anuradhapura, b) Polonnaruwa c) Puttalam and d) Kurunegala during 1983-2019 period.**

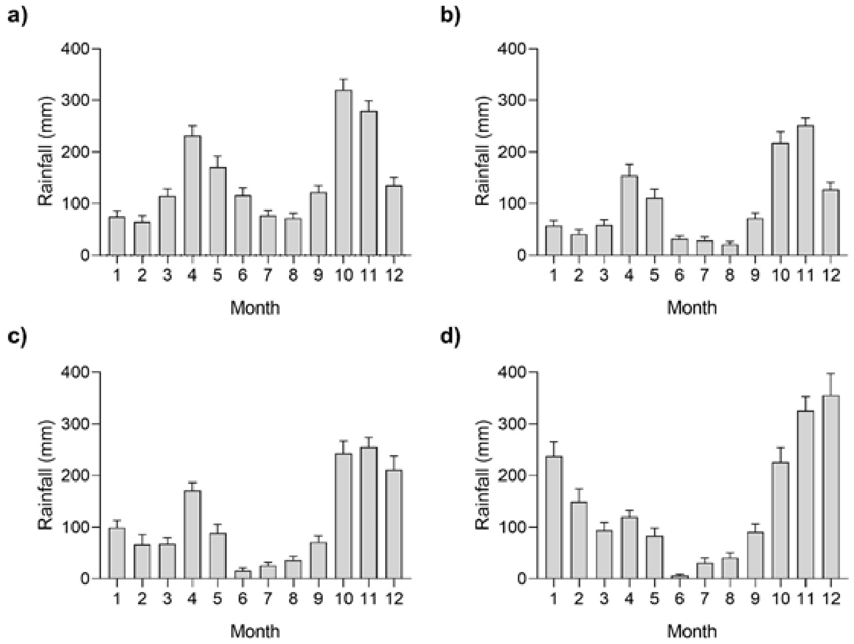



**Figure 03: Distribution of mean monthly rainfall at a) Anuradhapura, b) Polonnaruwa, c) Puttalam and d) Kurunegala during the 1983–2018 period. The standard error of the mean (SEM) is used in error bars.**

**Table 01: Averages and standard deviations of the data scatter**

| Season | Item | District | | | |
|---|---|---|---|---|---|
| | | Kurunegala | Puttlam | Anuradhapura | Polonnaruwa |
| *Yala* | Average rainfall (mm) | 435 | 193 | 187 | 162 |
| | SD (mm) | 185 | 114 | 130 | 119 |
| *Maha* | Average rainfall (mm) | 1111 | 826 | 1042 | 1449 |
| | SD (mm) | 272 | 213 | 335 | 516 |
| *Yala* | Rain fed yield (Mg/ha) | 2.87 | 3.18 | NA | NA |
| | SD (Mg/ha) | 0.46 | 0.68 | NA | NA |
| | Total yield (Mg/ha) | 9.91 | 9.7 | 8.6 | 8.38 |
| | SD (Mg /ha) | 1.2 | 1.62 | 3.5 | 2.67 |
| *Maha* | Rain fed yield (Mg /ha) | 3.35 | 3.05 | 3.21 | 3.83 |
| | SD (Mg /ha) | 0.47 | 0.71 | 1.03 | 0.55 |
| | Total yield (Mg /ha) | 11.38 | 9.99 | 11.89 | 12.73 |
| | SD (Mg /ha) | 1.16 | 1.62 | 1.78 | 1.29 |

Table 02 showcases the results from the non-parametric analysis (Mann Kendall and Sen's slope) in identifying the potential rainfall trends for the *Yala* and *Maha* seasons. Only the significant trends are presented here in Table 02. The insignificant trends are given up as they are unlikely to be realistic. Anuradhapura district does not show any significant rainfall trends in both seasons over the last 30 years. However, the neighboring district (Polonnaruwa) shows a positive significant rainfall trend in both seasons. Nevertheless, *Maha* season has a significantly higher rainfall trend than its *Yala* seasonal trend. These rainfall increments are interesting for further analysis. However, Polonnaruwa has a plain terrain and floods are frequent (Wijerathne and Senevirathna, 2018). These floods usually damage the paddy harvest. Therefore, the rainfall increments should be carefully utilized for water resources management without allowing to damage the paddy harvest. Puttalam district in North-western province is similar to Anuradhapura district in rainfall trends. No significant trends were identified in the Puttalam district. However, the neighboring district in the same province, Kurunegala shows a negative rainfall trend in *Yala* season (-4.6 mm). Even though Kurunegala receives a comparable higher rainfall among the four districts in concern for this analysis, dry weather patterns can also be observed in the area (Weerasinghe *et al.*, 2017). Therefore, this rainfall decrease in *Yala* season can be critical for Kurunegala paddy cultivation.

