Proceedings of 9th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2021 Month: March Volume: 9

Analysis of Spatial and Temporal Rainfall Variation in Pokhara Metropolitan City, Nepal

Sagar Kharel [a], Keshav Basnet [b]

[a, b] *Paschimanchal Campus, Institute of Engineering, Tribhuvan University, Nepal*
Corresponding Email: [a] kharelsagar99@gmail.com, [b] basnet.keshav@gmail.com

Abstract

The statistical characteristics of precipitation play important roles to yield agriculture and enhance different aspect of water resource management. Variation on the value of precipitation at different time domain daily, monthly and annually mostly affects agricultural sector. This project provides a statistical analysis to study the spatial and temporal variability in precipitation in Pokhara metropolitan city, which would help researcher and meteorological department to study the pattern of climatic change so that the agricultural yield of that place could increase, and the damages caused by heavy rainfall and drought can be minimize.

Here, for the hydrological study, daily rainfall data ranging 1999-2019 has been use, provided by Hydrological and Meteorological stations, Pokhara. Similarly, the monthly rainfall data of Pokhara Metropolitan City has been analyze for trends by graphical and statistical methods. Missing data have been calculate using the mean ratio method (for the percentage of missing records less than 10%) and then the quality control is checked. The involved methodology for the analysis of rainfall trends and variability over Pokhara metropolitan City is the time series analysis, single mass curve analysis, coefficient of variation and spatial analysis using ArcGIS 10.5 as well as the surfer-16 program. Some results obtained from the analysis shows that there is not a significant trend in all available stations. Similarly, Seasonal and Annual rainfall variability shows that some of the stations are reliable in rainfall events and some are not which states that larger the coefficient of variability, the lesser the reliability and vice-versa. Furthermore, the lowest and highest mean annual rainfall has also been determined which helps to know the basic information about the drought and moisture conditions of respective stations. Therefore, this study may help for continuously monitoring and forecasting extreme weather events like droughts and high flood scenario. Inverse Distance weighted (IDW) method is done to estimate cell value by averaging the value of sample data points of the neighborhood of each processing cell in which the result generates the new covariance value in an unknown station i.e. location of a point where spatial location is not known.

Keywords

Rainfall trend analysis, Spatial and temporal variability, Rainfall data analysis, Covariance and reliability of rainfall, Pokhara catchment

1. Introduction

A comprehensive hydrological study must be carries out in the rapid response catchments, which respond rapidly to rainfall events. There must be adequate requirements of the research and development in the rainfall events and their effects to enhance climate change study, the suitability of crop production, drainage design, etc. in such catchment [1]. The most basic challenges of spatial and temporal rainfall events are the prediction and quantification of rainfall data within a short interval of time and space. Hydrological studies are important and necessary for water and environmental resources management [2]. Demands from society on the predictive capabilities of such study and analysis of hydrological parameters are becoming higher and higher, leading to the need of enhancing existing research theories and even developing new theories. The Time series method, single mass curve method, coefficient of variation is the simplest method to analyze monthly, seasonal, and annual precipitation patterns from the available rainfall data. It is the most common method used to determine the variation in rainfall events. By the use of this, a histogram can be draw out to know the temporal variation between different stations.

Knowledge of the spatial variation of rainfall among each station that can be drawn out by plotting data into Surfer or GIS as optional [3].

The study area extends from 28.227421N/84.055926E to 28.224543N/83.856684E towards the east to west and 28.329535N/84.019180E to 28.131343N/84.002333E towards north to south. The Pokhara catchment includes an area of 464.94km^2, which consists of 23.01% area of Kaski District and 0.31% area of the Country. The temperature ranges from 7°C minimum to 31°C maximum with an annual rainfall of 3901mm. There are altogether Four Meteorological stations inside Pokhara Metropolitan City and two outside the Pokhara but within the Kaski district as shown in Figure 1.

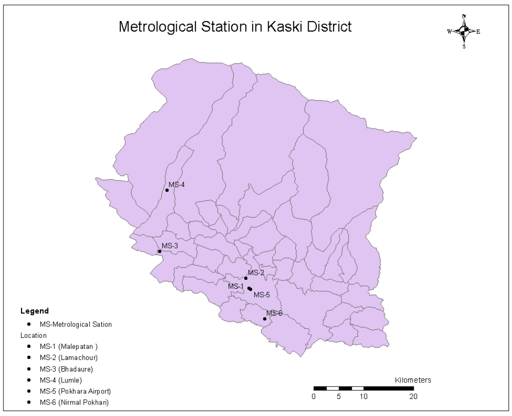

Figure 1: Study Area of Pokhara metropolitan City

Similarly, study area with variation in elevation ranges from 827m. to 1760m as shown in Figure 2. The study area is extend from Aarva Bijaya to Pumdi Bhumdi from east to west and Armala to Nirmal Pokhari towards north to south respectively.

