Spatio -Temporal Assessments of Rainfall Variability and Trends in the Highlands to Coastal Regions of Papua New Guinea

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Abstract
The present study assesses spatio-temporal rainfall variability of the most highlands to the coastal zones, comprising of eight provinces, of PNG. The variability investigation was carried out over for a period of 50 years starting from the year 1968 to 2018. After testing and checking for serial autocorrelation in the data series, Mann-Kendal non-parametric statistical evaluation was carried out to investigate rainfall trends and variability. Sen's method was also used to investigate the magnitude of change in millimeters (mm) per year. Furthermore, the ArcGIS spatial analysis tools were used for the calculation of mean rainfall and to carry out spatial investigation. The assessments were carried out on an annual and seasonal basis within each designated study zone. CRU TS 4.03 gridded rainfall data on a 0.50 x 0.50 spatial resolution was used as an input data for trend as well as variability investigation. The CRU gridded station wise analysis was carried out to understand the variability at each specific location. From the assessments, it was found out that a higher rainfall is observed in the Eastern parts of Morobe, Southern Highlands region and central to northern part of Madang Province, while a low rainfall was observed in Goroka, the Western part of Morobe, Simbu, Western Highlands, Jiwaka and Enga province. From the trend investigation, it was observed that more grid stations show an increasing trend than a decreasing trend. On annual assessments, the significant decreasing trend is observed in the Enga and SH province, while significantly increasing trend is observed in the whole parts of Madang, and to the northern part of EH and Simbu Province. From overall assessments, it was found out that, there has been an increasing trend since 1968 up to the present.

1. Introduction

Rainfall is one of the common climatic variables among others to be considered for the variability assessments. Especially within subtropical or equatorial regions, variability assessment of climatic variables like rainfall, temperature, humidity and cloudiness emanating from differential solar irradiance can greatly enhance the understanding of climate change. Rainfall is a common factor to be considered and assessed and finally to be integrated with agricultural knowledge base culminating in a sound appraisal of productivity, food security and distribution. Furthermore, irregular rainfall patterns can also trigger various disasters such as floods, drought, erosion, landslide, and salinity. The documentation and understanding of variability and analysis of trend over time can greatly assist in taking up proper adaptation or mitigation processes.

PNG is one of the Pacific regions that is located within subtropical and equatorial regions and hence home to wettest climates of the world. According to the GFDRR, (2011) and McAlpine et al.,(1983), most areas of country PNG enjoys very high annual rainfall of 2500-3500 mm with the heaviest of 4000mm plus events of rainfall occurring in the highlands region towards north and south of the central reach. PNG often experiences a multitude of rainfall regimes resulting in the onset of disasters and or hazards, especially like flood, drought, landslides, river side bank erosion that affects most of the communities both the urban and the rural. The research works by Jana et al., (2015), Jana et al., (2019), Varo et al., (2019) and Mohanty et al., (2019) about the landslide and that includes Pal et. al., (2018) Varo et al., (2020) and Sekac et al., (2015) about flood hazard within Morobe province, PNG, Thailand, Fiji and Afghanistan has revealed that the potential impact towards the community. Furthermore, research works by Sekac et al., (2014), (2016) and Jana et al., (2014), had also revealed that the rainfall with river bank line erosion related

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impact towards Lae city community in Morobe Province. A study report by Robbins etal., (2013) show that the massive landslide in Tumbi (TagaliValey), Southern Highlands Province PNG, have affected several villages and their infrastructure, and was the result of heavy and continuous rainfall in the area. IFRC (2015), on the other hand, had reported on an appreciable period of drought due to reduced rainfall that had affected most of the provinces in PNG in year 2015. According to Mckennaet al., (2019), residents of Ohu and Bundi in Madang province, PNG, experienced substantial alterations in the frequency and intensity of rainfall, which dented the roads that leads to Madangtownship. Furthermore, according to Mckenna et al., (2019), residents of Hogave in Eastern Highlands province of PNG have been alarmed persistently on the potential for wildfires emanating from the shift of rainfall patterns and relatively higher temperatures.

There have been several studies carried out in PNG investigating the rainfall variability and trend analysis. For instance, Pereira et al., (2019), investigated the rainfall trends from 1996-2012 and have found out that there is an increasing trend of rainfall during this period. McAlpine et al., (1983), did a study especially on the rainfall variability and intensity (rate of rainfall per unit time) within 15 years'time period and have found out that, PNG has low rainfall variability and hence the rate of rainfall per unit time is 50mm per day. The PNG country profile by GFDRR (2011) has reported that in the northern Pacific the rainfall increases or decreases from -2.7% to + 25.8% and in the southern Pacific where PNG is one its regions, the rainfall increases or decreases from -14% to +14.6%.These are the standard ranges of expected figures of the trend. Again, according to PNG country profile by GFDRR (2011), the outlook of rainfall outlined throughout the Pacific region, either north or south has been a subject of persistent debate, with the projection of ±25% changes in precipitations. Till date researchers have failed to get a clear picture of precipitation variability owing to model uncertainties. Since PNG is the country of interest in the current research it was verified according to PCCSP (2011) that PNG annual rainfall would increase with more extreme rainfall events. Based on the several studies carried out, (Kuleshov et al., 2019, Pereira et al., 2019 and GFDRR, 2011), there are several key driving or influencing factors responsible for variability in rainfall within PNG. These can be or these are, north and southwest monsoon period, year to year El Nino and La Nino period including South Pacific Convergence Zone (SPCZ), a zone of high-pressure rainfall.

The current study mainly focuses on in-depth assessments of rainfall trend and or variability on the spatio-temporal basis within the specific zones of the country - PNG. The main aim of the research is to assess the historical rainfall data from the year 1968 to 2018 and then to calculate and document the possible average rainfall distribution, the variability and the trend within the study region. The output results provide indebt understanding of the rainfall pattern and or variability within the study region. Hence the main objectives of the research are;(1) to calculate the average rainfall distribution on a both annual and seasonal basis for 50 years' time period (1968 – 2018), (2) to calculate and spatially investigate the rainfall variability within the study region, (3) to calculate and investigate the trend over time using Mann-Kendall (MK) non-parametric statistical test (Mann, 1945 and Kendall, 1975) and (4) to investigate the magnitude of rainfall change in mm per year using Sen's method (Sen, 1968). The investigation and calculation were performed for all 57 points of the grid and on an annual and seasonal basis. The grid points are the data points from the Climate Research Unit (CRU).Within PNG such an approach, as of these current study, has not been fully carried out in any of the previous research studies, especially when talking about the provincial, district and even specific location-wise assessment of rainfall trend and variability. The current study aims to fill in the knowledge gap to the growing communities including Governmental Organisation and Non-Governmental Organisation to know at each specific zone the rainfall variability/pattern and trend, which will surely enhance proper planning and also augment mitigation measures in the case of natural disasters like flood, drought and landslide which are common in the study region. Furthermore, farmers, in general, need a better understanding of rainfall pattern and variability, and this will assist them in planning ahead for crop production and or livestock surveillance.

When thinking within the PNG context, the climate change and impact investigation or study is of primary importance now a day. It has been studied and documented from the past to the present. Rainfall is one of the climatic variables, therefore investigating the trend and or variability is part of the climate change study. Along with such mood of understanding, the current research was conducted based on current data, knowledge and tool availability to further facilitate, support and broadens the knowledge and understanding of climate and weather of the PNG.Non-parametric Mann–Kendall (MK) method (Mann, 1945 and Kendall, 1975) and Sen's Method (1968) are commonly used worldwide by several researchers to investigate the trend and or the magnitude of change in mm per year (Panthi et al., 2015, Taxak et al., 2014, Duhan and Pandey, 2012, Feizi et al., 2015).An investigation by Yue et al., (2002a) and (2002b)into comparing other non-parametric trend tests with MK non-parametric test has discovered that the MK test having similar power of pointing out the trend like another commonly used nonparametric test commonly known as Spearman's rho test. Furthermore, Hess et al., (2001), has mentioned that the methods were distribution-free, robust against outliers, and were superior to many other commonly used tests. In this research spatial analysis and investigation are predominantly considered.

