Rainfall trends in Anuradhapura: Rainfall analysis for agricultural planning

M.H.J.P. Gunarathna*, M.K.N. Kumari

Department of Soil and Water Resources Management, Faculty of Agriculture, Rajarata University of Sri Lanka.
*Corresponding author: *janaka78@rjt.ac.lk*

Abstract
The agriculture based economy at Anuradhapura district is suffering from water scarcity. Since traditional tank based systems are not sufficient to fulfill the water demands, it is vital to develop a crop plan, which can optimize the use of rainfall to reduce the water demand from tanks. An analysis was carried out in Anuradhapura for better management of surface water resources and to maximize the usage of rainfall for agriculture. Annual, seasonal, monthly and weekly rainfall trends were analysed with the Mann-Kendall statistical test and simple linear regression methods. The south west monsoon showed a decreasing trend in rainfall and number of rainy days. The Yala season also recorded decreasing numbers of rainy days. Ten year moving average rainfall values showed increasing trends of rainfall in Anuradhapura. First inter monsoon showed insignificant variation of rainfall while south west monsoon showed decreasing trend of rainfall. As a result, the Yala season showed a decreasing rainfall trend. It is alarming that, cropping calendars need to adjust for early cultivations to maximize the utilization of rainfall and avoid crop failures due to less rainfall during the latter part of the growing season. Rainfall in Maha season showed an increasing trend due to increasing trends of rainfall in both second inter monsoon and north east monsoon. Therefore proper planning and management of reservoirs can help to save more water for the next Yala season. Mann Kendall statistical test and simple linear regression analysis showed quite similar results in rainfall trend analysis and both methods could be successfully used to estimate rainfall trends.

Key words: Mann Kendall statistical test, Simple linear regression, Trend, Moving average, Seasonal rainfall

Introduction

Agriculture mainly depends on availability of water resources, and it is increasingly threatened by increasing water demands for domestic and industrial uses. Therefore it is vital to move forward with water saving cultivation practices to ensure food security of the country. In this context, water has become a prime concern in any development and planning of agricultural activities and scientists give their utmost attention to maximize the usage of rainfall for agricultural activities. With the effect of global warming and climate change, it should be carefully planned to safeguard the crops against the water shortages. Therefore study of long term rainfall data to understand about rainfall trends is vital.

With evidences from 1971 to 2005 rainfall data, significant decreasing of southwest monsoon rainfall and significant increasing of post monsoon rainfall was recorded in Kerala, India[1]. A study about long term rainfall data (1971 - 2010) proved that significant increase of rainfall in some months while significant decrease of rainfall in some months in Cuttack District, Orissa[2]. Rainfall data from 1965 to 2004 showed, decreasing trend of mean annual rainfall in Kalu Ganga basin in Sri Lanka[3].

Anuradhapura district includes 10% of total paddy land of Sri Lanka and around 50% of population is involving in agricultural sector[4]. Agriculture in Anuradhapura mainly depends on traditional tank based system. Today, traditional tank based system is not sufficient to fulfill the water requirement of crops grown in Anuradhapura district; therefore it is vital to develop a crop plan, which can optimize the use of rainfall to reduce the irrigation water demand from tanks. The objective of this study was to investigate long-term precipitation trends, in order to have better management of surface water resources and maximize the usage of rainfall for agricultural activities in Anuradhapura.

Materials and Methods

Anuradhapura is geographically located in 08°20′ N and 080°25′ E. In agro ecological zoning map, the area is categorized under $DL1_b$. To study the temporal distribution of rainfall and rainfall trends in Anuradhapura, daily rainfall data over 40 years (1971 - 2010) of Anuradhapura metrological station were collected from Meteorological Department of Sri Lanka, Colombo.

Features of rainfall

Mean annual, seasonal, monthly and weekly rainfall were calculated using arithmetic mean method. Annual, seasonal, monthly and weekly dependable rainfall values at 75% probability level were also calculated. Annual, seasonal and monthly number of rainy days were also calculated. In seasonal calculations, a year was divided into 4 rainy seasons as, first inter monsoon (FIM) rainy period (March - April), southwest monsoon (SWM) period (May - September), second inter monsoon (SIM) rainy period (October - November) and northeast monsoon (NEM) period (December - February)[5]. In sense of agriculture, understanding of seasonal rainfall as Yala (Dry) and Maha (Wet) seasons which are the major cultivation seasons in Sri Lanka is vital. Thus seasonal rainfall as Yala season (March to September) and Maha season (October - February) were also calculated. In weekly rainfall analysis a year was divided into 52 standard weeks. Annual and monthly calculations were done considering as calendar year and months.

