RAINFALL TREND ANALYSIS BY USING THE MANN-KENDALL TEST & SEN'S SLOPE ESTIMATES: A CASE STUDY OF DISTRICT CHAKWAL RAIN GAUGE, BARANI AREA, NORTHERN PUNJAB PROVINCE, PAKISTAN

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ABSTRACT: *This study focused on a key climatic variable i.e. the precipitation for analyzing changing trend of rainfall of a Barani Area Chakwal District located in Northern Punjab Province Pakistan. In this area agriculture is dependent on rainfall but occurrence of rainfall is unpredicted and erratic which produces an adverse effects on the cropping system and also causes negative effects on natural water resources. Rainfall data of 37 years (1977 to 2013) on daily basis was processed to find out the monthly, seasonally and annual rainfall variability (trend and slope magnitude) by using nonparametric analysis. The Mann-Kendall (MK) Test for monotonic analysis of trend together with nonparametric Sen's Slope Estimator was used to estimate the magnitude of trend for time series data.*

Monthly, seasonally and annually precipitation trends has been drawn using 37 years daily data. The statistical analysis of whole reference time series data highlight that (1) the trend looks predominantly positive (increasing), both at the annual and seasonal scales (2) the spring, pre-monsoon and post-monsoon seasons showed decreasing trend (3) Individually seven months (Jan, Feb, May, Jun, July, Aug and Sep) represents rising trend while other five months (Mar, Apr, Oct, Nov and Dec) represent falling trend (4) The total annual rainfall and monsoon seasons showed positive significant increasing trend with 99 % and 95 % confidence level respectively.

Key Words: *Rainfall trend; Mann-Kendall test; Sen's Slope Estimates; Trend Analysis*

1. INTRODUCTION

Globally water resources of any region has become a major concern for planning and development of projects such as sustainable development of agricultural and food production projects, effective water resource management techniques and erosion and flood estimation and control methodologies etc. Rainfall is a source of fresh water and important element of all types of life and agriculture mainly depends upon time of occurrence and amount of rainfall on any area to meets others numerous needs and demands such as industrial, domestic water supply. The changes in rainfall trends/patters are directly associated with climatic changes and according to IPCC 2007 reports "global surface temperature is increasing at the rate of 0.74 ± 0.18°C over the period of 1906–2005 and due to this climate change the availability of fresh water will reduced in future and it has been also demonstrated that in the middle of 21st century the available water and average annual runoff will reduced up to 10 – 30%" [1]. The changing in precipitation trend based on time series is the temporal shift in rainfall patterns which may be either increasing or decreasing and this trend change is the dominant component of the climatic variations. Human interventions are also the primary and leading factors of climate change with reference to changing landuse from the impact of agricultural and irrigation practices [2]. So the subject of climate change with changes in rainfall patterns directly affects water resources, agricultural divisions and disaster management sectors. Pakistan is agronomic and agrarian country, having diverse, uneven and arid to semi-arid type climate where agriculture depends upon rainfall occurrence and amount. Due to non-friendly environmental activities the temperature variation of country is increasing beyond its normal limits which creates an optimistic impact on the production of crop and this climatic change produces the problems like glacier melting, ostentatious floods, and severe drought conditions etc. in different parts of country which swaying the social and economic situations and produced affects particularly on those peoples which mainly depends upon agriculture and food. The Task Force on Climate Change (TFCC) [3] give a report on climate change in Pakistan and according to TFCC the country is exposed to a number of natural disasters, including intense rainfall storms, cyclones, tornedoes, severe drought, unadorned floods, and earthquakes.

The recent studies of Pakistan on climate change predicted that in most regions the rainfall patterns have become very unreliable, uneven and unpredicted. These types of climatic changes produces difficulties for peoples to live in this environment, to make appropriate solutions and arrangements for their life safety, agricultural crops and livestock. For instance Pakistan has faced a super flood on 29th July 2010, due to heavy monsoon rainfall in provincial areas of Khyber Pakhtunkhwa, Sindh, Punjab and some parts of Balochistan and it was estimated that about two thousand people were dead and seven hundred thousand homes were destroyed and damaged. A record-breaking 274 mm rainfall was measured in Peshawar during 24 hours; while the previous record was 187 mm in April 2009. On the other hand the southern and central parts of the country has faced severe droughts from 1998 to 2001, So keeping in view these problems related to climate change and its effects in Pakistan, this study was conducted for precipitation trends analysis of district Chakwal.