2. Study Area Background

Papua New Guinea is one of the counties in the pacific region. The country is very complex in terms of its geographical settings from the higher elevation lands to the coastal. The country occupies about 463,900sq.km of total land area and is made up of 22 provinces and a total population of 8.2 million-plus. The country is home to multiple mineral and gas extraction zones and also is home to intensive agricultural activities. The country is mountainous and its climate is described as a tropical climate of high rainfall, humidity and high temperatures which stay put more or less uniform around the year (Igua, 2001and McAlpine et al., 1983). Hence PNG is highly prone to the climate change and related impacts. The temperature to the coastal plains averages 28°C, while the inland and mountain areas have a mean temperature of 26°C, and the higher mountain regions having about 23°C. The relative humidity is quite high and ranges between 70 and 90 percent (McAlpine et al., 1983).

Normally the country experiences two (2) seasonal periods that is a wet and dry spell. Generally speaking, the wet spell starts somewhere around months October or November and ends March or April and the dry spell starts around the month April or May and ends in September or October. During wet spell, the country experiences higher rainfall and during dry spell the country experiences lower rainfall. However, on the other hand, the country sometimes experiences wetness throughout the year. Sometimes the seasons vary across provinces within PNG, that is during the wet spell season some provinces experience lower rainfall while others experience higher rainfall and during dry spell the vice-versa happens. The extreme disparity in rainfall is associated with the north and south westerly monsoons. Western and northern parts of Papua New Guinea go through the most of precipitations, just because of the north and westward-moving monsoon clouds are laden with heavy moisture by the time they reach these more distant regions (McAlpine et al, 1983 and GFDRR, 2011).

The study was carried out concentrating within 8 provinces of country PNG to evaluate and assess the rainfall variability and or the trend. The provinces selected are; Southern, Eastern and Western Highlands Provinces including Jiwaka, Madang, Enga and Morobe Provinces. The study zone is located within 142 and 148 ^{0}E as well as 8 and 3 ^{0} S. The study zone (8 provinces) covers a good distribution from the higher lands to the coastal zones, where fair analysis is done considering both higher and lower coastal areas are considered. The common physiographical units that do contributes or dominates the study zone in terms of climatic variability are; Adelbert Range, Saruwaget Range, Owen Stanley Range, Huon Peninsula, and Mt William. Central parts of the study zone are prone to drought due to a low amount of rainfall. Figure 1 illustrates the study zone where the research was carried out.

3. Materials and Methods

3.1 Data Used

In the present study, CRU TS 4.03 datasets were used. CRU TS 4.03 is the newly updated version after version 3.10, 4.01 and 4.02 that covers the year ranges from 1901 – 2018 (Harris et al., 2014). There are a total of ten (10) climatic variables. The climatic variable 'rainfall' was the only variable considered and assessed in the present study. The monthly gridded rainfall data in mm for 50 years' time period (1968 – 2018)was downloaded following the link; https://crudata.uea.ac.uk/cru-/data/hrg/ with the NetCDF file extension at 0.5 by 0.5 degree spatial resolution. Hence this was the resolution of the data used throughout the study. By using the 'R' and 'ArcGIS' software the data was successfully extracted to user-friendly software/format, that is 'Excel (csv&xlxs)'. The data was arranged and prepared for each grid points, hence the total of 57 CRU grid points with its latitude–longitude information were prepared within the designated study zone. The prepared and arranged time series data then goes through certain serial auto-correlation testing including a pre-whitening processes.

