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Original Research Article

Analysis of Spatial and Temporal Rainfall Variation in Gandaki Province, Nepal

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Abstract

Daily, seasonable and annual variation on precipitation should be carried out properly to enhance the better relaxation caused by damaging drain structure, hydraulic parameters and even climatic disorder. In order to incorporate all these needs and to enhance the existing research theories and even on developing new theories, this study will surely provide basic framework. The problems for the researcher as well as meteorological department for the further study of climatic change action and to provide basic knowledge to the farmer and agricultural department to yield seasonal wise crops without consideration of hydrological analysis (i.e. precipitation data) associates problems like flood risk and drought causing loss of lives and property. For the hydrological study, daily and monthly rainfall data was obtained from meteorological station from the year 1991-2020. The monthly and daily precipitation concentration were determined using Time series analysis, single mass curve analysis, coefficient of variation and spatial analysis and were represented using Histogram chart, Spreadsheet and GIS tool. With this, daily, monthly, seasonal wise variation on precipitation with respect to location wise (Spatial) as well as Time wise (Temporal) was obtained. The temporal characteristic shows that peak month of rainfall were July and August for all the regions. Considering Total Annual, the maximum value is at Beni Bazar i.e. more than 200000mm and least in the Ranipauwa i.e less than 10000mm. The mean annual rainfall of 30 years indicating that the Beni Bazar, Myagdi region has the highest rainfall and Ranipauwa, Mustang the least. Similarly, trend analysis shows that there are increasing (+ve), decreasing (-ve) and somewhat constant trends for the different stations. Furthermore, results from variability and reliability data shows that that Ranipauwa has the highest annual variability (138.86%) and Lumle has the least annual variability (15%) in which in turn implies that the rainfall at Lumle is more reliable than other areas. The computed Spatial and Temporal variation on rainfall has been developed as a basic tool for further research. It will also help farmers to know seasonal wise crops production as well as analysis of storm water for the construction of drainage system. These findings can be considered for monitoring extreme weather events like; erosion and floods. This would therefore contribute significantly to the effective management and sustainable development of the Gandaki Province and region having similar topographical features, which are rain dependent.

Keywords: Rainfall trend analysis, spatial and temporal variability, covariance and reliability of rainfall, Gandaki catchment, rainfall erosivity.

INTRODUCTION

Our country has been facing the problem of dependency on agriculture and scientific agricultural system for many years due to which every year we have to import millions of tons of agricultural products. Not only this, with the advent of climate change due to prevalence of the water over the time and the space, it leads to flood, drought, and rise in temperature. In addition to this, the catchment that responds rapidly to rainfall, leads to overflow problems, property and loss of lives as well. Therefore, the simultaneous change of water and the intensity of water in the vicinity should be the subject of present study so that the effects arouse on tomorrow could be easily minimized and the suitable plan can be prepared according to the place. Hence, a comprehensive hydrological study must be carried out in the rapid response catchments, which responds rapidly to rainfall events (Monjo, R. & Martin-Vide J., 2016). Also, adequate research and development are required to enhance climate change, suitability of crops production, drainage design etc. in such catchment.

The challenges of spatial and temporal rainfall events are the prediction and quantification of rainfall data within short interval of time and space. Hydrological studies are important and necessary for the management of water and environmental resources. Society’s demand for predictive ability to study and analyze such hydrological parameter is increasing, and as a result, existing research theories need to be improved and even new theories need to be developed.

The methods used to analyze monthly, seasonal and annual precipitation pattern from the available rainfall data are time series, single mass curve and coefficient of variation methods (Merabtene T. *et al*., 2016). It is the most common method used to determine the variation in rainfall event. By the use of this, histogram can be draw out to know temporal variation between station to station and knowledge of spatial variation of rainfall among each station can be drawn out by plotting data into Surfer or GIS as optional (Gungor M., 2010).