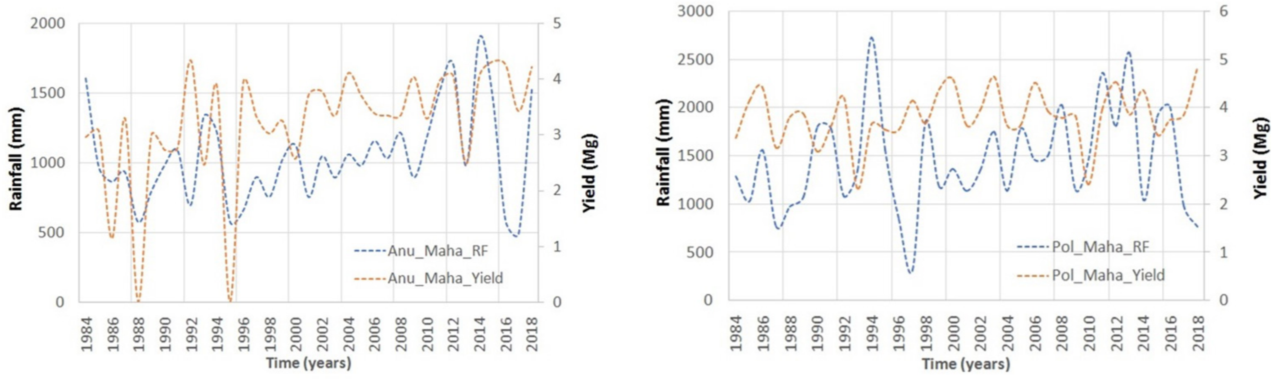
However, previous studies on rainfall trends in Anuradhapura reported both positive and negative trends for different periods. Karunathilaka *et al.,* (2017) have reported a significantly increasing annual rainfall while decreasing SWM rainfall for 1966-2015 period for Anuradhapura. Same statistical approach has showcased a decreasing trend for *Yala* season in Anuradhapura ($p > 0.05$) for 1971–2010 period (Gunarathna and Kumari, 2013). However, it was also reported an insignificant ($p = 0.05$) increasing trend for the *Maha* season for the same period. Nevertheless, the regression analysis of annual rainfall for 1981-2010 period showed an insignificantly ($p < 0.05$) increasing trend in Anuradhapura (Wickramagamage, 2015). Therefore, different study periods and methodologies of the previous work hinder the comparison of the results with the current study. Nevertheless, authors have not compared the trend analysis for annual, seasonal and monthly with the previous researchers as the authors were more interested on the two seasons.

In addition, the observations from Figure 03 can be linked to the harvesting patterns. However, this would be a visual link rather than a detailed scientific link. Nevertheless, authorities can re-visit the harvesting periods and cultivating seasons with the on-going climate change to have a more sustainable harvest. These planning strategies will even be helpful in reducing the damage due to the periodic natural disasters. However, this has to be done after a detailed analysis in consideration with all stakeholders.

Figure 04 shows the timely variation of yield and the rainfall of *Maha* season of Anuradhapura and Polonnaruwa districts. Even though the yield of the preceding year is not related to the yield of the present year and future years, they are linked by a dashed line to show the annual variation. The same pattern was used in the annual rainfall variation. The two variations in both districts have a similar trend. Similar observations can be seen in the other two districts (Puttalamand Kurunegala). Therefore, the mathematical analyses were carried out to identify the correlation between the rainfall and the rain fed yield for the 4 districts during 1984 – 2018 period.