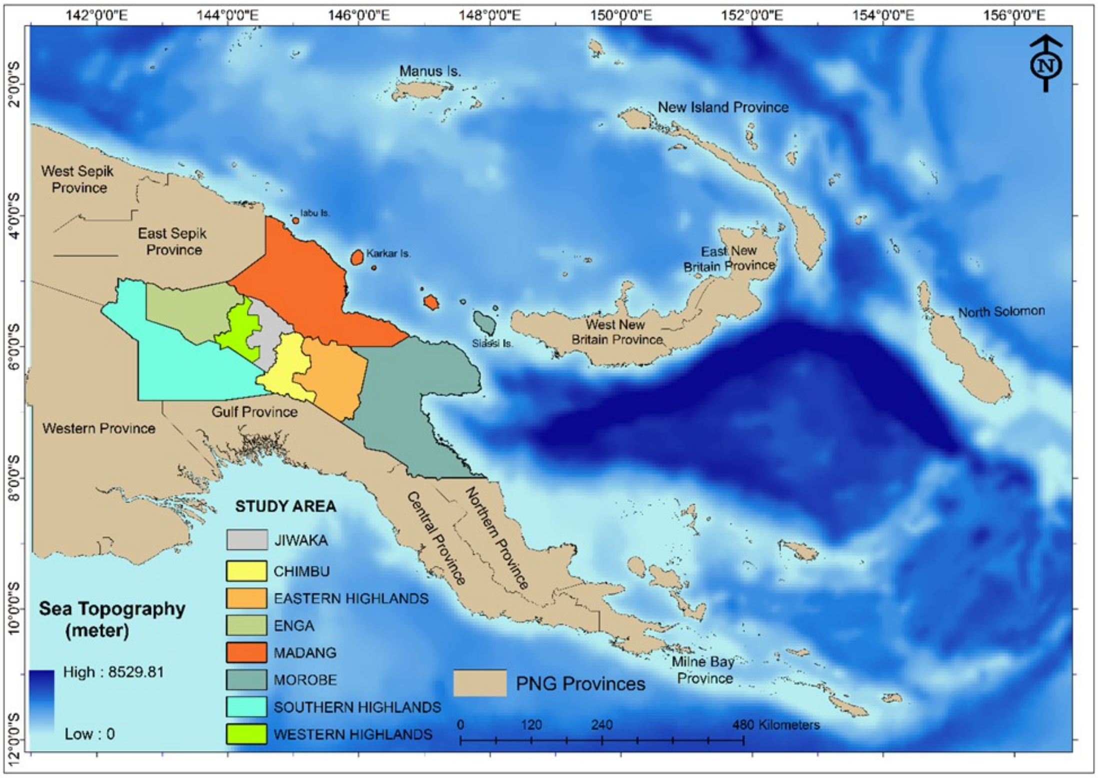


Figure 1: Study zone locality

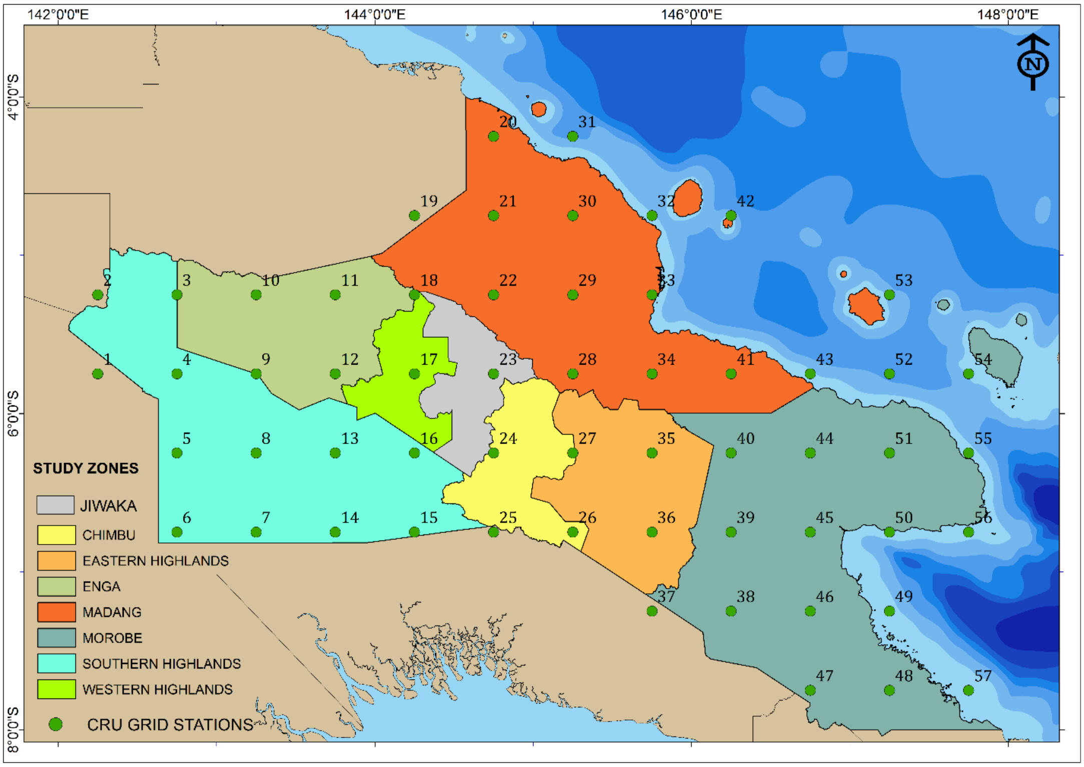


Figure 2: Spatial Distribution of CRU grid stations and the provinces it represents

According to Ahmad et al., (2014), the non-parametric statistical approach of calculating and investigating rainfall trend and or variability will be greatly affected if autocorrelation exists in time series data, therefore at first instance before proceeding into further statistical assessments, the serial data autocorrelation has to be tested, and if serial autocorrelation exists in the data series, the pre-whitening process has to be carried out. Figure 2 illustrates the grid station (CRU GRD STN) locations, and the provinces it represents. Each CRU GRD STN has rainfall data arrange and prepared to be assessed. It was prepared in such a way that each grid station carries a rainfall data ranging from the year 1968-2018 on an annual and seasonal basis. To suit the research gap, there were lots of problems and errors encountered during data download, arrangement and preparation; however, all were successfully minimized and overcame. Apart from the serial autocorrelation and the pre-whitening processes, physical in-depth data screening and validation were also carried out to at least minimize the outliers and mindfully enhance data to error-free.

Following Harries et al., (2014), the CRU data sets were processed from data obtained from various weather stations around the world using World Meteorological Organisation (WMO). Station Identifiers, furthermore such metadata as; location, elevation, station name and country name are also included. WMO in collaboration with the US National Oceanographic and Atmospheric Administration (NOAA, via its National Climatic Data Center, NCDC) the data is updated. Around the world, most of the researchers and or scientist have been using CRU data for climate study. To mention a few here; Taxak et al., (2014) have used CRU TS precipitation data to investigate the rainfall trend and variability in the Wainganga Basin of Central India. Also Mulugeta et al., (2019) have used CRU TS precipitation data to investigate the rainfall trend and variability in the Awash River basin of Ethiopia. Asfaw et al., (2018) have used CRU TS data to study the temperature trend and variability in the Woleka Sub-Basin in north-central Ethiopia. Furthermore, Sekac et al., (2020) have used CRU TS data to study the temperature trend and variability in the highlands to coastal regions of PNG.

3.2 Methodology

Monthly rainfall data were downloaded and annual and seasonal series were prepared. For annually, the data was arranged and prepared from the months January to December, for seasonal basis, the data was arranged and prepared from months May – October for dry season (Dry Spell) and November to April for wet season (wet spell). Within the PNG context, the dry spell or dry season are the months in a year that the country is vulnerable to less rainfall while wet spell or wet season are the months in a year that the country is vulnerable to high rainfall. There were about fifty-seven (57) CRU grid stations prepared within the study zone and hence assessments and or analyses of rainfall trend or variability were done for each grid station.

The methods of analysis are: (1) calculate mean, standard deviation, coefficients of variance (CV), Skewness and Kurtersis of rainfall distribution over time (Preliminary Rainfall Statistical calculation); (2) calculate the trend, either increasing or decreasing trend over time using MK Test (Mann, 1945 and Kendall, 1975) (3) calculate the magnitude of rainfall change mm per year using Sen's slope estimator (Sen, 1968); (4) calculate the variability of rainfall distribution using the ArcGIS 10.2 raster calculator spatial analysis tool; (5) calculating and determining the level of significance of the existing trend (Mann, 1945 and Kendall, 1975); (6) calculate the mean annual and seasonal rainfall distribution using ArcGIS raster calculator spatial analysis tool; (7) Perform Spatial Interpolation technique in ArcGIS 10.2 to investigate the trend, mean and variability over time.

Data analysis and calculation carried out were simply to understand rainfall variability and or trend over time within the study zone at each specific location (grid station). For the MK and Sen's slope test, the MEKESEN 1.0 tool which was developed by the Finnish Meteorological Institute (2002) was used. The tool was developed for detecting and estimating trends in the time series data and it is used worldwide. According to Gilbert (1987), the tool is used for two types of statistical calculation, firstly the Mann-Kendall test for detection of a monotonic increasing or decreasing trend over time and secondly the Sen's methodused to estimate the slope of a linear trend over time. The statistical tests that have been conducted throughout the study are discussed in detail below.

3.2.1 Auto-correlation test

Autocorrelation test in the present study is the correlation coefficient between two (2) values of the same variable instead of the correlation between two (2) different variables. After the time series, rainfall data was arranged and prepared, the auto-correlation test was conducted on every yearly and grid station data. The test was conducted at 95% confidence level (Equation 2), which is the confidence interval that is at a 5 % significance level, followed then by the calculation of upper and lower limit. If it is tested to be significance auto-correlation, that is serial correlation is detected at each grid stations, the pre-whitening procedure was performed. The formula in equation 1 highlights the Auto-correlation statistical test that was conducted.

$$r_1 = \frac{\sum_{i=1}^{n-1}(x_i - \mu)(x_{i+1} - \mu)}{\sum_{i=1}^{n}(x_i - \mu)^2}$$

Equation 1

r_1 is the autocorrelation coefficient. x_i is the data point value in a time series, μ is the mean of data value in time series and n is the number of data in a time series. To test the existence of a serial autocorrelation in the time series, r_1 was tested against the null hypothesis at a 95% confidence interval using two-tailed test. Equation 2 is the function, adopted and modified from Ahmad et al., (2014):

$$r_1(95\%) = \frac{-1 \pm 1.96\sqrt{(n-2)}}{n-1}$$

Equation 2

After the serial autocorrelation test and the pre-whitening procedure, the MK test was carried out to detect trend including the significance of the trend. Yaseen et al., (2014), On et al., (2012) and Shadmani et al., (2012) have also used this approach of checking and eliminating serial correlation in the time series data.