Surfer is a good example of freely available tools used worldwide which can calculate and analyze the rainfall characteristics of an area within a distinguished period of time and the response to risk associated with engineering designs. It is an indicating tool and helps to show the probable future scenario of urban flood, drought condition, soil moisture study and management for the study area (Zuliziana Suif, M. A., 2018). The seasonal wise consideration was done by dividing the 3 months in each season; i.e. winter (December-February), spring (March-May), summer (June-August) and autumn (September-November). Annual Standard coefficient of variation and reliability were determined using the interpolation techniques from the nearest neighboring 3 stations to know the actual concentration of respective stations. (Lu Y. *et al*., 2019). Both Unimodal and Bimodal rainfall regime patterns of rainfall were checked for the seasonal and monthly basis of rainfall event (Rocky T. *et al*., 2018). and district-wise monthly analysis of rainfall occurrence patterns was done to know the consistency of rainfall over the passes of time at the particular location. (Francesco A. *et al*., 2019). Effect of rainfall value in form of energy formation, which may cause the soil erosivity problem at a particular location is another indicator that leads to soil erosion (Naimah Yusoff, R. Z., 2013). So, mitigation measures should be well carried out in order to overcome such a problem.

The catchment area of Gandaki province is 21,773 km^2, which is about 14.66% of the total area of Nepal. The state extends between latitude 27°-20' N ~ 29°-20' N and longitude 82° 52' E ~ 85°-12' E. In terms of terrain, it spans the Himalayan, Hilly and Terai region of Nepal. The area of 5,919 km^2 (26.8%) corresponds to the Himalayan Region, 14,604 km^2 (67.2%) corresponds to the Hilly region and 1,310 km^2 (6%) corresponds to the Terai region. There are altogether thirty meteorological stations with available data in Gandaki Province in which our study will be more concerned. Study area is extended from Borlang, Gorkha to Gurja Khani, Myagdi from east to west and Fu, Manag to Pakwadi, Syangja towards north to south respectively. The Gandaki province's catchment that is under study is shown in Figure 1.

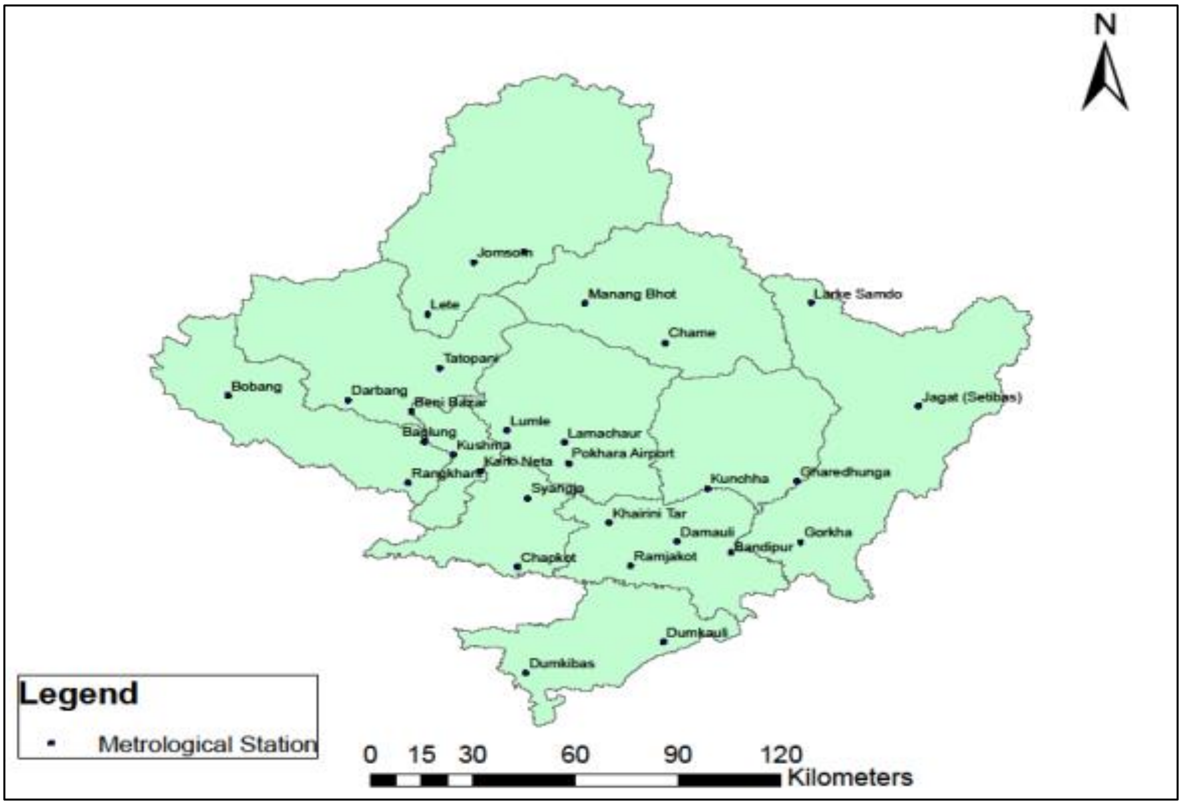


Fig-1: Study Area of Gandaki Province (station wise) Catchment

The study and analysis of Spatial and Temporal rainfall data of this Gandaki Province's catchment is thus essential for designing effective drainage management system. This study will further help in climate change study, to upgrade and change in the crops production with respect to variation in time as well on the basis of location.