Rainfall trends

Simple linear regression analysis (SLR): Annual, seasonal (FIM, SWM, SIM, NEM, Yala and Maha), monthly and weekly rainfall trends using simple linear regression analysis were done using Micro soft Excel data analysis tool pack. Since mean annual rainfall shows high variation, 10 year moving average values were also tested to understand the trends of rainfall. Annual, seasonal and monthly trends of number of rainy days using simple linear regression analysis were also estimated.

Mann Kendall Statistical test (MKST): Non parametric MKST which is being successfully used to studying the trends of hydro climatic data series was used to study the rainfall trends. Annual, seasonal (FIM, SWM, SIM, NEM, Yala and Maha), monthly and weekly rainfall trends were estimated using a computer program developed for the Kendall family of trend tests[6]. Ten year moving average values were also tested to understand the trends of rainfall. Annual, seasonal and monthly trends of number of rainy days using MKST were also estimated.

Results and Discussion

Rainfall features

Mean monthly, seasonal and annual rainfall, standard deviation (SD), coefficient of variation (CV), percent contribution to the annual rainfall (AR) and 75% probability dependable rainfall (DR) values of Anuradhapura are listed in Table 1. The mean annual and annual dependable rainfall at 75% probability level were 1255 and 1075 mm respectively. Contribution of rainfall in Yala and Maha seasons were 37% and 63% respectively. SIM is the highest contributor (38%) to the annual rainfall with lowest coefficient of variation, indicating that major contributor to the annual rainfall is much stable compared to the other contributors. February recorded the highest coefficient of variation (203%) followed by June (181%). Monsoonal rains recorded quite higher coefficient of variation

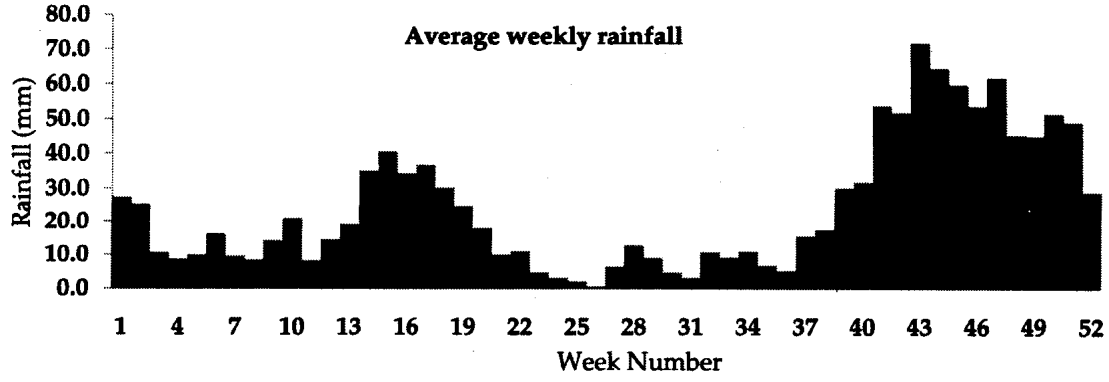

Figure 1. Average weekly rainfall of Anuradhapura during the period 1971-2010.

Table 1. Monthly, Annual and Seasonal mean rainfall and rainy days in Anuradhapura during the period 1971-2010.