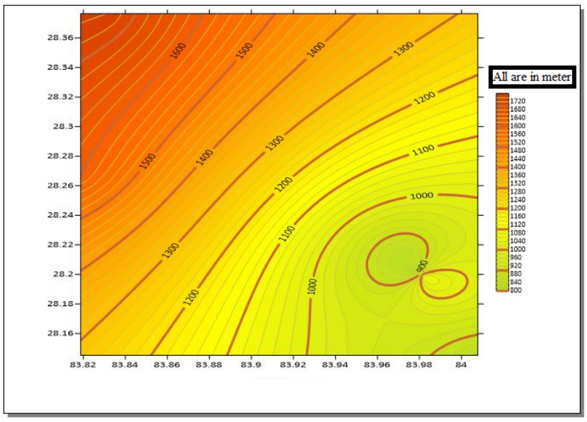

Figure 2: Contour map of the study area

The study and analysis of Spatial and Temporal rainfall data of this Pokhara catchment are thus essential for designing an effective storm water system, to study climate change, to upgrade and change in the production of the crops for variation as time as well as location basis. Unpredictable weather events within a limited territory and even a short interval of time is a known situation in Pokhara Valley Rainfall variability in the amount and its distribution has long-term and short-term effects on natural resources, such as lakes and rivers particularly for those who live around the shore of the region's major lakes, wetland, and river flood plain. In addition, rainfall variation plays a significant role in the yield variation of most major crops in many parts of Pokhara. Besides this, the scientific way of storm management is another challenge in Pokhara valley because of over flooding problem [4]. The main objectives of the study was to analyze rainfall trends and variability over Pokhara Metropolitan City using GIS software. In addition to that, the temporal pattern of rainfall over Pokhara Metropolitan City was also identify by statistical and graphical approach by using GIS and Surfer software. Monthly and annual variability and spatial variability of rainfall over the Pokhara was also determine. Parameters like; rise in temperature, climatic disordered, etc. that may also play a significant role in rainfall variation was not consider. This is a limitation in forecasting extreme weather condition.

2. Data and Methodology

2.1 Selection of stations and Rainfall Data interpolation

The rainfall data used in this work are daily rainfall totals that are representative of various climatic rainfall zones over Pokhara. Rainfall data cover the period of 21 years i.e. from 1999 to 2019 for six meteorological stations. The daily rainfall data were obtain from the Department of Hydrology and Meteorology located at Pokhara. The list of rainfall stations has shown in Figure 1 and Table 1.

During analysis, missing and unsteady data can be calculated using either the arithmetic mean method, correlation method, Isohyetal linear interpolation, or mean ratio method over Pokhara Metropolitan city as recommended by WMO (1996). There are altogether four meteorological stations in which data about twenty years are available around Pokhara

Metropolitan City and two outside the Pokhara metropolitan City but within Kaski District, which was consider and analyzed. The spatial arrangement was made by naming Six stations as MS1 (Malepatan station), MS2 (Pokhara Airport), MS3 (Lamachaur), MS4 (Bhadaure Deurali), MS5 (Malepatan), and MS6 (Nirmal Pokhari) i.e. spatial coordinate of all Five stations are shown in Table 1. To find out the homogeneity in rainfall data, total cumulative rainfall against the time has plotted and called as single mass curve [5]. Trend analysis is then be calculated using a graphical method i.e. plotting of seasonal rainfall (i.e. Summer from June-August) against time for unimodal rainfall regime and plotting of non-seasonal (i.e. Winter from December- February) for bimodal rainfall regime. During the analysis, data have divided into two subgroups i.e. 1999-2009 into one group and 2010-2019 into another group to know the difference in mean.