In addition, rainfall variation plays a significant role in the yield variation of most major crops in many parts of Urban as well as rural areas. Although the other factors may also play a role in reduction of crops yield like; soil type, use of chemical and organic fertilizer, temperature, lack of agriculture input, proper supervision practice, etc. Beside this, scientific way of storm management is also another challenge in rainfall dependent areas like; Pokhara valley because every year flooding and urban overflow hits the region very severely. Furthermore, these aspects need to be considered for the proper planning of the city in terms of scientific water management system. The main objective of the study was to analyze rainfall trends and variability over Gandaki Province. The following specific objectives were conducted to achieve the main objective: Analyze the temporal pattern of rainfall over Gandaki Province, determine the monthly Seasonal wise and annual variability of rainfall over Gandaki Province and determine the spatial variability of rainfall over the Gandaki Province. Furthermore, the rainfall trend is an important area of interest for both hydrology and climatology to investigate climate change scenarios and enhance climate impact research. Therefore, this work is crucial for planning and designing Pokhara's climate change adaptation, water resource management, flood prediction, agriculture practice, hydroelectric power generation among others. Although it has lots of scopes but there are some limitations too; the study will not consider the factor causing rainfall variation such as a rise in temperature and climatic disorder though they play a significant role in rainfall variation. Similarly some of the meteorological stations are close to each other. Therefore, we cannot work elsewhere other than specified places for spatial variation.

DATA AND METHODOLOGY

Data

Rainfall Data

The rainfall data used in this work are daily rainfall totals that are representative of various climatic rainfall zones over Gandaki Province. Rainfall data cover the period of 30 years i.e. from 1991 to 2020 for thirty meteorological stations. The Monthly rainfall data were obtained from the Department of Hydrology and Meteorology located at Babarmahal, Kathmandu. The list of rainfall stations has shown in Table 1.

During analysis, missing and unsteady data can be calculate using either the arithmetic mean method, correlation method, Isohyetal linear interpolation, or mean ratio method over Gandaki Province as recommended by WMO (1996).

There are altogether thirty meteorological stations in which data about thirty years are available around Gandaki Province and some other stations hasn't cover sufficient data for the analysis. The spatial arrangement was made by naming thirty stations as by their name i.e. spatial coordinate of all thirty 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. 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. 1991-2005 into one group and 2006-2020 into another group.

Similarly, data reliability and coefficient of variability of different stations were examined 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 calculated 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.

Table-1: Meteorological Station Details (Source: WRCO, Kathmandu)

SN	Name of stations	District	Easting	Northing	Elevation
1	Baglung	Baglung	83.6003	28.2636	964
2	Bobang	Baglung	83.0845	28.3974	1722
3	Rangkhani	Baglung	83.5582	28.1441	1728
4	Chame	Manang	84.2333	28.5500	2680
5	Manang Bhot	Manang	84.0226	28.6663	3556
6	Bandipur	Tanahun	84.4064	27.9418	991
7	Damauli	Tanahun	84.2651	27.9737	347
8	Khairini Tar	Tanahun	84.0866	28.0270	515
9	Ramjakot	Tanahun	84.1428	27.9024	660
10	Beni Bazar	Myagdi	83.5667	28.3508	835
11	Darbang	Myagdi	83.4000	28.3833	1160
12	Tatopani	Myagdi	83.6404	28.4775	1161
13	Chapkot	Syangja	83.8459	27.8999	617
14	Syangja	Syangia	83.8725	28.0987	871
15	Walling	Syangja	83.7553	27.9773	756
16	Dumkauli	Nawalparasi	84.2285	27.6807	183
17	Dumkibas	Nawalparasi	83.8677	27.5910	167
18	Gharedhunga	Lamjung	84.5800	28.1475	1088
19	Kunchha	Lamiung	84.3449	28.1268	820
20	Gorkha	Gorkha	84.5894	27.9714	724
21	Jagat (Setibas)	Gorkha	84.9000	28.3667	1334
22	Larke Samdo	Gorkha	84.6167	28.6667	3650
23	Jomsom	Mustang	83.7298	28.7840	2741
24	Lete	Mustang	83.6092	28.6327	2490
25	Ranipauwa (M.Nath)	Mustang	83.8622	28.8156	3671
26	Karki Neta	Parbat	83.7482	28.1773	1642
27	Kushma	Parbat	83.6769	28.2249	900
28	Lamachaur	Kaski	83.9687	28.2617	992
29	Lumle	Kaski	83.8179	28.2965	1738
30	Pokhara Airport	Kaski	83.9795	28.2002	827