Month/ season	Rainfall (mm)					Rainy days			
	Mean	SD	CV (%)	DR	% of AR	No.	SD	CV (%)	% of AR
January	75.8	75.9	100.0	13.1	6.0	7.5	4.9	65.4	7.2
February	44.7	90.7	203.0	0.0	3.6	4.1	4.1	100.1	3.9
March	68.0	65.8	96.8	17.3	5.4	6.1	3.7	60.6	5.8
April	158.3	68.0	42.9	113.8	12.6	13.4	4.1	30.6	13.0
May	78.8	68.0	86.3	24.2	6.3	6.6	4.0	61.4	6.3
June	17.0	30.7	180.7	0.4	1.3	3.1	2.7	88.5	3.0
July	34.0	44.4	130.7	1.6	2.7	3.4	2.7	78.5	3.3
August	35.9	46.3	128.8	0.1	2.9	3.4	2.9	87.4	3.3
September	71.6	54.7	76.4	27.1	5.7	6.8	3.5	51.6	6.6
October	232.3	116.5	50.2	134.9	18.5	15.5	5.6	35.9	14.9
November	245.8	104.2	42.4	162.4	19.6	18.4	5.3	28.9	17.8
December	193.3	123.9	64.1	88.8	15.4	15.5	4.9	31.3	15.0
Annual	1255.4	244.6	19.5	1075.1	100.0	103.8	12.8	12.3	100
FIM	226.3	87.0	38.4	168.8	18.0	20.3	5.1	25.3	19.6
SWM	237.2	126.6	53.4	114.1	18.9	23.3	7.0	30.3	22.5
SIM	478.1	160.9	33.7	372.0	38.1	33.9	8.4	24.7	32.8
NEM	313.7	174.4	55.6	154.1	25.0	27.1	8.4	31.1	26.2
Yala	463.6	126.9	27.4	375.3	36.9	43.6	7.7	17.7	42.1
Maha	791.9	222.7	28.1	604.2	63.1	61.0	12.2	20.0	58.9

values (SWM - 53%, NEM - 56%) compared to inter monsoonal rains (FIM - 38% and SIM - 34%). It reveals that inter monsoonal rains were quite stable than monsoonal rains.

The mean annual rainy days in Anuradhapura is 104 with a standard deviation of 13. Distribution of rainy days in Yala and Maha seasons are 42% and 59% respectively. As similar to the mean rainfall, number of rainy days in monsoonal periods recorded quite higher coefficient of variation values (SWM - 30%, NEM - 31%), compared to inter monsoonal periods (FIM - 25% and SIM - 25%) confirming that inter monsoonal rains were quite stable than monsoonal rains. SIM was the highest contributor (33%) to the number of annual rainy days in Anuradhapura with lowest coefficient of variation, indicating that major contributor to the annual rainfall is bit stable compared to the other contributors. Figure 1 shows the average weekly rainfall for the period of 1971 - 2010. Highest average rainfall in Yala and Maha seasons were 40 mm (15th week) and 72 mm (43rd week) respectively. Lowest average rainfall of 1 mm was recorded in the 26th week.

Rainfall trends estimated using observed data

Annual, seasonal and monthly trends of rainfall in Anuradhapura and their significance calculated using simple linear regression (SLR) analysis and Mann Kendal statistical test (MKST) are listed in Table 2. SWM showed a decreasing trend of rainfall which was significant MKST as Y =303.92 - 3.13 X, where Y is rainfall and X is number of year starting from 1971 (ie. 1971 = 1, 1972 = 2). January showed significantly increasing trend of rainfall, which was confirmed by MKST. May showed a significantly decreasing trend of rainfall which was confirmed by MKST and SLR.

Second and seventeenth weeks showed significantly increasing weekly rainfall trend (Figure 2) and 29th and 38th weeks showed significantly decreasing rainfall trend. In SLR analysis, 17th week showed significantly increasing trend and 37th week showed significantly decreasing rainfall trend.

Results of trend analysis of annual and seasonal rainy days in Anuradhapura (Table 3) revealed that, SWM showed decreasing trend of number of rainy days which was significant in both MKST and SLR. Number of rainy days in Yala season showed a significant decrease which was confirmed by MKST.

Table 2. Monthly, Annual and Seasonal rainfall trends in Anuradhapura during the period 1971-2010.