Table 1: Meteorological Station Details (Source: WRCO, Kaski)

Name of Staion	Latitude (N)	Longitude (E)	Elevation (m)
Pokhara Airport	28.200°	83.979°	827°
Malepatan	28.218°	83.974°	856
Bhadaure Deurali	28.266°	83.818°	1600
Lumle	28.376°	83.831°	1740
Lamachaur	28.198°	83.981°	1070
Nirmal Pokhari	28.145°	84.007°	854

Similarly, data reliability and coefficient of variability of different stations were examine by calculating the coefficient of variability and reliability as mentioned in the above methods. In addition to these; the monthly average, seasonal average, and annual average are then plotted using Surfer and ArcGIS. Therefore, the temporal rainfall event was calculate using the graphical method i.e. by plotting histogram against time and it gave the information about unimodal and bimodal rainfall regimes. Similarly, spatial rainfall analysis was obtain by using the spatial plot to the coefficient of variability and was drew by using Surfer and ArcGIS in which monthly, seasonal wise and annual rainfall regime has known.

2.2 Methodology

Different methods were conducted which are listed below;

2.2.1 Data quality control

Consist of tests designed to ensure Hydrological and meteorological data meet certain standards or not; it involves looking for errors in the carried data sets. Data quality control involves the estimation of missing data and their homogeneity test.

2.2.2 Missing data calculation

Many methods are available for the estimation of missing data as recommended by WMO (1996), such as arithmetic mean methods, correlation methods, Isohyetal linear interpolation and mean ratio method [6]. In our study missing rainfall records were encountered in the observed rainfall data from Three different stations they are; Pokhara Airport, Lumle, and Bhadaure Deurali. The percentage of missed records were found to be 2.28% (less than 10%) therefore mean ratio method was carried out for the estimation of missing records. To find the missing precipitation P_x of station X the following formula was used to calculate missing gaps.

$$P_x = \frac{N_x}{M}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + ... + \frac{P_M}{N_M}\right] \tag{1}$$

Therefore, by using this formula yearly missing rainfall data of three different stations has obtained. These are 2005th-year data of Lamachaur and Malepatan and 2011$^{\text{th}}$ year of Nirmal Pokhari station. In addition, monthly missing data (i.e. 6th Month of 2011) of Lamachaur station was determined using linear interpolation techniques is given by Equation 2.

$$Y - Y_1 = \frac{Y_2 - Y_1}{X_2 - X_1}(X - X_1) \tag{2}$$

2.2.3 Homogeneity test

A single mass curve was use to analysis, which involves plotting of total cumulative rainfall of each station vs. time.

2.2.4 Temporal Distribution of Rainfall

Inside our study, plotting of mean monthly rainfall vs. Month of each station has done i.e. drawing of Histogram shows Unimodal and Bimodal rainfall regime over Pokhara metropolitan City.

2.2.5 Trend Analysis

A graphical plot of rainfall data series and statistical methods was use to analyzed seasonal as well as annual rainfall patterns by determining slope, intercept, and coefficient of variability and reliability. It involves both time and space variability. Coefficient variability for different stations has plotted for spatial analysis.

2.2.6 IDW interpolation Techniques

Inverse Distance Weighted (IDW) is a method of interpolation that estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The closer a point is to the centered of the cell being estimate, the more influence, or weight; it has in the averaging process. With IDW, we can control the significance of known points on the interpolated values based on their distance from the output point as shown in Table 2.

Table 2: Spatial arragement with covariance value

SN	Stations	Location	Easting	Northing	Cv	Distance (m)
1	MS-1	Pokhara Airport	83.979°	28.200°	15.5102	2329.31
2	MS-2	Malepatan	83.974°	28.218°	12.2467	2181.48
3	MS-3	Bhadaure Deurali	83.818°	28.266°	13.6768	17956.66
4	MS-4	Lumle	83.831°	28.376°	10.5217	16481.03
5	MS-5	Lamachaur	83.981°	28.198°	13.0759	2369.06
6	MS-6	Nirmal Pokhari	84.007°	28.145°	22.5687	4368.06

To find the cell value at unknown point (say P) by utilizing known points following formula is use in ArcGIS 10.5

$$C_v at any point p = \frac{\frac{(cv)_1}{d_1} + \frac{(cv)_2}{d_2} + ... + \frac{(cv)_6}{d_6}}{\frac{1}{d_1} + \frac{1}{d_2} + ... + \frac{1}{d_6}} \quad (3)$$

Where $(Cv)_1$ to $(Cv)_6$ is the coefficient of variance of respective stations and d_1 to d_6 is the Distance of respective stations.