Trend analysis can be done using parametric and non-parametric approached such as t-test is parametric test while nonparametric The Mann-Kendall (MK) Test [4, 5] give positive or negative trend for a given confidence level both at seasonal and annual scale. Mann-Kendall Test mostly used by different researchers to find out the trends of temperature, evapotranspiration (ET) and rainfall on monthly, seasonally and annually scale, the results of which had showed some significance in case of rainfall and temperature. In Zambia MK Test and CUSUM (Cumulative Summation) test was used to analyze the long term rainfall trend by [6]. The trend of precipitation and run-off was studied by Xu et al. [7] in major Chinese rivers by Mann-Kendall statistics for the detection of trends. The objective of this study is to analyze rainfall trends/patterns using long time series data and to assess the significance of rainfall trends over selected study area by using The Mann-Kendall (MK) Test to gather with Sen's Slope Estimator.

2. Study Area

This research was conducted as a case study for precipitation trend analysis of district Chakwal raingage installed by Pakistan Meteorological Department having Latitude 32º 55' and Longitude 72º 51' at 519 m elevation.

District Chakwal is a Barani district having total drainage area 6609 Km^2, located in the southern zone of Pothwar plateau, bordered by district Mianwali in West, district Jhelum in East, district Khushab in South and districts Rawalpindi and Attock in North as shown in Fig.1. The terrain is mostly hilly, due to laying at the beginning of Pothwar plateau and salt range. The soil is silt loam to loam and its considerable area is covered by forests and plains of district are cultivated by even those placed in hilly range and cultivation is mainly depend upon occurrence of rainfall because there is no proper canal irrigation system so agriculture in this area is very precarious.

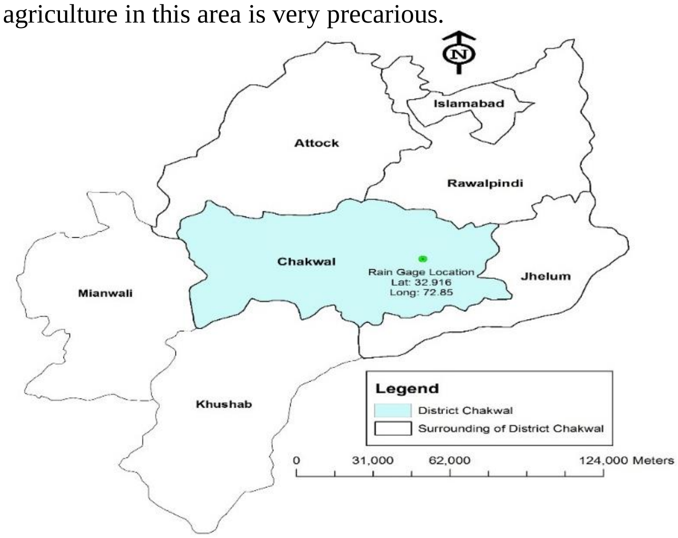

Figure 1: Location map of study area

3. MATERIAL AND METHODS

Daily rainfall data of thirty seven years (1977 – 2013) for district Chakwal was collected from Pakistan Metrological Department (PMD) Lahore and Soil and Water Conservation Research Institute (SAWCRI) Chakwal. This data included daily precipitation, maximum and minimum precipitation during a month and peak rainfall event with intensity and duration. The time series analysis of rainfall data was done on monthly, seasonally and yearly basis. Monthly data were arranged in such a way that nine number of seasons were used and then these seasons were separated into three sub categories depending upon temperature variation, amount of rainfall and cropping system. Depending upon temperature variation of a whole year four seasons named as winter (October to March), summer (April to September), spring (March to May) and autumn (September to October) were used. According to amount of rainfall variability three seasons were used named as pre-monsoon (March to May), monsoon (June to September) and post-monsoon (October to December) similarly depending upon the cropping system two seasons Rabi (November to April) and Kharif (May to October) were used for seasonal trend analysis. Generally the statistical distribution was applied to assess the behavior of data and the trend/pattern analysis was done as discussed below.