Season	SLR		MKST	
	Relationship	Significance	Relationship	Significance
January	Y =47.97 + 1.36 X	NS (P=0.19)	Y = 19.37 + 1.48 X	S (p = 0.02)
February	Y =47.51 – 0.14 X	NS (P=0.91)	Y = 12.9 + 0.73E-1 X	NS (p = 0.54)
March	Y =52.67 + 0.74 X	NS (P=0.41)	Y = 47.53 + 0.28 X	NS (p = 0.66)
April	Y =135.30 + 1.12 X	NS (P=0.23)	Y = 125.71 + 1.23X	NS (p = 0.17)
May	Y =115.98 - 1.81X	S (P=0.05)	Y = 101.54 – 1.54X	S (p = 0.03)
June	Y =12.81 + 0.20 X	NS (P=0.63)	Y = 6.75 + 0.00 X	NS (p = 0.92)
July	Y =50.44 - 0.80 X	NS (P=0.19)	Y = 20.09 – 0.17 X	NS (p = 0.23)
August	Y =37.12 - 0.06 X	NS (P=0.92)	Y = 11.30 + 0.00 X	NS (p = 0.74)
September	Y =78.00 - 0.31 X	NS (P=0.68)	Y = 81.01 – 0.92 X	NS (p = 0.15)
October	Y =235.41 - 0.15 X	NS (P=0.93)	Y = 212.49 + 0.28 X	NS (p = 0.94)
November	Y =199.46 + 2.26 X	NS (P=0.11)	Y = 184.90 + 2.29 X	NS (p = 0.14)
December	Y =181.85 + 0.56 X	NS (P=0.75)	Y = 143.58 + 1.00 X	NS (p = 0.49)
Annual	Y =1194.5 + 2.97 X	NS (P=0.38)	Y = 1080.2 + 5.55 X	NS (p = 0.15)
FIM	Y =187.97 + 1.87 X	NS (P=0.12)	Y = 183.55 + 1.75X	NS (p = 0.11)
SWM	Y =294.36 – 2.79 X	NS (P=0.11)	Y = 303.92 – 3.13 X	S (p = 0.04)
SIM	Y =434.87 + 2.11 X	NS (P=0.35)	Y = 391.42 + 2.46 X	NS (p = 0.29)
NEM	Y =277.33 + 1.78 X	NS (p=0.46)	Y = 222.24 + 3.50 X	NS (p = 0.08)
Yala	Y =482.33 – 0.92 X	NS (P=0.60)	Y = 467.02 - 0.94 X	NS (p = 0.57)
Maha	Y =712.20 + 3.89 X	NS (p=0.21)	Y = 657.84 + 5.03 X	NS (p = 0.15)

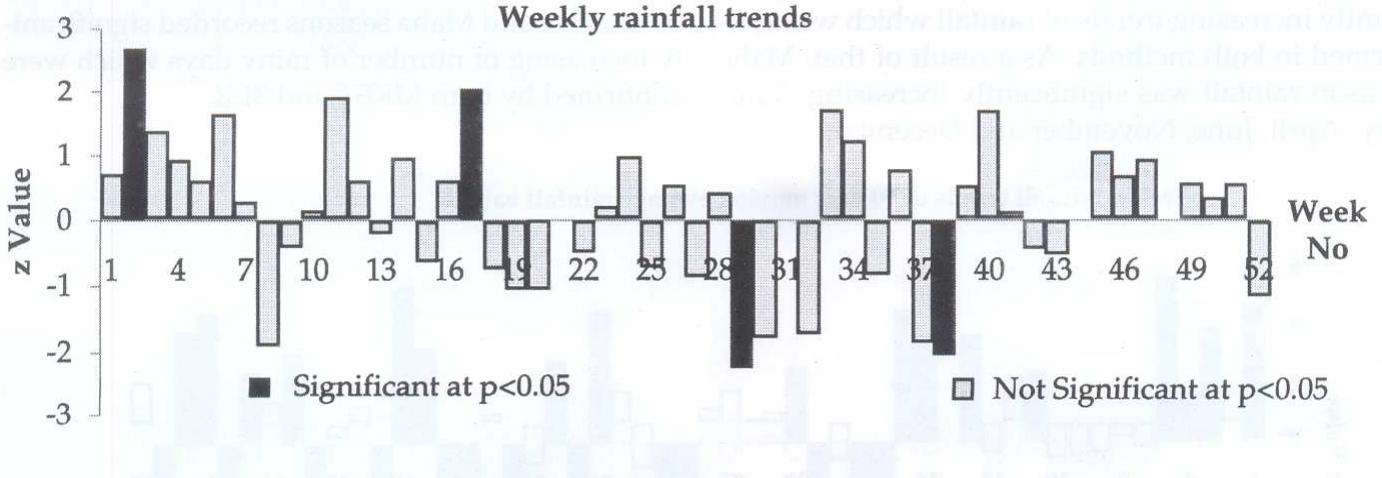

Figure 2. Weekly rainfall trend in Anuradhapura estimated using the Mann Kendall test.

Table 3. Trends of changing annual and seasonal rainy days in Anuradhapura during the period 1971-2010.