3. Results and Discussion

3.1 Results from data quality control

The main objective of data quality control is to detect and remove errors in the data sets [7]. Furthermore, data quality control also involves the estimation of missing gaps and homogeneity tests. Therefore, less the error in data, more would be quality i.e. limited missing around different stations ensure higher quality.

3.2 Missing data

It was found that missing rainfall data from the set of records was due to either Natural or Human cause. Natural cause was due to flood and the temporary absence of people nearby gauge stations was the Human Cause. The percentage of missed records were found to be 2.28%, given that the study requires continuous data therefore mean ratio method was used for the estimation of missing records.

3.2.1 Test for Data Homogeneity

The single mass curve is use to test for the homogeneity of the data i.e. plot of annual cumulative rainfall against time. The mass curves for most of the stations are almost straight lines indicating that data from most stations are homogeneous. Sample Figure for Pokhara Airport showing homogeneity is indicated in Figure 3. These figures show straight lines which indicated data is of good quality.

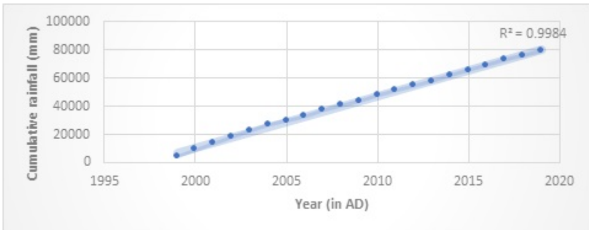

Figure 3: Single mass curve for Pokhara Airport from 1999-2019

3.3 Result from temporal distribution mean monthly rainfall

The temporal distribution of rainfall over the studied region is investigate. The rainfall regime over the most parts of Pokhara was almost all unimodal regime having peak rainfall in July and August. Results shows Lumle has more than 32500mm amount of precipitation value and Pokhara Airport has the least i.e. nearly 18500mm.

3.4 Results from trend analysis

In this study, the trend analysis is determined through graphical plot of the rainfall data series and statistical methods.

3.4.1 Graphical Method

Increasing trends (positive) and decreasing trends (negative) of mean seasonal is checked. It is found that except for the winter season of Lumle and the winter season of Malepatan, all other stations during the winter and summer season have shown almost negative trends which indicates that the particular region is facing atmospheric evaporation followed by water downpour over the period. The phenomena occurs when temperatures are usually high and precipitation is not usually low for the season. Therefore, suitable measures should be adopt to maintain regular precipitation in those areas. Sample for the negative trend for the Summer season of Pokhara airport and positive trend for Winter season of the Lumle is indicated in given Figure 4 and Figure 5 respectively.

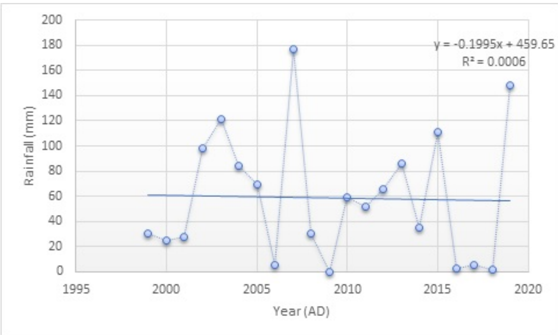

Figure 4: Winter Rainfall for Pokhara Airport from 1999-2019

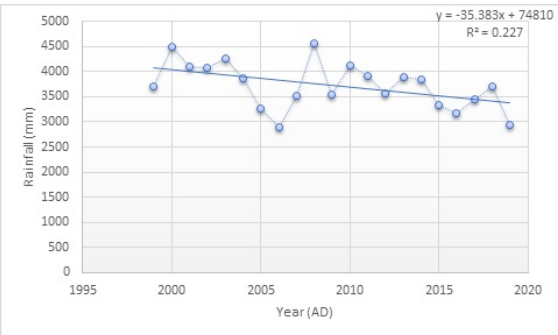

Figure 5: Summer Rainfall for Lumle from 1999-2019

3.4.2 Results from statistical analysis of trend

The significance of the trends used to test by Statistical method [8]. Results from statistical methods suggest that there are trends i.e. Means are different as shown in Table 3. This confirms that the population from which two means computed is not the same and thus rainfall has changed. Similarly, results from the statistical method depicts that there are trends in all Rainfall stations, however, at 95% confidence, there are sufficient statistical evidence to conclude that trends in all rainfall stations are not significant except Pokhara Airport station during Winter and Summer. It is checked at the P-value 0.05, the level difference between the two conditions are either significant or not as shown in Table 3.