METHODOLOGY

Different methods were conducted which are listed below;

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.

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. In our study missing rainfall records were encountered in the observed rainfall data from different available stations. The percentage of missed records were found to be 4.89% (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.

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

Therefore, by using this formula yearly missing rainfall data of three different stations has obtained. These are 2012th-year data of Ranipauwa (M. Nath), Mustang and Chame, Manang and 2019th year of Darbang, Myagdi and Damauli, Tanahun and 2009th year of Chapkot, syangja. In addition, monthly missing data (i.e. 11th Month of 2017) of Jagat setibas, Gorkha, 8th month of Dumkauli, Nawalpari(east) and 6th month of Lamachaur, Pokhara station was determined using linear interpolation techniques. The equation is mention below:

$$Y - Y1 = \frac{Y2 - Y1}{X2 - X1}(X - X1) \qquad \text{Equation 2}$$

Homogeneity test

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

Selection of stations

Rainfall stations were selected as per the WMO guidelines. WMO categorized the station selection criteria based on terrain classification and the type of rain gauze i.e. recording or non-recording type.

Table-2: Minimum densities of precipitation station (Source: WMO manual)

Physiographic Unit	Minimum density per unit (Area in Km^2 per station)	
	Non-recording	Recording
Coastal	900	9000
Mountainous	250	2500
Inter plains	575	5750
Hilly/Undulating	575	5750
Small Island	25	250
Urban Areas	10-20	10-20
Polar/arid	10000	100000