Season	SLR		MKST	
	Relationship	Significance	Relationship	Significance
Annual	Y = 104.8 – 0.06 X	NS (P=0.72)	Y = 104.9 + 0.00 X	NS (p = 0.82)
FIM	Y =20.23 + 0.00 X	NS (P=0.95)	Y = 19.00 + 0.00 X	NS (p = 0.77)
SWM	Y =27.23 – 0.19 X	S (P=0.04)	Y = 29.63 – 0.25 X	S (p = 0.01)
SIM	Y =31.84 + 0.10 X	NS (P=0.38)	Y = 31.76 + 0.00 X	NS (p = 0.37)
NEM	Y =26.35 + 0.04 X	NS (p=0.76)	Y = 24.50 + 0.00 X	NS (p = 0.49)
Yala	Y =47.46 – 0.19 X	NS (P=0.07)	Y = 48.56 - 0.22 X	S (p = 0.04)
Maha	Y =58.19 + 0.14 X	NS (p=0.42)	Y = 58.72 + 0.00 X	NS (p = 0.09)

Rainfall trends estimated using ten year moving average data

Annual, seasonal and monthly trends of rainfall in Anuradhapura were estimated using ten year moving average values of rainfall data, over the period 1971 – 2010, which were calculated using SLR analysis and MKST (Table 4). Results of trend analysis revealed that, annual rainfall in Anuradhapura was significantly increasing. According to the SLR analysis, trend can be explained as Y =1190.6 + 1.90 X, where Y is rainfall and X is number of year starting from 1971. MKST also proved that the increasing trend as Y = 1180.7 + 2.12 X. FIM showed insignificant variation of rainfall while SWM showed significantly decreasing trend of rainfall which was confirmed in both methods. Similar to SWM, Yala season showed significantly decreasing rainfall trend which was confirmed in both methods. Both SIM and NEM showed significantly increasing trends of rainfall which was confirmed in both methods. As a result of that, Maha season rainfall was significantly increasing. January, April, June, November and December recorded significantly increasing trends of rainfall while months of May, July and September recorded significantly decreasing trends of rainfall which were confirmed in both methods.

Figure 3 shows the trends (z value) of 10 year moving average weekly rainfall. Seventeen weeks showed significantly increasing trends and 13 weeks showed significantly decreasing rainfall trends. In simple linear regression analysis, 18 weeks showed significantly increasing trends and 15 weeks showed significantly decreasing rainfall trends. Trends of changing annual and seasonal rainy days in Anuradhapura estimated using 10 year moving average data over the period 1971 – 2010 are shown in Table 5. Results of trend analysis revealed that, SWM and Yala seasons showed decreasing trend of number of rainy days which was significant in both MKST and SLR. Annual, SIM, NEM and Maha seasons recorded significantly increasing of number of rainy days which were confirmed by both MKST and SLR.

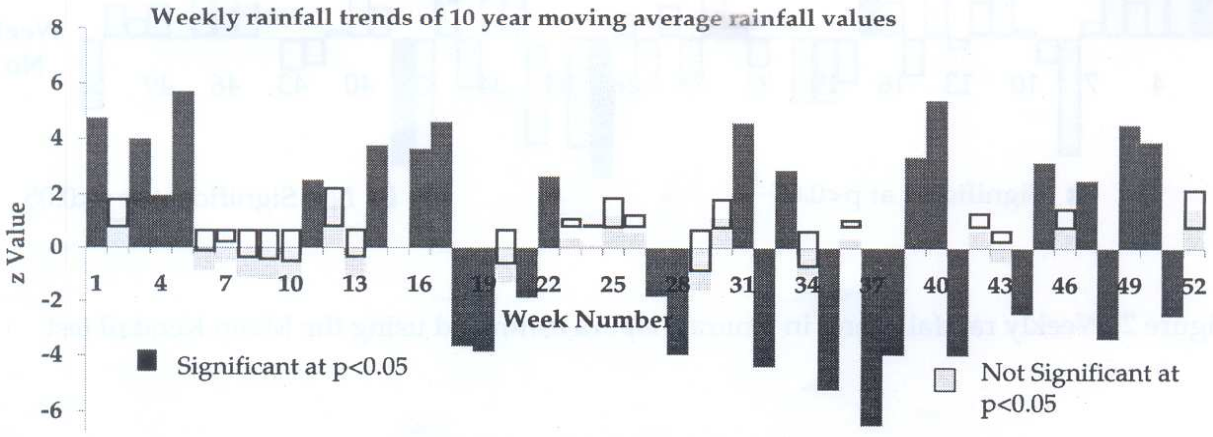

Figure 3. Ten year moving average rainfall (weekly) trend in Anuradhapura estimated using MKST.