Table 3: Results of seasonal rainfall t-test statistic at a 95% confidence interval

Stations	Seasons	Difference in mean	Slopes	Trends	P-value	Significance of trends
Pokhara Airport	Winter	4	-0.199	-ve	0.05	Significance
	Summer	323.774	-50.5	-ve	0.05	Significance
Malepatan	Winter	9.92	0.104	+ve	0.11	Not significance
	Summer	102.428	-27.179	-ve	0.11	Not significance
Bhadaure Deurali	Winter	13.017	-1.411	-ve	0.14	Not significance
	Summer	64.278	-20.515	-ve	0.15	Not significance
Lumle	Winter	655.06	0.796	+ve	0.18	Not significance
	Summer	249.274	-35.383	-ve	0.39	Not significance
Lamachaur	Winter	6.765	-0.014	-ve	0.26	Not significance
	Summer	143.279	-7.894	-ve	0.13	Not significance
Nirmal Pokhari	Winter	-	-7.195	-ve	-	NA
	Summer	-	-78.715	-ve	-	NA

3.5 Results from analysis of variability

In this study results of seasonal as well as annual variability and reliability is calculated and compared [9]. Results from the seasonal coefficient of variation found that the largest value of variability is observe during the winter season at Lamachaur. This implies that there is little rainfall in these regions during the winter season; also, high variability confirms that rainfall is less reliable. Furthermore, the lowest variability found in the summer season at Lumle this implies that the summer season rainfall of Lumle is more reliable in most parts of the Kaski. Also, the analysis of Annual Variability indicates that the highest value of variability is in Pokhara Airport i.e. 15.51%, while the lowest is at Nirmal Pokhari i.e. 2.56% which means that Pokhara Airport rainfall are less reliable and Nirmal Pokhari rainfall event is more reliable. All the outcomes of results as shown in the Table 2.

3.6 Results from spatial analysis

In this study, we determine the mean annual rainfall of 21 years indicating that the Lumle region has the highest rainfall and Nirmal Pokhari the least. For the case of Lumle, this is possibly due to the availability of moisture content around those locations [10]. Similarly, the Nirmal Pokhari region has the lowest rainfall event. This may be due to less contribution of rainfall to their catchment so that drought conditions can arise in near future, which is represent in Figure 7. Similarly influencing area was analyze in Figure 8 which indicates MS-1, MS-2 and MS-5 stations depicts the higher rainfall influencing area. Similarly, MS-6 station shows lesser impact in nearby region followed by MS-4 station. Special care should be taken to those areas where there is maximum precipitation value in order facilitate the storm design criteria. Likewise, for the lower impacting areas of rainfall value special care should be considered mainly in rainy season to incorporate accidental scenario i.e. higher flood level. Results from the spatial plot of annual reliability shows that the lowest year-to-year rainfall reliability occurs in the southeast part of Kaski i.e. at Nirmal Pokhari followed by Pokhara Airport. Similarly, the lowest and highest reliability value occurs in Nirmal Pokhari and Lumle respectively, which shows rainfall, is more reliable which depicted the highest reliable value i.e. in Lumle region and lowest in Nirmal Pokhari region as shown in Figure 6.

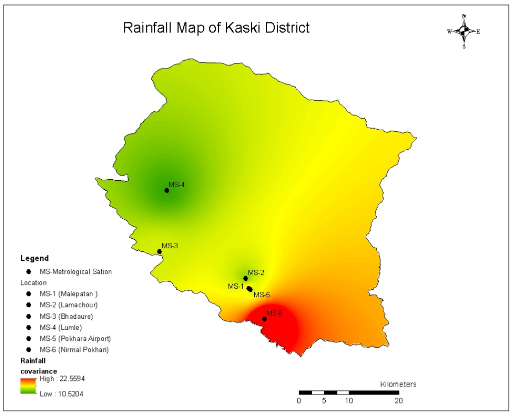

Figure 6: The spatial pattern of the coefficient of variation (%) for the annual rainfall