**Table 02: Rainfall trends for harvesting seasons (Mann Kendall and Sen's slope estimator test results)**

| District | Season | Trend / No trend | Sen's slope (mm/season) |
|---|---|---|---|
| Anuradhapura | *Yala* | No | |
| | *Maha* | No | |
| Polonnaruwa | *Yala* | Yes | 4.5 |
| | *Maha* | Yes | 14.2 |
| Puttlam | *Yala* | No | |
| | *Maha* | No | |
| Kurunegala | *Yala* | Yes | -7.6 |
| | *Maha* | No | |




*a) For Maha season - Anuradhapura* *b) For Maha season - Polonnaruwa*

**Figure 04: Variation of paddy yield and the rainfall**

Correlation studies were carried out in between rainfall and paddy production by many researchers in Sri Lanka. Suppiah (1985) has carried out correlation studies and concluded four relationships between rainfall and paddy production. In addition, rainfall data at a single location was used to analyze a particular area. Mathanraj and Kaleel (2016) have investigated the relationship in between the rainfall variability and the paddy production in the Batticaloa district. The relationship was analyzed using the Pearson correlation factors. They have found that there is a strong correlation in between rainfall and the paddy production to the Batticaloa district. Similar study for the same district using different time spans shows the same results and Selvanayagam (2018) has concluded the correlation between rainfall and paddy production.

Not only in Sri Lanka but also in many other countries these correlation studies were carried out to understand the relationships between rainfall and paddy production. Alam *et al.* (2014) have discussed linear and log linear regression models to understand the relationships in between rainfall and paddy production in one of the important agricultural areas in Malaysia. They have used representative rainfall data from 1992 to 2007 for their study. Rahman *et al.* (2017) and Karthk *et al*. (2015) are a couple of examples from many other correlation analyses in between rainfall and the paddy. Rainfall at a representative gauging station was used in all above stated analysis. Therefore, as it was stated earlier, not only linear correlations, but also non-linear correlations were conducted in this research. Therefore, it is believed that this is the first time to carry out nonlinear relations ahead of the types of non-linear correlations, what other researchers pointed out (*for example; as log linear regressions*).

The linear correlation analyses are given in Pearson's correlation coefficients in Table 03. Even though it was expected to have good and positive correlations in between seasonal rainfall and yield, the mathematical analyses show that there are no correlations in between these two-time variables. In other words, if the correlation coefficients are closer to +1, there is a positive correlation between these two variations. However, the analyses show that the coefficients are closer to "0", which suggests us there is no correlation. Therefore, non-linear analyses were carried out to check if there is a correlation in between yield and *Yala* and *Maha* rainfall and corresponding rain fed yield.

However, this may be due the fact of the non-linearity of the real-world case. In addition, rainfall itself is not a direct influencing factor to the harvest. Therefore, this suggests the importance of non-linear analysis in searching relationships. Furthermore, other climatic factors may have an influence to the paddy harvest.

The results from non-linear analyses under various functions were presented in Table 04. As it was already stated above, these non-linear analyses were carried out to 14 predefined functions (given in the 1st column of Table 04). These functions cover the common mathematical functions which include polynomial, logarithmic, exponential and trigonometric functions.

However, the analyses show that there are no good relationships between the rainfall and rain fed yield as per these predefined mathematical functions. The calculated coefficients of determination are always less than 0.3 and most of them are even closer to 0. Therefore, there is no clear relationship between the rainfall and rain fed yield.

**Table 03. Pearson's correlation coefficients of rainfall and rain fed yield – linear analysis**

| District | Season | Correlation coefficient |
|---|---|---|
| Anuradhapura | *Yala* | 0.19 |
| | *Maha* | 0.36 |
| Polonnaruwa | *Yala* | 0.26 |
| | *Maha* | 0.17 |
| Puttlam | *Yala* | 0.01 |
| | *Maha* | 0.05 |
| Kurunegala | *Yala* | -0.14 |
| | *Maha* | 0.08 |