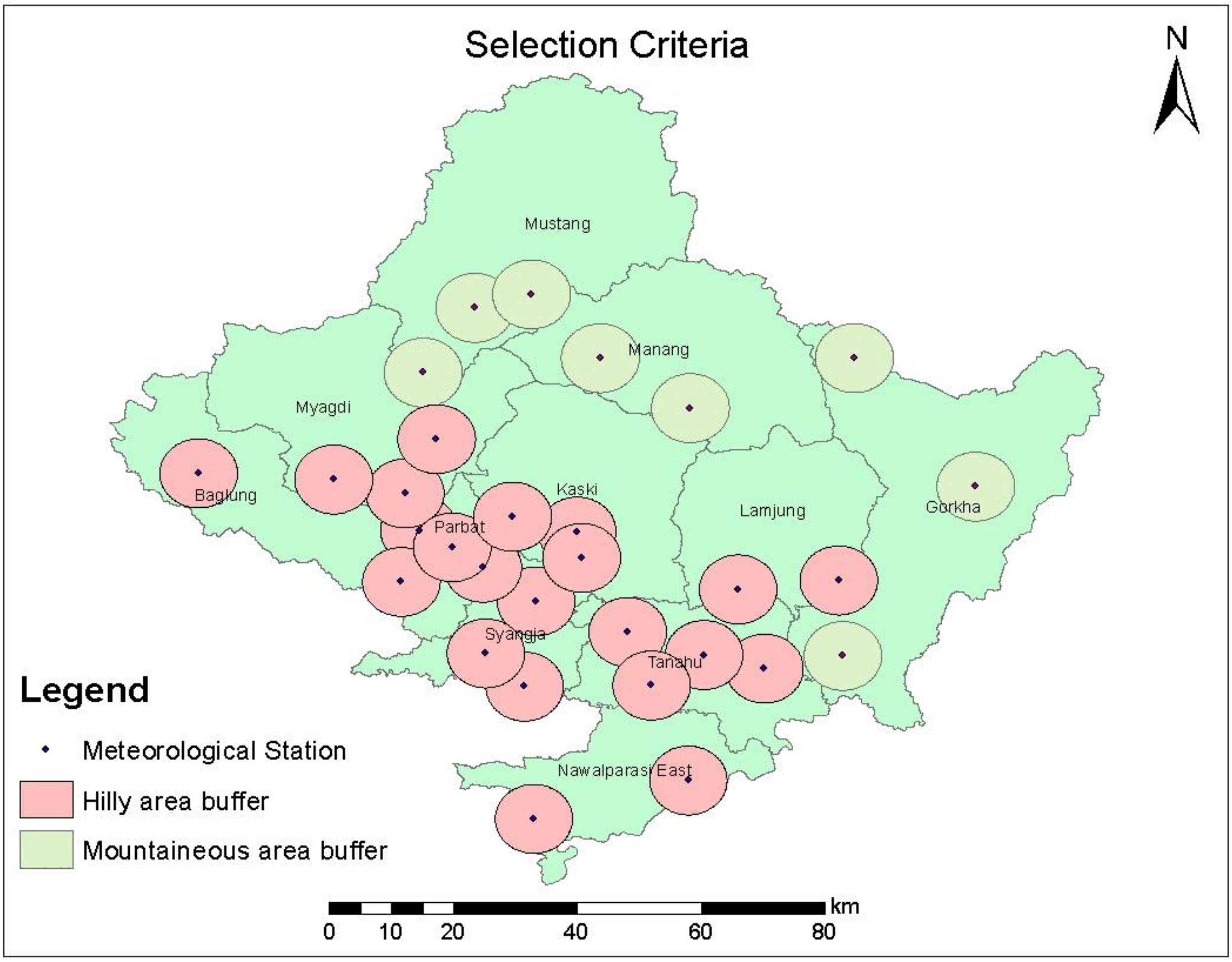


Fig-2: Buffering Method of rainfall station selection

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 Gandaki Province.

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.

Table-3: Spatial arrangement with covariance value

SN	Station Name	District	Autumn Cv	Summer Cv	Spring Cv	Winter Cv	Annual Cv
1	Baglung	Baglung	0.1891	0.0802	0.2340	0.0335	0.219626
2	Bobang	Baglung	0.1903	0.0678	0.2117	0.0491	0.231123
3	Rangkhani	Baglung	0.2217	0.1195	0.1323	0.0420	0.330441
4	Chame	Manang	0.2216	0.2054	0.1932	0.0376	0.476036
5	Manang Bhot	Manang	0.2766	0.1950	0.2034	0.0262	0.491348
6	Bandipur	Tanahun	0.1996	0.1105	0.1358	0.0319	0.289776
7	Damauli	Tanahun	0.1832	0.0782	0.1164	0.0264	0.19768
8	Khairini Tar	Tanahun	0.1784	0.0758	0.1291	0.0263	0.163396
9	Ramjakot	Tanahun	0.1973	0.0816	0.1433	0.0332	0.202699
10	Beni Bazar	Myagdi	0.2118	0.0988	0.2991	0.1493	0.217986
11	Darbang	Myagdi	0.2078	0.0892	0.1687	0.0453	0.309755
12	Tatopani	Myagdi	0.1674	0.0538	0.1016	0.0244	0.156936
13	Chapkot	Syangja	0.2015	0.0840	0.1310	0.0335	0.219192
14	Syangja	Syangia	0.1867	0.0740	0.1113	0.0269	0.173641
15	Walling	Syangja	0.2074	0.0832	0.1336	0.0324	0.204261
16	Dumkauli	Nawalparasi	0.1883	0.0799	0.1823	0.0248	0.215734
17	Dumkibas	Nawalparasi	0.2070	0.1160	0.1924	0.0497	0.255277
18	Gharedhunga	Lamjung	0.1867	0.0622	0.1434	0.0259	0.183679
19	Kunchha	Lamiung	0.1824	0.0873	0.1393	0.0280	0.239495
20	Gorkha	Gorkha	0.2171	0.0962	0.1535	0.0210	0.308371
21	Jagat (Setibas)	Gorkha	0.2239	0.1130	0.1633	0.0798	0.37616
22	Larke Samdo	Gorkha	0.1817	0.0926	0.3393	0.0741	0.37874
23	Jomsom	Mustang	0.1716	0.1134	0.1967	0.0147	0.641447
24	Lete	Mustang	0.1571	0.0556	0.1084	0.0397	0.206095
25	Ranipauwa (M.Nath)	Mustang	0.4061	1.2373	1.8248	0.0125	0.388623
26	Karki Neta	Parbat	0.1914	0.9300	0.9366	0.0290	0.1677
27	Kushma	Parbat	0.1833	0.0587	0.9265	0.0283	0.256835
28	Lamachaur	Kaski	0.1516	0.0574	0.9262	0.0302	0.153611
29	Lumle	Kaski	0.1586	0.0405	0.0921	0.0321	0.15001
30	Pokhara Airport	Kaski	0.1632	0.0749	0.1069	0.0247	0.168452