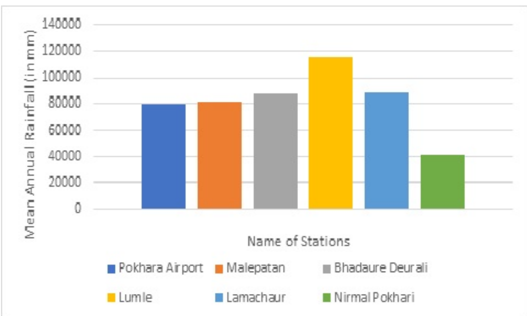

Figure 7: The spatial distribution of mean annual rainfall from 1999-2019

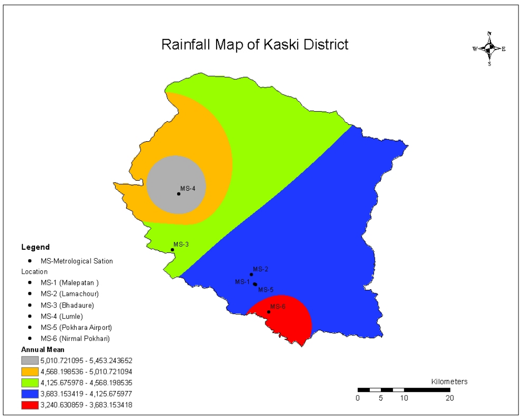

Figure 8: Station with their Area of influencing from 1999-2019

3.7 Results from the IDW interpolation Techniques

After the IDW interpolation, the unknown position of any point where there is not the availability of rainfall stations can be compute so that it helps to calculate the rainfall trend in those areas. After the interpolation, point near Sardi Khola was computed which lies nearly 13.78 Km east to Lumle, 12.91 Km from Lamachaur, and 19.57 Km from Pokhara Airport where the stations are available as shown in Figure 9. After knowing the position or location of that point covariance value is calculated i.e. 14.711% by using equation 3. Hence, value is somewhat similar to Bhadaure Deurali stations so it can cover the precipitation pattern similar to Bhadaure Deurali, which as shown in Figure 10 and 11.

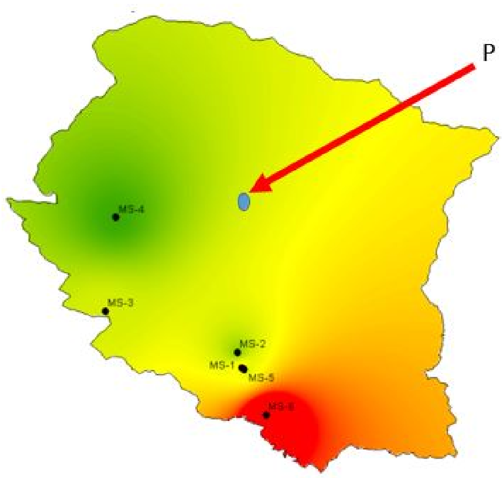

Figure 9: Location of unknown point (say P)

3.8 Monthly Precipitation of heavy precipitation and lowest precipitation areas

Inside this, we studied the last 10 years' monthly rainfall analysis from 2010-2019 of two stations namely; Pokhara Airport where there is large variability i.e., lower reliability value.

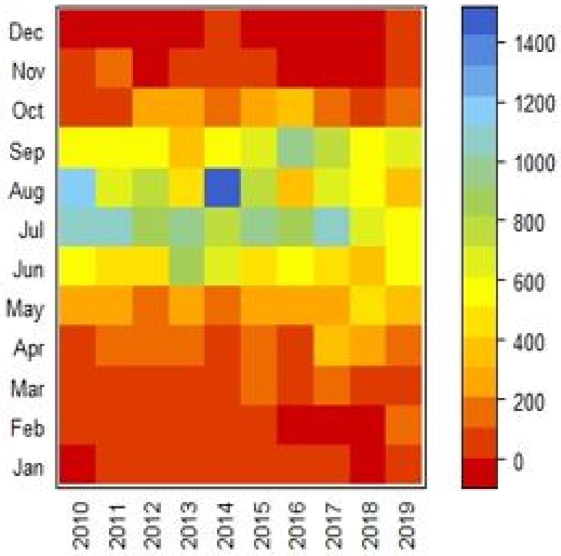

Figure 10: Monthly rainfall of PA

Similarly, a station with the highest rainfall reliability value on Lumle station was analyzed and the result are mention in Figure 12 and 13 respectively.