**Table 04: Results of the non-linear correlation analysis**

| Non-Linear Functions | Coefficient of determination ($R^2$) | | | | | |
|---|---|---|---|---|---|---|
| | Puttalam | | Kurunegala | | Anuradhapura | Polonnaruwa |
| | *Maha* | *Yala* | *Maha* | *Yala* | *Maha* | *Maha* |
| $y = \alpha + \beta x + \gamma x^2$ | 0.029 | 0.012 | 0.049 | 0.025 | 0.134 | 0.025 |
| $y = \alpha x / (\beta + x)$ | 0.022 | 0.007 | 0.003 | 0.012 | 0.136 | 0.021 |
| $y = \alpha e^{\beta x}$ | 0.003 | 0.003 | 0.005 | 0.017 | 0.126 | 0.021 |
| $y = \gamma / \left(1 + e^{-\alpha - \beta x}\right)$ | 0.003 | 0.003 | 0.014 | 0.017 | 0.134 | 0.021 |
| $y = \alpha + \left((\delta - \alpha) / \left(1 + e^{\beta \ln x - \gamma}\right)\right)$ | 0.002 | 0.006 | 0.007 | 0.017 | 0.136 | 0.025 |
| $y = \alpha + \left((\delta - \alpha) / \left(1 + \left(x/\gamma\right)^{\beta}\right)\right)$ | 0 | 0.008 | 0 | 0 | 0.137 | 0.025 |
| $y = \left(e^{\alpha + \beta x} / (x+1)^{\gamma}\right) + \left(e^{\delta + \lambda x} / (x+1)^{\mu}\right)$ | 0.043 | 0.011 | 0.011 | 0.054 | 0.135 | 0.025 |
| $y = \alpha + \beta \cos 2\pi\gamma x + \delta \sin 2\pi\gamma x$ | 0.180 | 0.054 | 0.120 | 0.165 | 0.061 | 0.350 |
| $y = \alpha + \beta \cos 2\pi\gamma x$ | 0.062 | 0.033 | 0.070 | 0.077 | 0.004 | 0.063 |
| $y = \alpha + \beta \sin 2\pi\gamma x$ | 0.170 | 0.020 | 0.010 | 0.101 | 0.035 | 0.101 |
| $y = \alpha x^{\beta}$ | 0.001 | 0.006 | 0.007 | 0.017 | 0.135 | 0.025 |
| $y = \alpha + \frac{\delta - \alpha}{\left(1 + \left(x/\gamma\right)^{\beta}\right)^{\lambda}}$ | 0 | 0.007 | 0.001 | 0.037 | 0.134 | 0.025 |

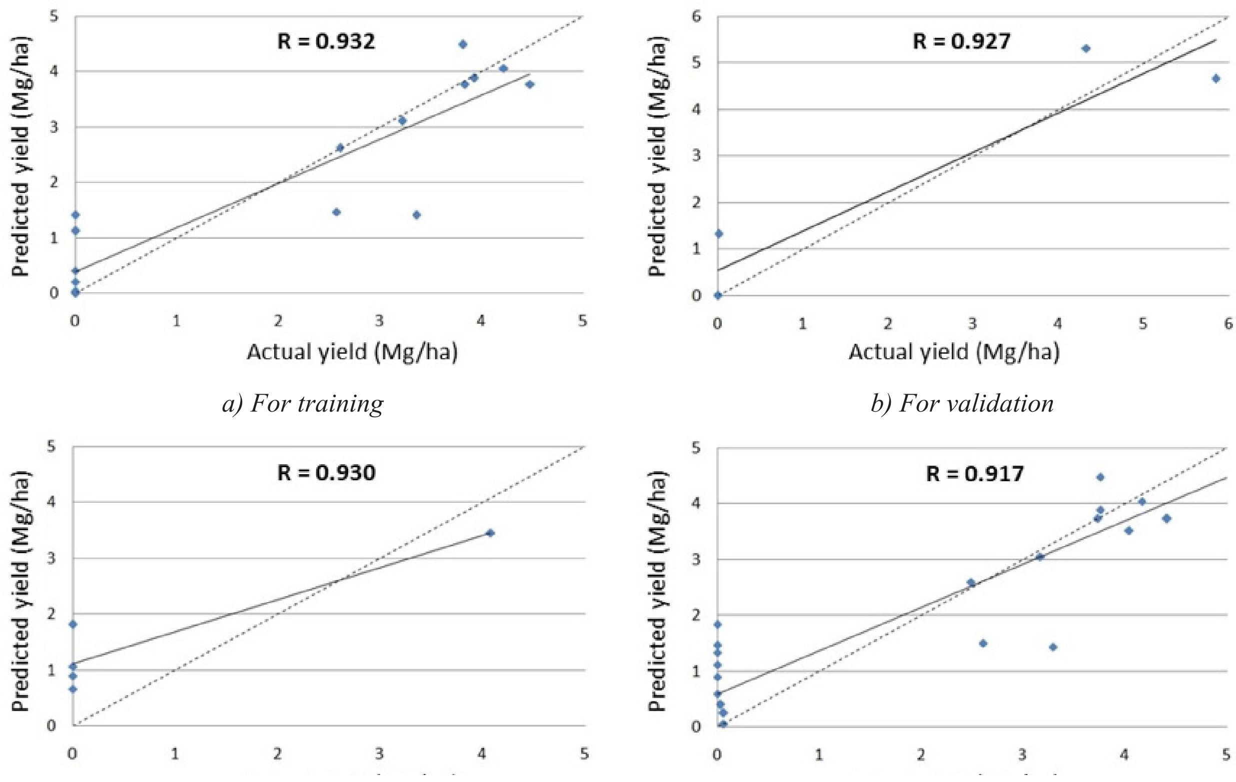
In summary, none of the linear or non-linear analysis proposes a relationship to the yield and rainfall. Therefore, it can be clearly observed that the linear and default non-linear relationships are not the best functions to analyze the paddy harvest with respect to the rainfall for these four districts.