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.

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

$$=\frac{\frac{(Cv)1}{d1}+\frac{(Cv)2}{d2}+\frac{(Cv)3}{d3}+\frac{(Cv)4}{d4}+\frac{(Cv)5}{d5}+\cdots}{\frac{1}{d1}+\frac{1}{d2}+\frac{1}{d3}+\frac{1}{d4}+\frac{1}{d5}+\cdots} \qquad Equation\ 3$$

Where $(C_v)_1$, $(C_v)_{2, \ldots\ldots}$ = coefficient of variance of respective stations and d_1, $d_{2,\ldots}$ = Distance of respective stations.

Data validation

For the data validation, sample of three stations were selected namely; Beluwa station from Terai region which lies in Nawalpur district. Similarly other two were Lamachaur and Naar which lies in Mountainous and Himalayan region respectively. For the data validation, interpolations were carried out from all the stations to those stations where we needed validation stations. Mean annual rainfall data which were not used in the interpolation of respective stations were cross checked with interpolation data of respective stations. All the stations satisfied the analyzed results of mean annual rainfall from previously determined value.

Rainfall Erosivity analysis

This method was collecting the rainfall data at the different meteorological station of Gandaki province. Monthly data of two season were collected which is rainy and dry season. This method helps to identify how the soil is detached and enhance the soil erosion cycle. The product of total rainfall energy and its 30 minutes rainfall amount is used to determine the best single rainfall related to the soil loss. Figure 3 shows the rainfall erosivity values which contribute to the soil erosion process.

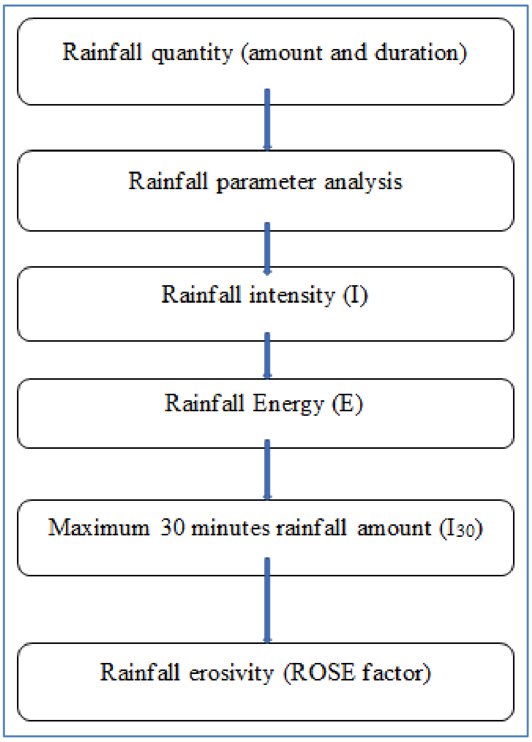


Fig-3: Process of rainfall erosivity

$I=\sum\frac{Amount\ of\ rainfall}{period\ of\ rainfall}$ *Equation 4*

$E=210+89\log_{10}I$ *Equation 5*

$R=E*I_{30}$ *Equation 6*

Where E is the kinetic energy in tonne.m/ha.cm and I_{30} is the 30 minutes maximum rainfall intensity in cm. The final result from this analysis is the ROSE index or R-factor in tone. m^2/ha.hr. and finally converted to MJ.mm/ha.hr. which shows the amount of soil loss cause by the heavy drops and amount of rainfall at the particular location. The threshold of rainfall that can contribute to the soil erosion including the landslide occurrence is defined (Zuliziana Suif *et al.*, 2018) as;

Table-4: Rainfall erosivity category ('ROSE' index)

ROSE index (MJ.mm/ha.hr)	Category
<5000	Low
5000-10000	Moderate
10000-15000	High
15000-20000	Very High
>20000	Critical

RESULT AND DISCUSSION

Data quality control

The main objective of data quality control is to detect and remove errors in the data sets. 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 ensured higher quality.