3.1 Trend Analysis

Statistically trend is a significant change over time which is detectable by parametric and non-parametric procedures while trend analysis of a time series consists of the magnitude of trend and its statistical significance. In this study statistical significance trend analysis was done by using Man- Kendall test while for the magnitude of trend was determined by non-parametric Sen's estimator method.

3.1.1 Mann–Kendall Test

This is a statistical method which is mostly used to check the null hypothesis of no trend versus the alternative hypothesis of the existence of monotonic increasing or decreasing trend of hydro-climatic time series data. The non-parametric Mann-Kendall test is fit for those data series where the trend may be assumed to be monotonic (i.e. mathematically the trend consistently increasing and never decreasing or consistently decreasing and never increasing) and no seasonal or other cycle is present.

MAKESENS [8] performs two types of statistics depending upon the number of data values i.e. S – statistics is used if number of data values are less than 10 while Z – statistics (normal approximation/distribution) for data values greater than or equal to 10.

The statistic S is calculated as shown in equation (i)

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

Where,

x_j and x_i are annual values in years j and i, j > i respectively, n is the number of data points and $sgn\left(x_j - x_i\right)$ is calculated using equation (ii)

$$sgn\left(x_j - x_i\right) = \begin{cases} 1 & if\ x_j - x_i > 0 \\ 0 & if\ x_j - x_i = 0 \\ -1 & if\ x_j - x_i < 0 \end{cases} \qquad \text{(ii)}$$

A positive or negative value of S indicates an upward (increasing) or downward (decreasing) trends respectively. If number of data values are 10 or more, the S – statistics approximately behave as normally distributed and test is performed with normal distribution with the mean and variation as given below equations (iii) & (iv).

$$E(S) = 0 \qquad \text{(iii)}$$

$$Var\ (S) = \frac{n\ (n-1)(2n+5) - \sum_{i=1}^{n} t_i(t_i-1)\ (2t_i+5)}{18} \qquad \text{(iv)}$$

Where, n is number of tied (zero difference between compared values) groups and t_i is the number of data points in the i^th tied group. The standard normal distribution (Z – statistics) is computed using equation (v).

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var\,(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{Var\,(S)}} & if\ S < 0 \end{cases} \qquad \text{(v)}$$

Statistically the significance of trend is assessed using Z-value. A positive value of Z shows upwards (increasing) trend while the negative value indicates downward (decreasing) trend.

In MAKESENS the two-tailed test is used for four different significance levels α: 0.1, 0.05, 0.01 and 0.001. The significance level 0.001 means that there is a 0.1% probability that the values xi are from a random distribution and with that probability we make a mistake when rejecting H_0 (null hypostasis) of no trend. Thus the significance level 0.001 means that the existence of a monotonic trend is very probable. Respectively the significance level 0.1 means that there is a 10% probability that we make a mistake when rejecting H_0.

3.1.2 Sen's Estimator method

Sen's non-parametric estimator method has been used for predicting the magnitude (true slope) of hydro-metrological time series data. The Sen's slope estimator method uses a linear model for the trend analysis. The slope (Ti) of all data pairs is calculated using equation (vi) by [9].

$$T_i = \frac{x_j - x_k}{j-k} \quad for\ i = 1, 2, 3, \ldots\ldots\ldots\ldots\ldots\ldots n \qquad \text{(vi)}$$

Where, x_j and x_k are data values at time j and k (j > k) separately.

The median of these n values of Ti is represented by Sen's slope of estimation (true slope) which is calculated using equation (vii)

$$Q_i = \begin{cases} T_{\frac{n+1}{2}} & for\ n\ is\ odd \\ \frac{1}{2}\left(T_{\frac{n}{2}} + T_{\frac{n+2}{2}}\right) & for\ n\ is\ even \end{cases} \qquad \text{(vii)}$$

Sen's estimator (Q_{med}) is calculated using above equation depending upon value of n is either odd or even and then (Q_{med}) is computed using 100 (1 – α) % confidence interval using non-parametric test depending upon normal distribution. A positive value of Q_i indicate increasing (upward) trend while negative value of Q_i represent downward or decreasing trend of time series data.