3.2.2 MK trend detection test

When using MK Test, the null hypothesis (H_0) of no trend and hypothesis (H_A) of the existing trend either increasing or decreasing is tested. In order to test the hypothesis, the observations (x_i) are arranged or ordered in time basis and are evaluated and compared with its subsequent data values, that is, According to Drapela and Drapelova, (2011) and Gilbert (1987), if a data value from a later time period is more than a data value from a prior time period, the statistic $'S'$ is increased by 1. On the other hand, if the data value from a later time period is lesser than a data value sampled previously, $'S'$ is decreased by 1. The net result of all such increase and decrease gives rise to the final value of $'S'$ (Shahid, 2011). The M-K test statistic $'S'$ is computed using Equation 3:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k)$$

Equation 3

$$sgn(x_j - x_k) = \begin{cases} +1 & if\ (x_j - x_k) > 0 \\ 0 & if\ (x_j - x_k) = 0 \\ -1 & if\ (x_j - x_k) < 0 \end{cases}$$

Equation 4

Using the above formula $'S'$ was the common statistics that is to be determined. $'S'$ may be explained as it is a sum of signs of divergence between any two observations. In the above formula, it can be seen that x_j and x_k are the practical standard values at time j and time k . For example, rainfall value recorded in the year 1968 was 2100mm and in the year 1969 was1200 mm. In the real case, imagine all the temperature values for each CRU grid stations (57 grid stations) starting from the year 1968 to 2018 that was computed using the formula. The positive and negative signs of computed $'S'$ determines the upward and downward trend and the value of $'S'$ itself denotes the level of significance (Equation 4). The level of significance 'α' was tested at 0.001, 0.01,0.05 and 0.1 which means, 0.1%, 1%, 5% and 10% probability level where hypothesis (H_0& H_A) are tested. Again it can be also addressed as, the level of significance was tested at 99.9%, 99%, 95% and 90% confidence level.

The absolute value and signs of $'S'$ is compared directly if the number of data value computed is less than 10 (9 and less), meaning the end results of whether increasing or decreasing trend including the level of significance is compared directly. However, if the data values used are 10 and above the standard and or normal, test of approximation is used. In this approach validity of the standard approximation can be reduced if the tied group exist in the data series. To rule out this, the calculations are furthered into the determination of Variance of 'S'(Equation 5) and then followed by determination of 'Z' statistics (Equation 6), where calculated $'S'$ and variance of $'S'$ plays an input into the formula to compute test statistics 'Z. In the present study, the computed 'Z' value was used to evaluate either presence or absence of significance trend. The levels of significance 'α' were tested at 0.001, 0.01, 0.05 and 0.1 which is a two-sided test at 10% significance level. The Hypothesis (H_0 or H_A) are tested at each significance 'α' level, that is, H_0 is rejected at 'α' if the absolute 'Z' value is calculated to be greater than '$Z_{\alpha/2}$, and H_A is accepted meaning there is a significant increasing or decreasing trend detected at such α level. In the calculation if it is calculated to be not of significance, then it is significant at other significance levels, let's say above 10%. The levels of significance 'α' are indicated or represented by symbols; *** (0.001), ** (0.01), * (0.5), and + (0.1). The signs of 'Z', that is either positive or negative indicates increasing or decreasing trend.

$$VAR(S) = \frac{1}{18} n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5)$$

Equation 5

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} \longrightarrow if S > 0 \\ 0..... \longrightarrow if S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} \longrightarrow if\ S < 0 \end{cases}$$

Equation 6

Equation 5 and 6 above highlights the way forward into calculating 'Z' statistics. From the VAR(S) calculation (Equation 5), as shown below, it can be noted that 'n' denotes the number of data used in the study and 'q' denotes the number of tied groups in the data series and *tp*is the number of data values in the *p*th group. Hence the test statistics 'Z' is computed from 'S' and variance of 'S'as follows;

3.2.3 Sen'sstatistical test

In the current study, to determine the magnitude of rainfall change in mm/year or in the other words, to determine how much the rainfall has either increased or decreased per year at each CRU grid station, the true slope (Q) of the detected trend was calculated using Sen's nonparametric method (Equation 7 and 8). The Sen's non-parametric statistical test is a method where the magnitude of the trend in a time series data is calculated (Panda and Sahu, 2019).

Furthermore,where the current trend can be taken as linear, according to Salmi et al., (2002) and Gilbert (1987), the Sen's method is to be used. For each station, the calculations were carried out to determine the changes mm/year. Firstly the *N'* of a slope, 'Q' was computed (Equation 7) for each grid station, that is the slope of all data value pairs. $x_{i'}$ indicates the present data value at the present time period (i') and x_i indicates the past data value at the past time period (i). After computing all pairs year by year, the median of all computed data pairs is taken for each station (Equation 8). Hence the median value is the true slope that determines the magnitude of change mm/year at each station. This can be either positive or negative values indicating upward or increasing trend and or downward or decreasing trend. The formula here fully explains what has been discussed so far.

$$Q = \frac{x_{i'} - x_i}{i' - i}$$

Equation 7

$$Q_{\left[\frac{N'+1}{2}\right]} if\ N' is\ odd$$
$$\frac{1}{2}\left(Q_{\left(Q\left[\frac{N'}{2}\right]\right.} + Q_{[N'+2]/2}\right) \text{ if } N' \ is\ even$$

Equation 8

3.2.4 Rainfall spatial analysis

To investigate and visualize the calculated rainfall trend or variability including mean rainfall distribution within the study area extent, the spatial interpolation method was used. According to Yi et al., (2013) the method is widely used across the world to show the spatial distribution of climatic variables for example; mean temperature and or rainfall. In this study, the Inverse Distance weighting (IDW), an ArcGIS spatial interpolation analysis tool was employed into investigating the spatial distribution and pattern of mean annual and seasonal rainfall trend and magnitude of rainfall change mm/year that was calculated including the rainfall mean within the study region. In the case of rainfall mean calculation, the ArcGIS cell statistics spatial analysis tool was also used in combination with the interpolation tool. The interpolation was carried out for all CRU grid station points. Furthermore, the calculated CV was interpolated to investigate the rainfall variability at each specific zone within the study area. The calculated results are at first graphically reported followed by spatially illustrating on maps and or figure.

4. Results and Discussions

4.1 Rainfall Preliminary Assessments

The preliminary assessments were carried out for each CRU grid station (STN 1 to STN 57) on a both annual and seasonal basis. The mean annual rainfall range varies between 1797.31 mm in the Eastern Highlands province (CRU GRD 35) to 4582 mm in the southern highlands province (CRU GRD 7). The assessments on annual basis show that southern highlands province, the western part of Enga Province, central and north-western part of Madang province, the eastern and north-eastern part of Morobe Province receives the highest amount of rainfall. Goroka, Chimbu, Western Highlands, the whole of westerly part of Morobe Province Southern part of Madang and to the central and eastern part of Enga receives the lowest rainfall. The standard deviation varies between 142 and 446.