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 4.89%, given that the study requires continuous data therefore mean ratio method was used for the estimation of missing records.

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. Figure 4 shows the single mass curve for Baglung station in which it shows straight lines passing through origin which indicate data is of good quality.

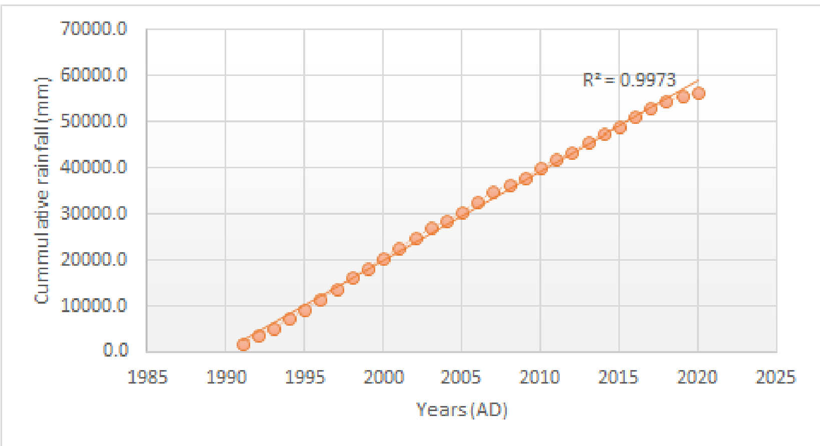


Fig-4: Single mass curve for Baglung (1991-2020)

Temporal distribution mean monthly rainfall

The temporal distribution of rainfall over the studied region is investigated. The rainfall regime over the most parts of Gandaki Province was almost all unimodal regimes having peak rainfall in July and August. The sample figure for temporal distribution at Baglung is represented in Figure 5.

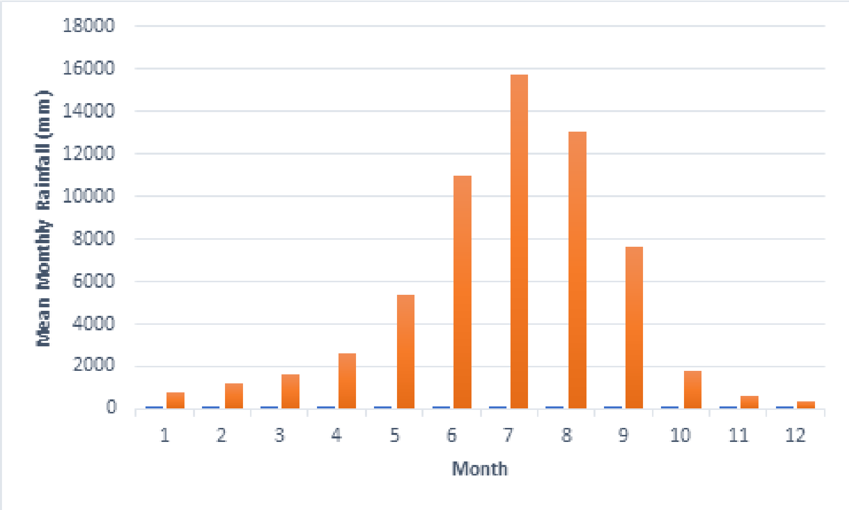


Fig-5: Mean monthly rainfall at Baglung (1991-2020)

RESULTS FROM TREND ANALYSIS

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

Graphical Method

Increasing trends (positive) and decreasing trends (negative) of mean seasonal is checked. It is found that some of the stations shows positive and minor of the stations shows no trends i.e. almost trend remains constant and all other remaining stations have shown almost negative trends which indicates that the particular region is facing atmospheric evaporation followed by water downpour over the period. The phenomena occur when temperatures are usually high and precipitation is not usually low for the season. Therefore, suitable measures should be adopted to maintain regular precipitation in those areas. The results of all the some selected seasonal wise trend analysis as shown in Figure 6 to 8.