4. RESULTS AND DISCUSSION

In the present study trend analysis of rainfall of district Chakwal rain gauge was done using Mann-Kendall to gather with Sen's slope estimator for 37 years of time series data (1977- 2013) on monthly, seasonally and yearly basis.

4.1 Monthly Rainfall Trend Analysis

The variation in rainfall data (trend) on monthly basis is calculated individually for each month using Mann-Kendall statistically method and magnitude of slope is calculated with Sen's slope estimator as represented in Fig. 2. It was analyzed that there is significant changes in monthly rainfall data mean some of the months showed increasing (upward) trend and some showed decreasing trends. Seven months (Jan, Feb, May, Jun, July, Aug and Sept) give positive values of Z–Statistics which represent rising trend while other months (Mar, Apr, Oct, Nov and Dec) represent falling trend as shown in Fig.3

The estimated Sen's Slope (Q) was also calculated for each month separately and the month Jan, Feb, May, Jun, July, Aug and Sept give increasing slope magnitude and the month of March and April showed non-significant decreasing trend. But the month of Oct, Sept and Dec showed no change in Sen's Slope magnitude as shown in Fig.4.

The analysis mentioned in Fig.3 and Fig.4 to gather indicated that the months of Feb May, Jun, July and Aug give significant increasing trend due to positive value of both Z and Q statistics while the months of Jan and Sept showed non-significant increasing trend. The month of March give significant decreasing trend due negative value of Z and Q statistics and the month of April give non-significant decreasing trend.

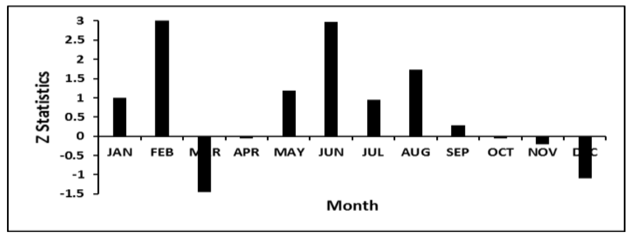

Figure 3: The Mann-Kendall Z -Statistics for Monthly Trend Analysis

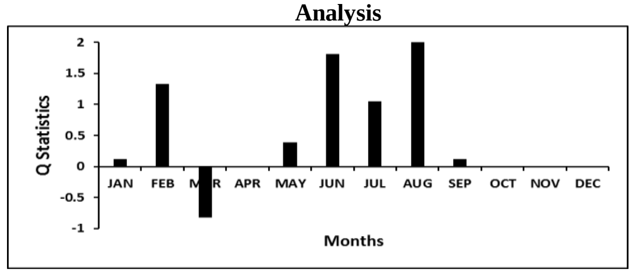

Figure 4: The magnitude of trend using Q –Statistics

4.2 Seasonally Rainfall Trend Analysis

Rainfall trend was analyzed on three sub-categories of seasons as discussed below.

4.2.1 Seasonal variation of rainfall trend depends upon temperature variation

Four seasons were used depending upon temperature i.e. winter, summer, spring and autumn. The value of Z and Q –Statistics for three seasons, winter, summer and autumn is positive which showed significant increasing trend while the spring season indicate decreasing trend as shown in Fig.5

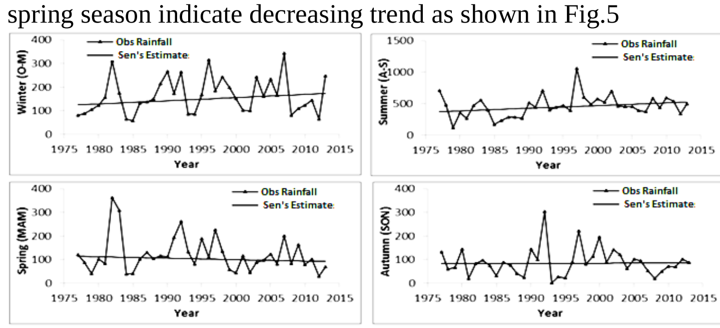

Figure 5: Seasonal Variation of Rainfall Trend Depending upon Temperature

4.2.2 Seasonal variation of rainfall trend depend upon amount of Rainfall variation

Depending upon the amount of rainfall, three type of seasons were used, i.e. pre-monsoon (March to May), monsoon (June to September) and post-monsoon (October to December). The monsoon seasons showed significant upward trend having positive values of both Z and Q – Statistics while pre-monsoon and post-monsoon seasons showed downward trend due to negative value of Z and Q – Statistics as represented in Fig.6