However, neural network analyses show some different results compared to the linear and non-linear results stated above. Figure 05 illustrates the best correlation coefficients obtained for Anuradhapura district for *Yala* season. The results are very encouraging. They have given a greater level of prediction possibility to the paddy yield with respect to the rainfall.

Nevertheless, the above stated observation is not valid for most of the other district for both seasons. Correlation coefficients given in Table 05 clearly showcase the lack of reliability in ANN work too. The validation coefficients are not among the best for all districts for both Maha and *Yala* seasons. In fact, some are in the ranges of minus values. As it was stated previously, these results are the best results obtained after 20 random runs for each case.

Fig 06 justifies the discussion on the Table 05. The deviations from the reality can be clearly observed for *Maha* season in Polonnaruwa district. The performance of the neural network might have influenced by the number of data points in each cluster of analyses. However, it is always advised to carry out more analyses using more data. In other words, it is advisable to extend the analysis for more than 30 years for sound conclusions.

In addition, it can be always argued that the yield does not only depend on the corresponding rainfall; however, it can be only one variable among many others. These other variables may include other climatic parameters, technological advances of irrigation patterns, attitudes of the farmers, usage of pesticides, new variety of crops and many others. In addition, the extreme climate cases were not taken into consideration and these extreme weather records may impact the harvest in higher resolutions (daily). It was observed several higher rainfall events even in monthly resolution and their corresponding yields in the season to have some significant reductions. This has to be analyzed in detail using extreme climatic patterns and their relationships to the yield.