Table 4. Monthly, Annual and Seasonal rainfall trends of 10 year moving average rainfall in Anuradhapura during the period 1971-2010.

Season	SLR		MKST	
	Relationship	Significance	Relationship	Significance
January	Y =24.90 + 2.16 X	S (P=0.00)	Y = 38.38 + 1.97 X	S (p = 0.00)
February	Y =48.78 - 0.01 X	NS (P=0.98)	Y = 50.99 - 0.26 X	NS (p = 0.52)
March	Y =78.53 - 0.60 X	NS (P=0.15)	Y = 87.54 - 0.88 X	NS (p = 0.12)
April	Y =119.99 + 1.31 X	S (P=0.00)	Y = 119.49 + 1.31X	S (p = 0.00)
May	Y =131.51 - 1.95 X	S (P=0.00)	Y = 135.72 - 1.81 X	S (p = 0.00)
June	Y =5.534 + 0.55 X	S (P=0.00)	Y = 4.89 + 0.49 X	S (p = 0.00)
July	Y =55.78 - 0.82 X	S (P=0.00)	Y = 54.31 - 0.84 X	S (p = 0.00)
August	Y =34.31 - 0.17 X	NS (P=0.15)	Y = 35.62 - 0.20 X	NS (p = 0.13)
September	Y =102.97 - 1.27 X	S (P=0.00)	Y = 97.94 - 1.22 X	S (p = 0.00)
October	Y =226.97 - 0.16 X	NS (P=0.72)	Y = 231.13 + 0.00 X	NS (p = 0.97)
November	Y =217.99 + 1.26 X	S (P=0.00)	Y = 221.85 + 1.25 X	S (p = 0.00)
December	Y =143.37 + 1.28 X	S (P=0.01)	Y = 141.58 + 1.39 X	S (p = 0.01)
Annual	Y =1190.6 + 1.90 X	S (P=0.03)	Y = 1180.7 + 2.12 X	S (p = 0.02)
FIM	Y =198.51 + 0.71 X	NS (P=0.09)	Y = 215.28 - 0.09 X	NS (p = 0.80)
SWM	Y =330.11 - 3.65 X	S (P=0.00)	Y = 327.44 - 3.64 X	S (p = 0.00)
SIM	Y =444.96 + 1.42 X	S (P=0.04)	Y = 462.54 + 1.15 X	S (p = 0.02)
NEM	Y =217.05 + 3.43 X	S (p=0.00)	Y = 245.63 + 2.90 X	S (p = 0.00)
Yala	Y = 528.62 - 2.95 X	S (P=0.00)	Y = 523.91 - 3.16 X	S (p = 0.00)
Maha	Y =662.01 + 4.84 X	S (p=0.00)	Y = 665.56 + 4.83 X	S (p = 0.00)

Table 5. Trends of annual and seasonal rainy days in Anuradhapura using 10 year moving average data

Season	SLR		MKST	
	Relationship	Significance	Relationship	Significance
Annual	Y = 99.50 + 0.15 X	S (P=0.02)	Y = 99.63 + 0.16 X	S (p = 0.04)
FIM	Y =19.44 + 0.02 X	NS (P=0.47)	Y = 19.80 + 0.00 X	NS (p = 0.93)
SWM	Y =27.94 - 0.18 X	S (P=0.00)	Y = 27.88 - 0.15 X	S (p = 0.00)
SIM	Y =30.80 + 0.13 X	S (P=0.00)	Y = 31.55 + 0.11 X	S (p = 0.00)
NEM	Y =22.15 + 0.19 X	S (p=0.00)	Y = 21.71 + 0.19 X	S (p = 0.00)
Yala	Y =47.38 - 0.16 X	S (P=0.00)	Y = 47.49 - 0.16 X	S (p = 0.00)
Maha	Y =52.95 + 0.32 X	S (p=0.00)	Y = 52.90 + 0.30 X	S (p = 0.00)

Conclusion

Mean annual rainfall, dependable annual rainfall at 75% probability level and average number of rainy days of Anuradhapura over the period of 1971 - 2010 are 1255 mm, 1075 mm and 104 days respectively. FIM, SWM, SIM and NEM contribute 18%, 19%, 38% and 25% respectively to the mean annual rainfall in Anuradhapura. Coefficient of variation values showed that inter monsoonal rains are quite stable than monsoonal rains.

Yala season showed significantly decreasing rainfall trend. It is alarming that, cropping calendars