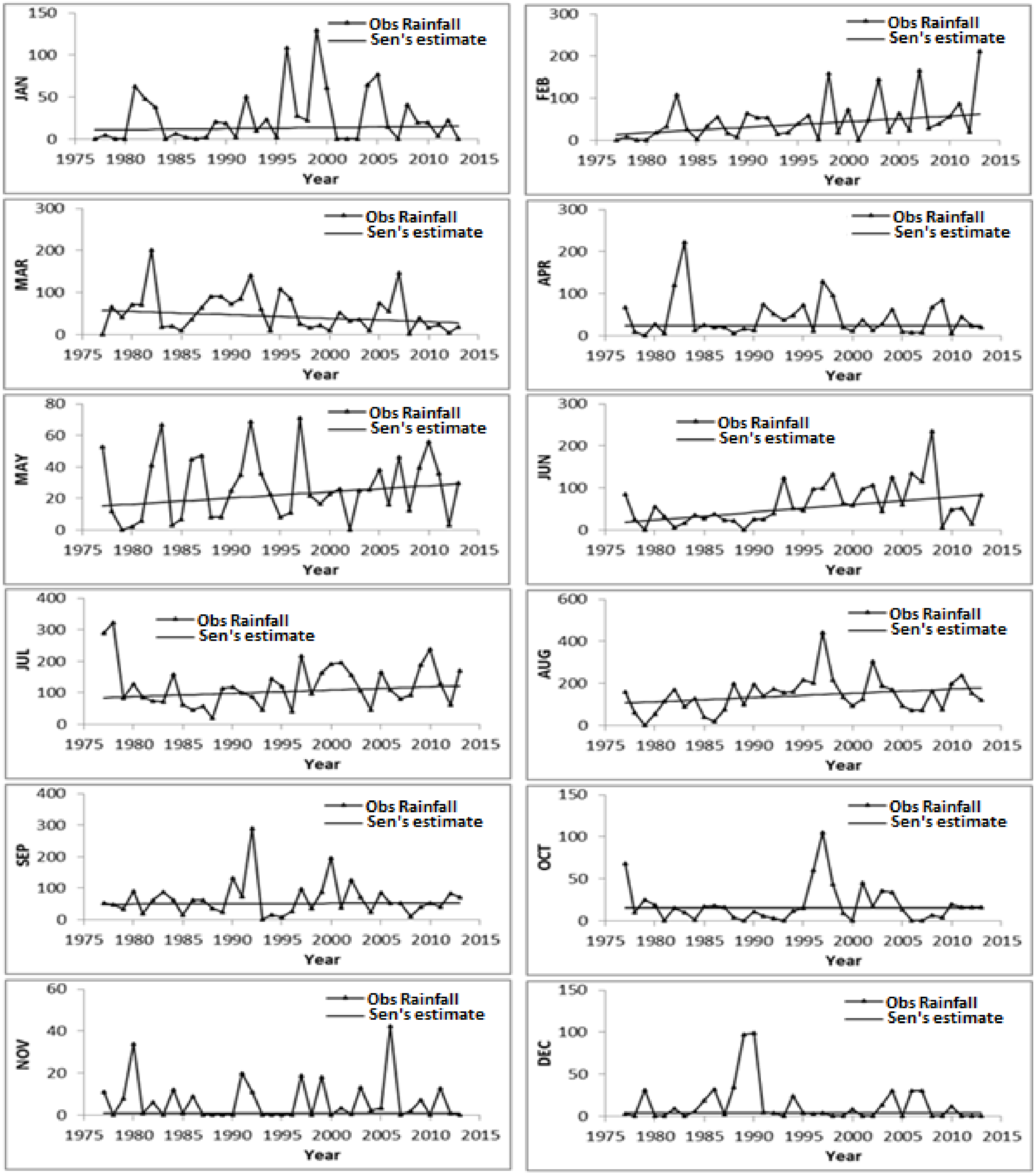

Figure 2: Monthly Rainfall Trend Analysis

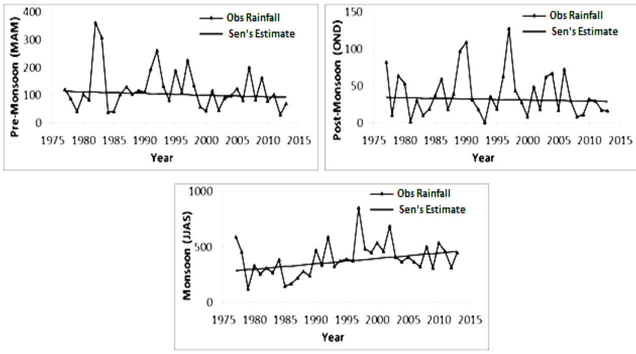

Figure 2: Seasonal Variation of Rainfall Trends Depending upon Amount of Rainfall

4.2.3 Seasonal variation of rainfall trend depend upon cropping system

Rabi season consist of Nov to April months and this seasons showed increasing trend due to positive values of Z and Q statistics similarly Kharif season (May to Oct) also showed increasing trend as shown in Fig.7

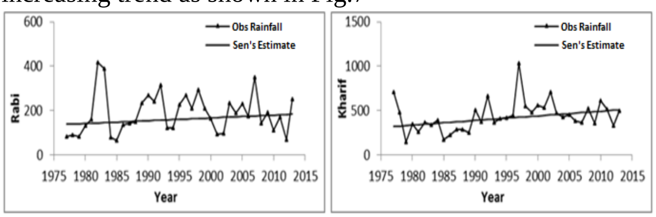

Figure 3: Seasonal Variation of Rainfall Trend Depending upon Cropping System

4.3 Annual Rainfall Trend Analysis

The trend of total annual rainfall of 37 years data is represented in Fig.8 which depicted that the total maximum annual rainfall (1241 mm) has occurred in the year 1997 while minimum total annual rainfall (225 mm) has occurred in 1979 of whole reference period. Average annual rainfall of 37 years data is 625 mm. The positive vale of Z and Q – Statistics showed that there is rising trend with upward slope of rainfall on annual basis.

4.4 Mann-Kendall Trend and Sen's Slope

The statistical analysis of rainfall data was done using central tendency parameters i.e. (mean and median) and the dispersion of data from mean was done using standard deviation and coefficient of variance as shown in Table.1.