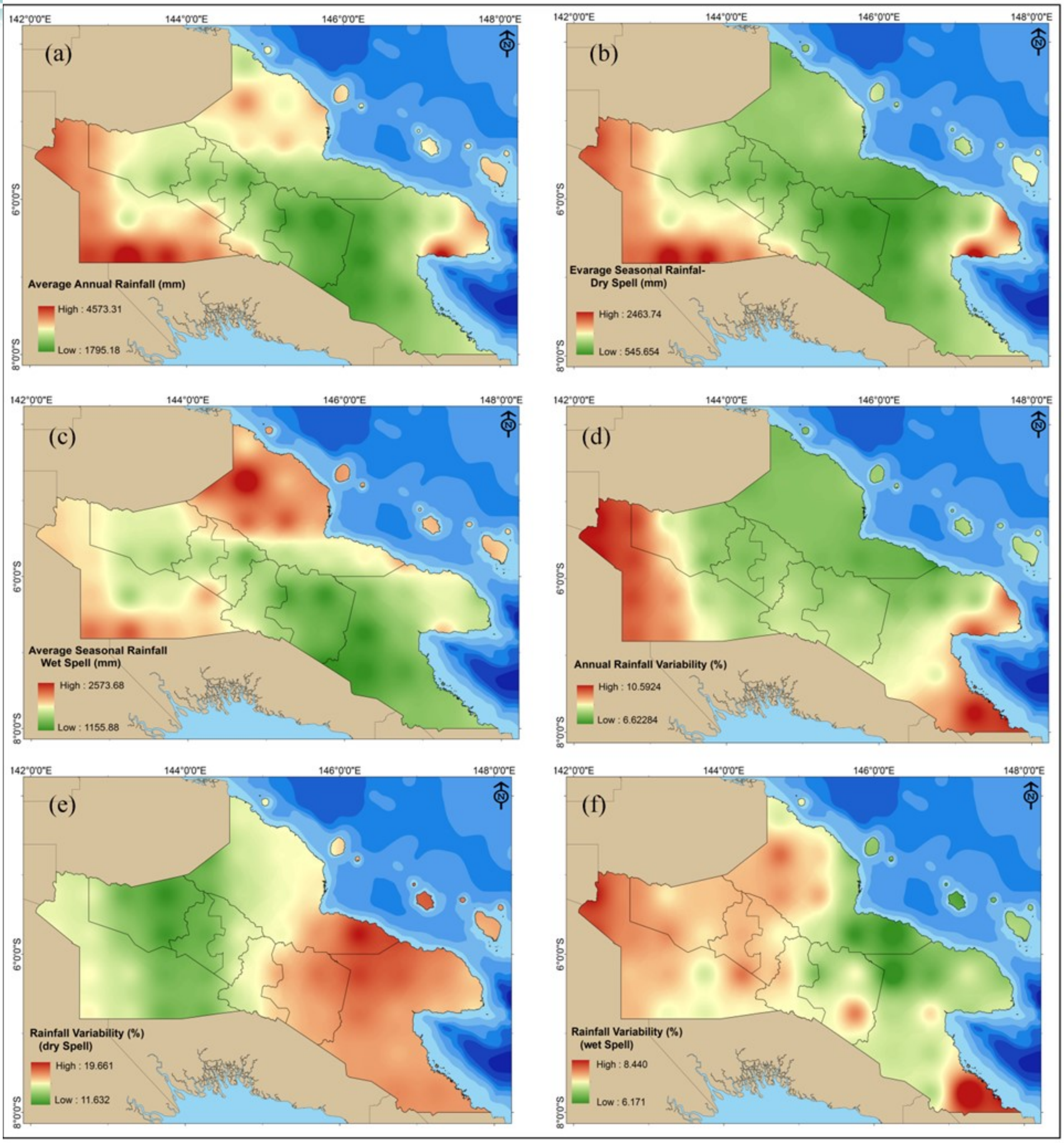


Figure 3: Spatial investigations of rainfall mean and variability; a. annual mean rainfall, b. seasonal mean rainfall – dry spell, c. seasonal mean rainfall – wet spell, d. annual rainfall variability (%), e. seasonal rainfall variability (%) – dry spell, f. seasonal rainfall variability (%) – wet spell

The skewness on the annual basis was calculated to be range between (– 0.13) – (- 0.82), and this shows the negative skewness with an average of (-0.53), therefore the data distribution is moderately symmetric. The kurtosis was calculated to be range between 0.91 – 5.23 with an average of 2.12. Figure 3a illustrates the spatial distribution of annual rainfall within the study zone.

On seasonal basis during a dry spell, the mean rainfall distribution varies between 549.9 mm (CRU grid STN 35) and 2248.5 mm (CRU grid STN 50) and the standard deviation varies between 99.3 and 413. During wet spell, the mean rainfall distribution varies between 1136.12 mm (CRU grid STN 37) and 2573.68 mm (CRU grid STN 20) and the standard deviation varies between 80 and 172. The preliminary rainfall analysis during dry spell (May – October), shows that the highest amount of rainfall was experienced in the southern highlands province and to the eastern and north-eastern part of Morobe Province and hence medium to lowest rainfall are experience in the whole part of Madang, Eastern

Highlands, Simbu, Western Highlands, Jiwaka, Eastern Part of Enga and the western part of Morobe Province. During wet spell (November to April) the analysis shows that central to northern part of Madang and Southern part of Southern Highlands Province experiences the highest rainfall and hence to the central to the northern part of southern highlands, Enga, Jiwaka, Simbu, Eastern Highland, Western Highland and Morobe Province, receives medium to low rainfall.Figure 3(b and c) illustrates the spatial distribution of seasonal rainfall within the study zone. The figure shows the actual location of where seasonal rainfall differences occur. It can be concluded that, though on annual or seasonal, the Eastern Highlands, Western Part of Morobe Part of Simbu, some parts of Enga, Jiwaka and WH Provinces receives low rainfall and the higher rainfall is mostly experienced in the parts of Southern Highlands Province and a least at eastern part of Morobe Province and central to the western part of Madang province.

According to Duhan and Pandey (2013) CV is the statistical measure of the dispersal of data points in a dataset. In their study, the calculated CV was used to investigate the variability of rainfall within the study region of interest. For the present study, the CV (%) was calculated at each grid station on a both annual and seasonal basis to investigate the inter-annual and seasonal rainfall variability between the year 1968 and 2018. On annual basis, the assessments show that the CV varies from 7.3% to 11.5% and on the seasonal basis, the CV varies from 12.3% to 20.4% for dry spell and 6.5% to 12.8% for a wet spell with an average CV for each at 8.3%, 18.4% and 7.2%.The analysis shows that within the study region, either on an annual or seasonal basis the rainfall variability was at least medium to low. During dry spell, the variability is higher when compared with wet spell and on annual. It can be concluded from the assessment that on average, the variability is high to the zones where higher rainfall is experienced. In other words, it can be said as; Higher the zones of rainfall, more the variability. Figure 3(d, e, f) illustrates the spatial distribution of rainfall variability in each section or zones within the study region.