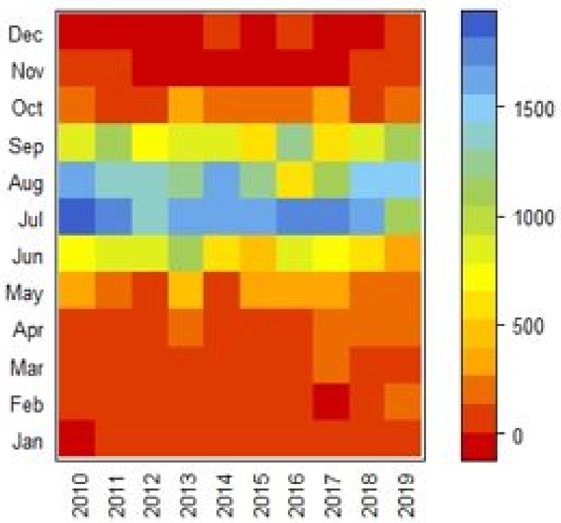

Figure 11: Monthly rainfall of Lumle

Results of both the stations although Lumle has higher reliability indicates that there is a considerable amount of precipitation i.e. ranges from 1000-1500 mm in the Summer season which reveals that there is not the countable decrease as compared to another season. However, there is a considerable decrease in the rainfall amount to all other seasons except rainy season i.e., especially on winter. If the pattern goes like this over the next decade, surely it leads to a considerable decrease in rainfall amount. Therefore, special attention should be provide to those areas where there is a continuous decrease for rainfall.

Similarly, daily time series analyses, Box plots, and histograms of these two stations over the last decades (2010-2019) is analyzed and results are displayed as shown in Figure 14 and 15 respectively.

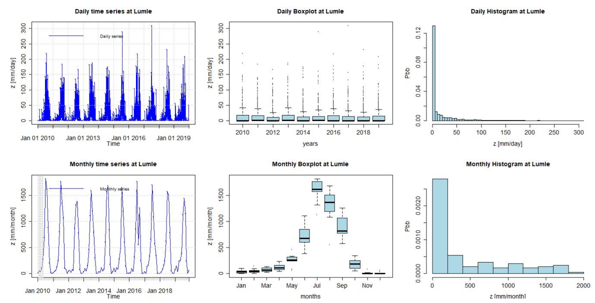

Figure 12: Hydrograph analysis of Pokhara Airport from 2010-2019

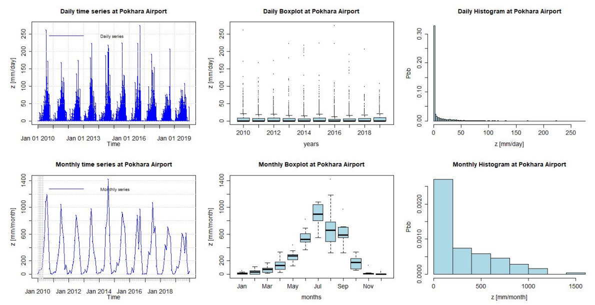

Figure 13: Hydrograph analysis of Lumle from 2010-2019

Figure 12 and 13 reveals the time wise changing pattern of rainfall over the last decades. The red color inside the box indicates a lower rainfall pattern i.e., more likely in December. Likewise, the blue color inside the box indicates a higher monthly precipitation amount that encounters more around July to September. Hydrograph showing daily box plot at Pokhara Airport is represented in Figure 12 shows the distribution of daily precipitation for the years 2010 to 2019. We can see the skewness and the outliers in the data set. We can see the unusual number of observations for the year 2015 and 2017, which is because of the maximum, precipitation occurred in these particular years. However, the average precipitation per day around the years is somewhere around 20 mm/day.

Similarly, the Monthly boxplot at Lumle in Figure 13 here shows the distribution of monthly precipitation for the years 2010 to 2019. From the figure, we can see the maximum precipitation in the month of July followed by August, September, and June whereas minimum in November, and December. July averages around precipitation above 1500 mm/day whereas August averages around precipitation of 1300 mm/day. Compared to the average daily boxplot, we can see very few unusual occurrences of precipitation for the monthly average boxplot.