Table.1 illustrated that minimum mean monthly rainfall occurred in the month of November (6 mm) for all these 37 year data followed by December (14 mm) and January (25 mm) while maximum mean monthly rainfall occurred in month of august (144 mm). It is also depicted from the table that total maximum rainfall was occurred in month of august (443 mm) of year 1997. The calculated mean annual rainfall for 37 year data is 625 mm and maximum total rainfall (1241 mm) occurred in 1997.

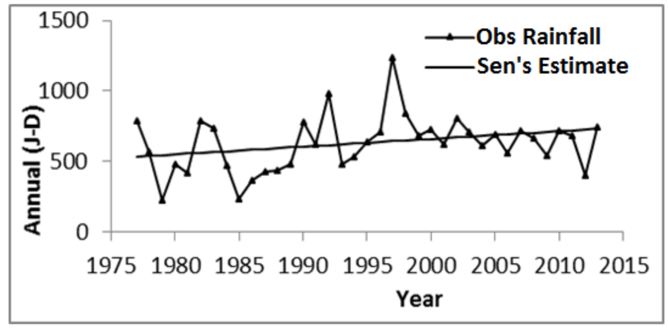

Figure 4: Annual Rainfall Trend Analysis

The Mann-Kendall trend, its statistical significance along with magnitude of Sen's slope for 1977 to 2013 year rainfall data is shown in Table.1. The months of February and June showed increasing monotonic trend with significance level 0.01, that mean there is a 1% probability that we make a mistake when rejecting H_o (null hypothesis) of no trend. Similarly those months and seasons which have single star (*) sign as given in significance (α) column of this table showed significance level 0.05 having 95 % significance interval of Q and the month of august and annual time series data having plus (+) sign showed 0.1 significance level having 99 % significance interval of Q and there is 10 % probability that we make a mistake when rejecting H_o. While the other months and seasons having column with (-) sign showed significance level greater than 0.1.