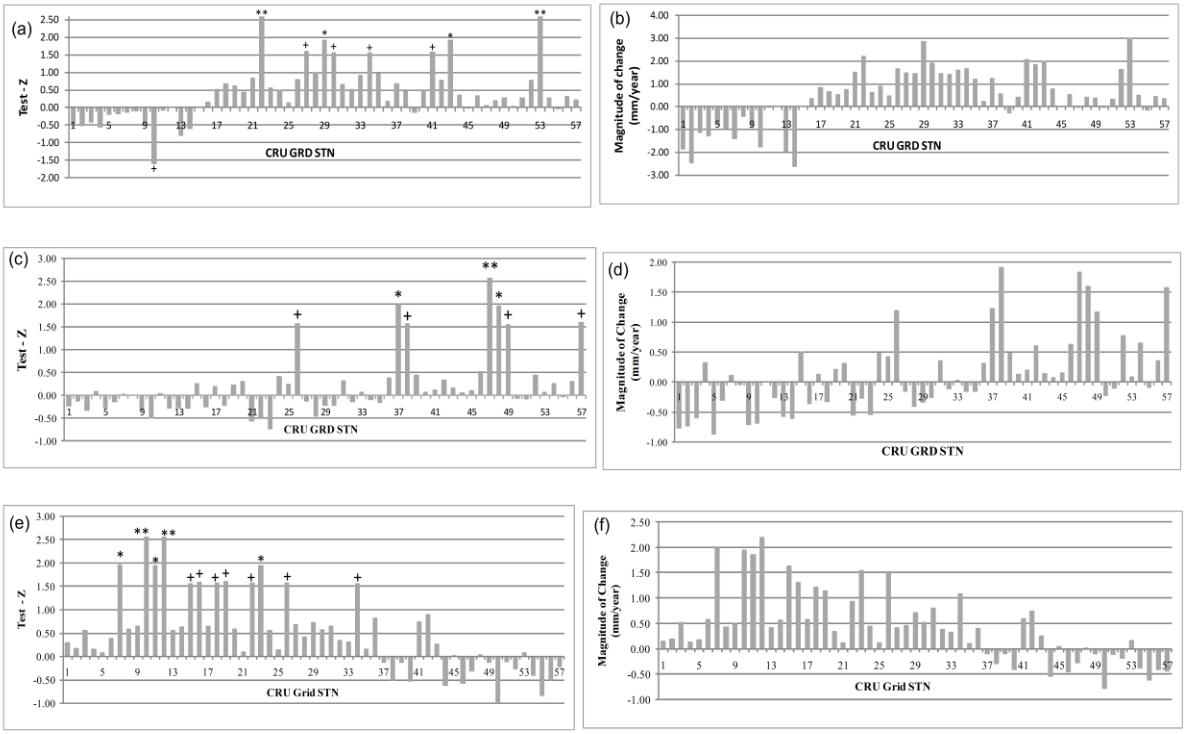
4.2 Annual and Seasonal Rainfall Trend

Rainfall trend investigation and analysis was carried out for all CRU GRD STNs (STN 1 – STN 57) on a both annual and seasonal basis. The results are tabulated (Table 1) with graphically (Figure 4) and spatially represented (Figures 5 and 6) to communicate the rainfall trend over the years since 1968. The test –Z (Figure 4 and Table 1) indicates or shows either increasing (positive values) or decreasing (negative values) trend and including the significance level. The calculated linear true slope indicates the magnitude of change (MOC) mm per year (Figure 4 and Table 1) that was spatially analysed to investigate the trend within the study region. The calculated value (magnitude of change) shows how much the rainfall has increased or decreased per year (Table 1).

4.2.1 Annual rainfall trend

On annual rainfall trend investigation, the decreasing rainfall trend was observed from STN 1-14, 39 and 55 and the increasing trend was observed from STN 16-38, 40 – 54, 56 & 57 (Figure 4a and Table 1). A more increasing trend was observed than decreasing trend within the study region. The decreasing rainfall trend was observed in the provinces such as Southern Highland, Enga and small parts of Morobe, where the magnitude of decreasing range between (-0.3mm/yr)–(-2.6mm/yr). The significant decreasing trend is observed in the parts of Enga and small portions of SH province, that means these zones are at high risk and of vulnerable to experiencing decreasing rainfall. Thereby precautions have to be taken when thinking in the context of disasters and or hazards that are posed by less or decreasing rainfall. The increasing rainfall trend was observed in Madang, Morobe, Simbu, Western Highlands, Jiwaka and Eastern Highlands Province and the magnitude of increase range between 0.5mm/yr – 2.9mm/year. The significant increasing trend was observed

in almost all zones of Madang province, the portion of Simbu and EH province to the north, and that means these zones are at high risk and of vulnerable to experiencing increasing rainfall. Thereby precautions have to be taken when thinking in the context of disasters and or hazards that are posed by high or increasing rainfall. Some provinces are not that significant in increasing or decreasing trend, however, they might be considered significant at other confidence levels. The graphical and spatial representations of annual rainfall trend investigations are illustrated in Figures 4, 5 and 6 and tabulated in Table 1. Figure 4(a,b) illustrates the graphical representations of statistical test Z and the magnitude of change mm/year, Figure 5(a) is the spatial distribution of the magnitude of change, either increasing or decreasing mm/year and Figure 6(a) is the spatial distribution and representation of zones experiencing significance increasing or decreasing trend.



*** Significance at 0.01, * significance at 0.5, and + significance at 0.1.*

Figure 4: Trend at each grid stations; a. Annual - test Z, b. Annual – Magnitude of Change mm/yr, c. Seasonal (dry spell) – Test Z, d. Seasonal (dry spell) - Magnitude of Change mm/yr, e. Seasonal (wet spell) – Test Z, f. Seasonal (wet spell) - Magnitude of Change mm/yr.

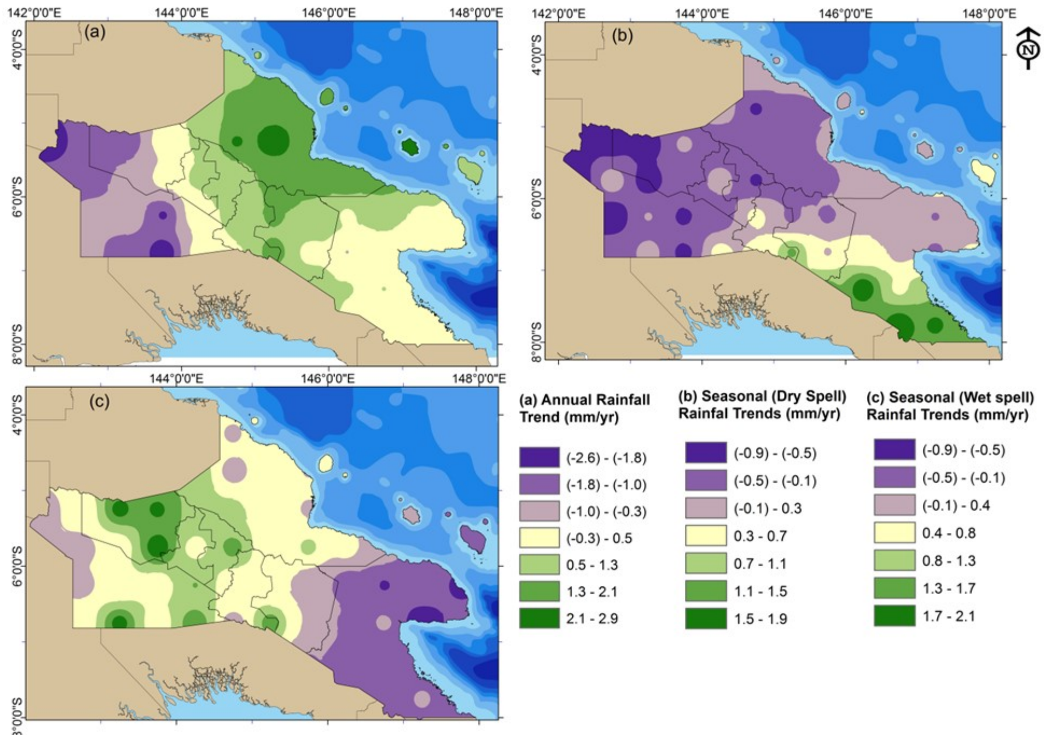


Figure 5: Spatial distribution of Rainfall Trend; a. Annual (January – December), b. Seasonal-Dry Spell (November to Following year April), c. Seasonal – Wet Spell (May – October)