4. Conclusion

The spatial and temporal variation on precipitation around Pokhara valley is such a major problem for people residing on these areas as it has a direct impact over agriculture and storm water management during rainy season [8]. Here, we have analyzed the rainfall data of different time-domain at different stations using mean-ratio method, graphical and statistical approach, IDW techniques, Box Plot method, significant t-test etc. to obtain the temporal and spatial variability of rainfall of Kaski district. The temporal characteristic shows that peak month of rainfall is July and August for all the regions considering monthly average ratio and the maximum value is at Lumle i.e. 32906.1mm on July. Similarly, trend analysis shows that there are increasing (+ve) as well as decreasing (-ve) trends for the different stations. Furthermore, results from variability and reliability data shows that that Pokhara Airport has the highest variability (15.51%) and Nirmal Pokhari has the least variability (2.56%) in which in turn implies that the rainfall at Nirmal Pokhari is more reliable than other areas. This may be due to the rain shadow effect of this region. Furthermore, results from spatial analysis indicates that rainfall is much higher in the regions close to water bodies or higher catchment areas i.e., in Lumle where the mean annual rainfall till date from 1999-2019 is the highest among other which is 114521.5*mm*. This is possible due to the station's closeness to water bodies, which contributes to a lot of moisture around this region. In addition, rain formation events depend on the sources of moisture.

5. Recommendation

This study depicts the seasonal as well as annual rainfall pattern over the study region. Except for Malepatan and Lumle, all other stations have shown almost negative trends which means there is a reduction in precipitation by high inter-annual variability that could disrupt various water-dependent activities such as agriculture, hydroelectric power generation among others. Therefore, we need further investigation or research activities by considering daily, monthly and annual data for a longer period, which have used in this study especially for those regions that show significant trends. Results from the analysis of variability focuses that Pokhara Airport has the largest variability value, which indicates it has less reliable rainfall event. In other words, there is little rainfall over the passes of time that may be either due to climatic change action or due to another imbalance in the ecosystem. Therefore, this study can be an alarming tool for farmers, agriculture planners as well as the climatological department of the country.

References

[1] Ramjee Prasad Pokharel and Narendra Raj Khanal. Open space: Typology and distribution in Pokhara Lekhnath Metropolitan city. *Geographical Journal of Nepal*, 11:25–44, 2018.

[2] Tarek Merabtene, Mohsin Siddique, and Abdallah Shanableh. Assessment of Seasonal and annual rainfall trends and variability in sharjah city, uae. *Advances in Meteorology*, 2016, 2016.

[3] Yujie Lu, Shanhu Jiang, Liliang Ren, Linqi Zhang, Menghao Wang, Ruolan Liu, and Linyong Wei. Spatial and temporal variability in precipitation concentration over mainland china, 1961–2017. *Water*, 11(5):881, 2019.

[4] Keshav Basnet, Anup Shrestha, Prakash Chandra Joshi, and Nisha Pokharel. Analysis of climate change trend in the lower Kaski district of Nepal. *Himalayan Journal of Applied Science and Engineering*, 1(1):11–22, 2020.

[5] Mahmut Firat, Fatih Dikbas, A Cem Koç, and Mahmud Gungor. Missing data analysis and homogeneity test for Turkish precipitation series. *Sadhana*, 35(6):707, 2010.

[6] G Arvind, P Ashok Kumar, S Girish Karthi, and CR Suribabu. Statistical analysis of 30 years rainfall data: a case study. In *IOP Conference Series: Earth and Environmental Science*, volume 80, page 012067. IOP Publishing, 2017.

[7] Peng Kang, Weiping Chen, Ying Hou, and Yuanzheng Li. Spatial-temporal risk assessment of urbanization

impacts on ecosystem services based on pressure-status-response framework. *Scientific reports*, 9(1):1–11, 2019.

[8] I Ibrahim, MT Usman, A Abdulkadir, and MA Emigilati. Analysis of rainfall distribution, temporal trends, and rates of change in the savannah zones of nigeria. *Atmosphere-Ocean*, 58(5):351–360, 2020.

[9] Jeeban Panthi, Piyush Dahal, Madan Lall Shrestha, Suman Aryal, Nir Y Krakauer, Soni M Pradhanang, Tarendra Lakhankar, Ajay K Jha, Mohan Sharma, and Ramchandra Karki. Spatial and temporal variability of rainfall in the gandaki river basin of Nepal himalaya. *Climate*, 3(1):210–226, 2015.

[10] Rocky Talchabhadel, Ramchandra Karki, Bhesh Raj Thapa, Manisha Maharjan, and Binod Parajuli. Spatio-temporal variability of extreme precipitation in Nepal. *International Journal of Climatology*, 38(11):4296–4313, 2018.