Generally those time series data give quite significant trends whose both Mann-Kendall trend (Z statistics) and Sen's Slope magnitude (Q statistics) having either increasing (positive)or decreasing (negative) values.

5. CONCLUSION and RECOMMENDATION

The results of study depicted that there is substantial year to year and season to season variability in rainfall pattern and rainfall pattern is generally erratic in nature. The statistical result of tests indicated that in some months there is an increasing trend while in some other months decreasing trend of precipitation. (1) Individually seven months (Jan, Feb, May, Jun, July, Aug and Sept) represents increasing trend while other five months (Mar, Apr, Oct, Nov and Dec) represent decreasing trend (2) the trend looks predominantly positive (increasing), both at the annual and seasonal scale (3) the spring, pre-monsoon and post-monsoon seasons showed decreasing trend while other showed increasing trend.

Table 1: Statistical Analysis of Rainfall data along with Mann-Kendall Trend and Sen's Slope

Time Series	Mean (mm)	Median (mm)	Maxi (mm)	Mini (mm)	St. Dev	Coef. Var	Mann-Kendall trend	Signific. (α)	Sen's Slope
JAN	25	14	130	4	32	130	1.003	-	0.121
FEB	48	33	213	7	51	106	3.011	**	1.332
MAR	52	40	201	3	45	87	-1.452	-	-0.823
APR	42	23	223	6	45	109	-0.052	-	-0.011
MAY	27	25	71	2	20	75	1.191	-	0.392
JUN	61	48	235	6	50	81	2.970	**	1.817
JUL	124	109	322	19	69	56	0.955	-	1.045
AUG	144	138	443	20	83	57	1.727	+	2.036
SEP	64	52	291	7	55	85	0.288	-	0.123
OCT	19	15	105	4	22	117	-0.052	-	0.000
NOV	6	1	42	2	10	153	-0.217	-	0.000
DEC	14	4	99	3	24	173	-1.092	-	0.000
Annual (J-D)	625	640	1241	225	197	32	1.674	+	5.515
Winter (O-M)	164	153	344	57	76	47	0.981	-	1.356
Summer (A-S)	461	454	1057	120	172	37	1.530	-	4.215
Cold Winter(DJF)	86	69	213	3	60	69	2.368	*	2.117
Spring (MAM)	121	103	363	30	75	62	-0.785	-	-0.597
Hot Summer (JJA)	329	326	759	84	134	41	2.538	*	5.182
Autumn (SON)	89	83	305	19	60	67	0.105	-	0.076
Pre-Monsoon (MAM)	121	103	363	30	75	62	-0.785	-	-0.597
Monsoon (JJAS)	393	373	856	119	149	38	2.106	*	4.863
Post-Monsoon (OND)	39	30	128	3	31	79	-0.864	-	-0.151
Rabi (ND, J-A)	186	172	418	65	90	49	0.876	-	1.265
Kharif (M-O)	438	414	1032	144	169	38	2.236	*	5.216

The monthly analysis indicated that the months of February, May, June, July and August give significant increasing trend due to positive value of both Z and Q statistics while the January and September showed non-significant increasing trend. The month of March give significant decreasing trend due negative value of Z and Q statistics and the month of April give non-significant decreasing trend. The trend of whole data on annual basis showed positive increasing trend.

The statistical analysis of whole series data indicated that the average annual rainfall of study area raingage is 625 mm with maximum average annual is 1241 mm and minimum average annual amount of rainfall is 225 mm also the value of standard deviation of rainfall data depicted that there is a great fluctuation in rainfall, about 70 % amount of rainfall occurs in the months of monsoon season also the months of July and August give maximum amount of rainfall while the months of November and December give minimum amount of rainfall.

Rainfall is the most important agro-climatic variable that determines the cropping system and overall agricultural productivity in rainfed areas of Pakistan and this increasing trend of rainfall on annual and seasonal basis can be used for better planning of water resources development and management schemes as well as conservation of soil moisture in study area of Pothwar region Pakistan.

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