Table 1: Grid Station wise rainfall trend on annual and seasonal basis

				Annual		**Seasonal (Dry)**		**Seasonal(Wet)**	
GrdStn	**Province**	**Lat**	**Lon**	**Test Z**	**MOC (mm/yr)**	**Test Z**	**MOC (mm/yr)**	**Test Z**	**MOC (mm/yr)**
1	SH (Nearest)	-5.75	142.25	-0.50	-1.848	-0.23	-0.758	0.29	0.150
2	SH (Nearest)	-5.25	142.25	-0.50	-2.463	-0.13	-0.732	0.16	0.195
3	Enga	-5.25	142.75	-0.41	-1.105	-0.32	-0.590	0.55	0.509
4	SH	-5.75	142.75	-0.56	-1.252	0.08	0.320	0.15	0.128
5	SH	-6.25	142.75	-0.19	-0.763	-0.26	-0.867	0.07	0.175
6	SH	-6.75	142.75	-0.18	-0.915	-0.15	-0.303	0.38	0.575
7	SH	-6.75	143.25	-0.13	-1.386	0.02	0.107	1.95 *	1.984
8	SH	-6.25	143.25	-0.10	-0.398	0.00	-0.044	0.58	0.427
9	Enga	-5.75	143.25	-0.45	-0.911	-0.32	-0.700	0.65	0.485
10	Enga	-5.25	143.25	-1.60 +	-1.763	-0.50	-0.686	2.55 **	1.945
11	Enga	-5.25	143.75	-0.07	-0.008	0.02	0.000	1.93 *	1.846
12	Enga	-5.75	143.75	0.00	0.000	-0.28	-0.259	2.56 **	2.197
13	SH	-6.25	143.75	-0.79	-1.926	-0.26	-0.571	0.54	0.412
14	SH	-6.75	143.75	-0.60	-2.600	-0.28	-0.600	0.63	0.564
15	SH	-6.75	144.25	0.00	0.000	0.24	0.500	1.55 +	1.633
16	SH	-6.25	144.25	0.15	0.333	-0.24	-0.357	1.59 +	1.305
17	WH	-5.75	144.25	0.51	0.824	0.19	0.125	0.65	0.574
18	WH	-5.25	144.25	0.67	0.650	-0.22	-0.317	1.56 +	1.220
19	Madang(Nearest)	-4.75	144.25	0.61	0.529	0.21	0.207	1.60 +	1.133
20	Madang	-4.25	144.75	0.44	0.744	0.29	0.310	0.58	0.333
21	Madang	-4.75	144.75	0.83	1.518	-0.56	-0.545	0.10	0.111
22	Madang	-5.25	144.75	2.57 **	2.206	-0.49	-0.267	1.57 +	0.933
23	WH	-5.75	144.75	0.54	0.636	-0.73	-0.538	1.94 *	1.534
24	Chimbu	-6.25	144.75	0.50	0.907	0.41	0.474	0.54	0.437
25	Chimbu (Nearest)	-6.75	144.75	0.12	0.468	0.24	0.417	0.14	0.118
26	Chimbu	-6.75	145.25	0.79	1.667	1.56 +	1.192	1.57 +	1.493
27	Chimbu	-6.25	145.25	1.60 +	1.473	-0.12	-0.149	0.68	0.414
28	Madang	-5.75	145.25	0.98	1.444	-0.45	-0.400	0.41	0.450
29	Madang	-5.25	145.25	1.92 *	2.839	-0.22	-0.336	0.71	0.711
30	Madang	-4.75	145.25	1.55 +	1.903	-0.22	-0.250	0.56	0.521
31	Madang	-4.25	145.25	0.65	1.445	0.31	0.352	0.64	0.803
32	Madang	-4.75	145.75	0.50	1.413	-0.14	-0.110	0.34	0.375
33	Madang	-5.25	145.75	0.90	1.600	0.06	0.028	0.31	0.323
34	Madang	-5.75	145.75	1.55 +	1.644	-0.10	-0.147	1.55 +	1.075
35	EH	-6.25	145.75	0.94	1.204	-0.15	-0.157	0.15	0.100
36	EH	-6.75	145.75	0.16	0.215	0.38	0.306	0.82	0.394
37	Morobe	-7.25	145.75	0.67	1.233	1.98 *	1.218	-0.13	-0.088
38	Morobe	-7.25	146.25	0.45	0.563	1.57 +	1.915	-0.51	-0.281
39	Morobe	-6.75	146.25	-0.14	-0.265	0.43	0.476	-0.13	-0.100
40	Morobe	-6.25	146.25	0.46	0.402	0.06	0.127	-0.53	-0.405
41	Madang	-5.75	146.25	1.57 +	2.043	0.11	0.191	0.73	0.594
42	Madang	-4.75	146.25	0.77	1.853	0.33	0.598	0.89	0.741
43	Madang	-5.75	146.75	1.92 *	1.983	0.15	0.139	0.26	0.248
44	Morobe	-6.25	146.75	0.36	0.778	0.04	0.071	-0.62	-0.542
45	Morobe	-6.75	146.75	0.02	0.000	0.09	0.156	0.02	0.038
46	Morobe	-7.25	146.75	0.32	0.534	0.51	0.624	-0.57	-0.455
47	Morobe	-7.75	146.75	0.05	0.019	2.56 **	1.829	-0.31	-0.266
48	Morobe	-7.75	147.25	0.19	0.408	1.96 *	1.600	0.03	0.012
49	Morobe	-7.25	147.25	0.26	0.369	1.55 +	1.171	-0.12	-0.095
50	Morobe	-6.75	147.25	0.02	0.017	-0.06	-0.222	-0.98	-0.780
51	Morobe	-6.25	147.25	0.27	0.323	-0.08	-0.097	-0.11	-0.107
52	Morobe	-5.75	147.25	0.76	1.632	0.44	0.772	-0.27	-0.184
53	Madang	-5.25	147.25	2.56 **	2.990	0.06	0.085	0.08	0.157
54	Morobe	-5.75	147.75	0.28	0.504	0.24	0.650	-0.40	-0.379
55	Morobe	-6.25	147.75	-0.04	-0.140	-0.03	-0.083	-0.83	-0.617
56	Morobe	-6.75	147.75	0.30	0.431	0.29	0.353	-0.50	-0.407
57	Morobe	-7.75	147.75	0.22	0.361	1.60+	1.571	-0.21	-0.439

*** Significance at 0.01, * significance at 0.5, and + significance at 0.1.*

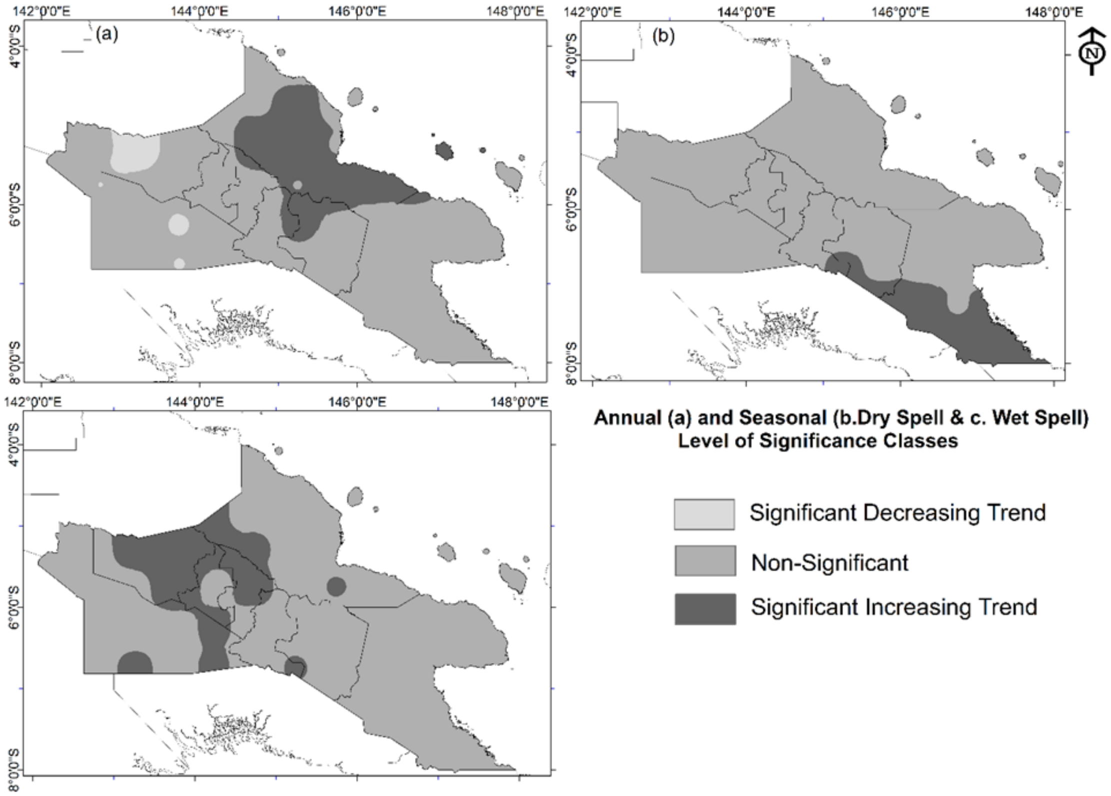


Figure 6: Spatial distribution of Rainfall Trend Significance; a. Annual (January – December), b. Seasonal-Dry Spell (November to Following year April), c. Seasonal – Wet Spell (May – October)

4.2.2 Dry seasonal rainfall trend

Between the months of November to the following year, April (dry season) the grid station observation of either increasing or decreasing trend varies greatly. Since 1968, more decreasing trend was observed than an increasing trend (Table 1) within the study zone. A decreasing trend was observed nearly across all provinces such as Southern Highlands, Enga, Western Highlands, Jiwaka, Madang, Northern and north-eastern Part of Simbu, Eastern Highlands and Morobe Province, where the magnitude of decreasing ranges between (-0.1 mm/yr) – (-0.9 mm/yr). There is no significant decreasing trend observed in the study zone, however, precautions have to be taken. The increasing trends are observed in the southern part of Morobe, Eastern Highlands Province and Simbu, where the magnitude of increasing ranges between 0.3 mm/yr – 1.9 mm/yr.