a) For training

b) For validation

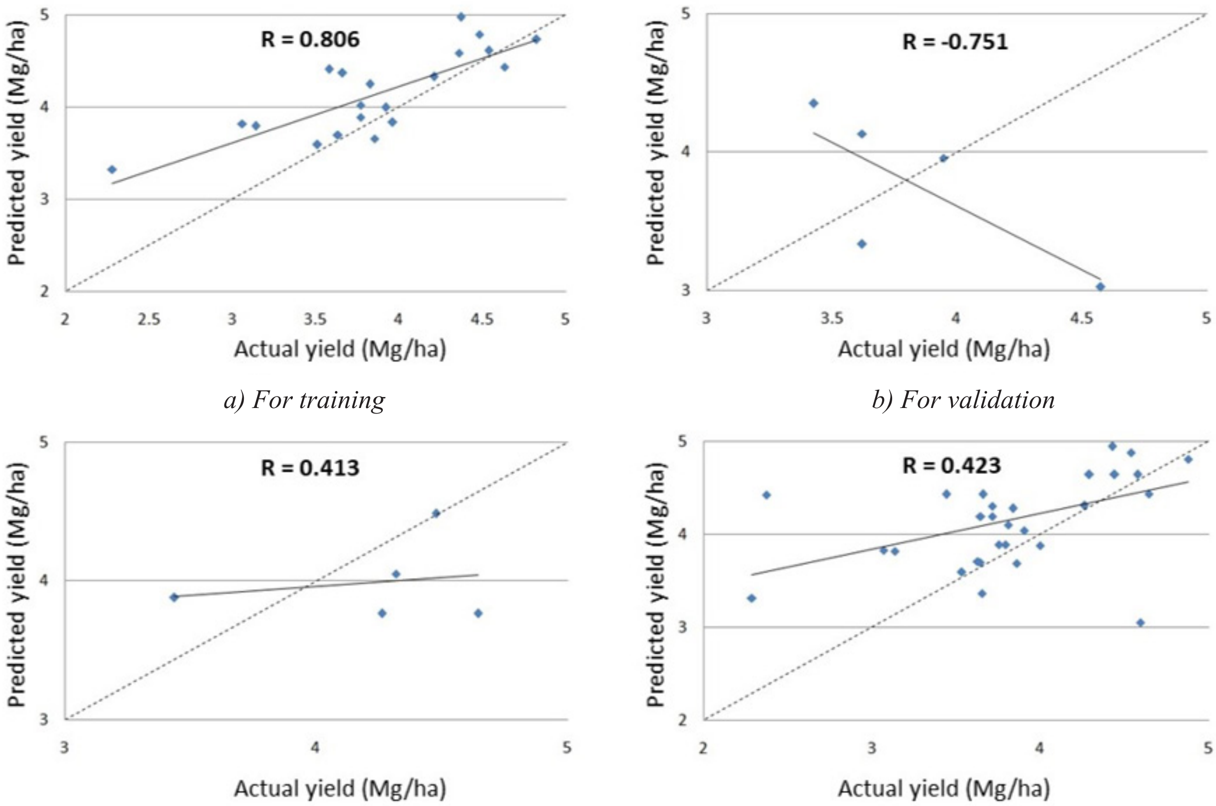
c) For test

d) For all

**Figure 05: ANN results for Anuradhapura district for *Yala* season**

**Table 05: Coefficients of correlation from ANN analysis**

| District | Training | | Validation | | Test | | All | |
|---|---|---|---|---|---|---|---|---|
| | *Yala* | *Maha* | *Yala* | *Maha* | *Yala* | *Maha* | *Yala* | *Maha* |
| Anuradhapura | 0.932 | 0.931 | 0.927 | 0.119 | 0.930 | 0.417 | 0.918 | 0.777 |
| Polonnaruwa | 0.583 | 0.805 | 0.698 | -0.751 | 0 | 0.421 | 0.598 | 0.422 |
| Kurungala | 0.968 | 0.956 | 0.792 | 0.981 | 0.478 | -0.489 | 0.909 | 0.868 |
| Puttalam | 0.997 | 0.996 | -0.030 | 0.807 | 0.304 | 0.926 | 0.721 | 0.914 |




*a) For training* *b) For validation*

*c) For test* *d) For all*

**Figure 06: ANN results for Polonnaruwa district for *Maha* season**

## CONCLUSIONS

There was no significant linear correlation between rainfall amount and the rainfed paddy yield in tested locations in North-central and North-western provinces, Sri Lanka. Therefore, the artificial neural network (ANN) approach was used to test the relationship between rainfall and paddy yield. However, no clear relationship between the rainfall and rain fed paddy yield was found in the 14 predefined polynomial, logarithmic, exponential and trigonometric functions derived using ANN. Therefore, it can be concluded herein, that the rainfall can only be one of the factors affecting the rainfed paddy harvest among many other important factors. Therefore, a detailed analysis is proposed to find out the most significant variables, which have an impact on the paddy harvest. In addition, higher orders of non-linear analysis like ANNs are proposed with more variables to understand the relationships among climatic factors to the paddy harvest. Research in light of soft computing techniques might be useful in the future analysis.

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### *Conflicts of Interest*

The authors declare that there are no conflicts of interest.

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