The significance increasing trend was observed in the southern part of Morobe and EH province, which means between the months November to following year April, these zones can be at high risk of experiencing increasing rainfall. Thereby precautions have to be taken when thinking in the context of disasters and or hazards that are posed by high or increasing rainfall within those months.The Provinces that are observed to be not significant in either increasing or decreasing trend can be significant at other confidence levels. The graphical and spatial representation of dry seasonal rainfall trend investigations is illustrated in Figures 4, 5 and 6 and is tabulated in Table 1. Figure 4(c, d) illustrates the graphical representations of statistical test Z and the magnitude of change mm/year, Figure 5(b) is the spatial distribution of the magnitude of change, either increasing or decreasing mm/year and Figure 6 (b) is the spatial distribution and representation of zones experiencing significance or non-significance in increasing or decreasing trend.

4.2.3 Seasonal – wet spell rainfall trend

Assessments of rainfall trend between the months May and October (wet season) show that there isa more increasing trend observed than decreasing trend (Table 1) within the study region since 1968. The decreasing rainfall trend was observed from STN 37 – 40, 44 – 52 and 54 – 57 and the increasing rainfall trend was observed from STN 1 – 36 and 41 – 43 (Figure 4 e and Table 1). The decreasing trends are observed in the eastern part of Eastern Highlands, the western part of Southern Highlands and the whole of Morobe province, where the magnitude of decreasing ranges between (-0.1mm/yr) – (- 0.9 mm/yr). There was no significant decreasing trend observed. The increasing rainfall trends are observed almost across whole parts of study region that is to the province of Madang, Jiwaka, Western Highlands, Simbu, Enga, parts of Eastern Highland and parts of Southern Highlands province, where the magnitude of increasing ranges between 0.4 mm/year – 2.1 mm/year.

The significance increasing trend was observed in nearly whole parts of Enga, Jiwaka and WH province, Southern and western parts of Madang province, the southern part of SH province and including small portion in the southern part of the Simbu province. Since it is significantly increasing, extra precautions measure has to be taken especially between the month of May and October every year in case there might be increasing or high rainfall related hazards and or disasters posed. The graphical and spatial representations of wet seasonal rainfall trend investigations are illustrated in Figures 4, 5 and 6 and tabulated in Table 1. Figure 4(e, f) illustrates the graphical representations of statistical test Z and the magnitude of change mm/year, Figure 5(c) is the spatial distribution of the magnitude of change, either increasing or decreasing mm/year and Figure 6(c) is the spatial distribution and representation of zones experiencing significance or non-significance in increasing or decreasing trend.

5. Conclusions and Recommendations.

The present study was to investigate the rainfall trend and or variability in the eight (8) provinces of the country - Papua New Guinea, between the year 1968 and 2018.The investigation and analysis were carried out on both at a spatial and temporal basis. Both parametric and non-parametric statistical calculations were carried out including spatial calculations to investigate spatial distributions of trend and variability. The average preliminary assessment on annual and seasonal basis show higher rainfall distribution in the Eastern part of Morobe, Southern Highlands region and central to the northern part of Madang Province, while low rainfall was observed in Goroka, Western part of Morobe, Simbu, Western Highlands, Jiwaka and Enga province. The rainfall variability within the study region was observed to be at least medium to high. The zones with higher rainfall experience high variability and the zones with lower rainfall experience low variability.

Over the base period the quantile mapping method enhanced three significant aspects of the weather cycle; the transitions from wet to dry and dry to wet spell and peak as well (Aslam et al., 2020). It was observed that more grid stations show increasing trend than the decreasing trend for both annual and seasonal basis investigation. The magnitude of increase varies between 0.5 to 2.9, 0.3 to 1.9 and 0.4 to 2.1 mm/yr for annual, dry seasonal and wet seasonal. The magnitude of decrease varies between (-0.3) to (-2.6), (-0.1) to (-0.9) and (-0.1) to (- 0.9) mm/yr on annual, dry seasonal and wet seasonal. To understand the significant decreasing trend, dry and wet seasonal trend assessment shows no significant decreasing trend, while annual trend assessment shows significant decreasing that is observed in the Enga and SH province. Again to understand a significant increasing trend, both annual and seasonal trend assessment shows significant increasing trend. On annual assessments, the significant increasing trend is observed in the whole parts of Madang, and to the northern part of EH and Simbu Province, on dry seasonal assessment the significant increasing trend was observed to the southern part of Morobe and EH Province and on wet seasonal assessment, the significant increasing trend was observed in the nearly whole part of Enga, Jiwaka and WH province, to the north-western parts of Madang, the southern part of SH and Simbu Province.

There have been some related impacts to rainfall pattern changes and variability within the study region. According to Mckennaet al., (2019), especially towards Madang province, there has been some report of continuous flooding and hence when reflecting to the current results, most parts of Madang province experience significance increasing trend including on annual mean rainfall distribution assessments, Madang province is the province vulnerable for higher rainfall. Furthermore, there has been report on wildfires including severe droughts towards EHP mention or reported by Mckennaet al., (2019), Bourke et al., (1999) and Kelly, (2016), when reflecting to the current research results, there has been decreasing trend observed within EHP region especially during wet and dry spell, and also in annual mean rainfall distribution, the EHP province was observed to have low rainfall pattern or is vulnerable for lower rainfall.

Overall assessments and on overall observation, it is concluded that within the entire study area there has been an increasing trend of rainfall throughout the year since 1968. To verify, the previous study was carried out by Bourke et al., (2000) and Pereira et al., (2019) shows the similar results. Actually they have used other approach of research method to come to that conclusion, however for the current research, the methodology applied for rainfall trend analysis, was not event been utilized in country PNG before. Hence in a spatial context, most of the study zones covered in the current study evince by and large increasing trend. Agricultural pattern is principally reliant on accomplish weather forecast with a longer lead time, mainly at seasonal scale. Essential judgment making entails higher risks in the nonexistence of such forecast systems here in country Papua New Guinea.However, despite their exposure to the climate induced extreme events, the community has not been able to develop their coping capacity. It has also been observer that the primary reason for diminishing resilience culture among communities, lack of public accesses to science based information, degradation of indigenous knowledge on hazard, gendered livelihood transformation and limited adaptive capacity (Das et al., 2020).

The study provides important and useful data and information that can be used as a tool by the governing bodies, NGO or even communities within the study region to plan ahead for the actual implementation of redress measures. The spatio-temporal assessment of rainfall trend has provided some insight into understanding our rainfall pattern and variability over time. The provinces or zones that were observed to have received higher rainfall and the provinces that were observed to have received lower rainfall including the provinces that were observed to have either significant increasing or decreasing rainfall trend between 1968 – 2018are susceptible to rainfall triggered disasters or hazards like flood and/or droughts. Those provinces need proper planning and mitigations measures. The results provided in this research can be incorporated with other results or data and be used as a tool for proper planning and addressing mitigation measures within the study region. This can greatly help prevent rainfall related disasters.

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