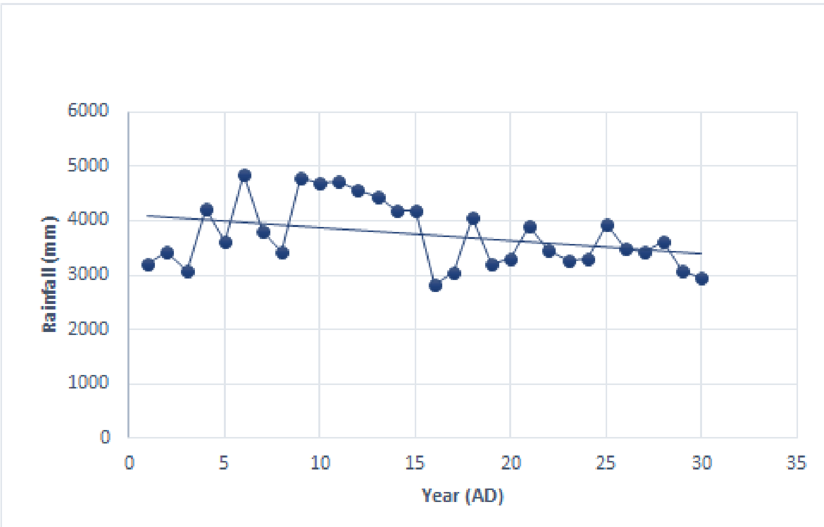


Fig-6: Winter Rainfall for Pokhara Airport (1991-2020)

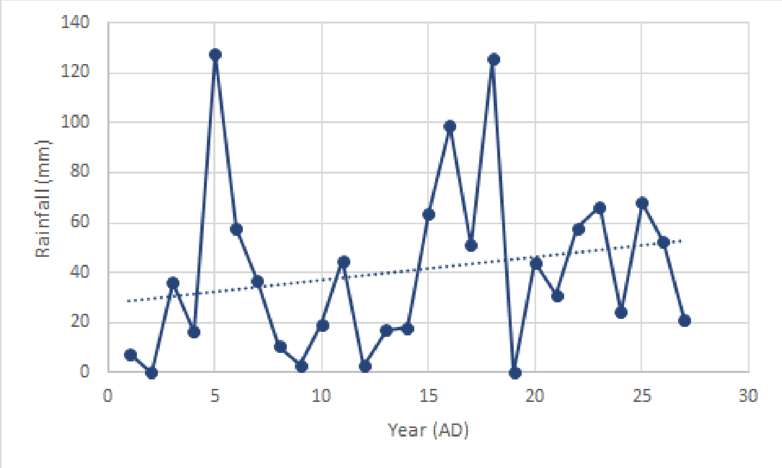


Fig-7: Spring Rainfall for Ranipauwa (M. Nath) (1991-2020)

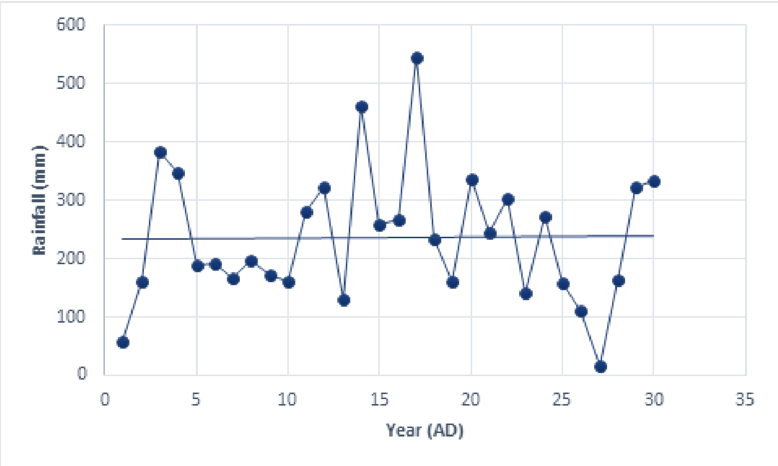


Fig-8: Autumn Rainfall for Damauli (1991-2020)

Statistical analysis of trend

The significance of the trends used to test by Statistical method. Results from statistical methods suggest that there are trends i.e. Means are different as shown in Table 5, 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. It is checked at the P-value 0.05, the level difference between the two conditions are either significant or not. All the selected station's details are shown in Table 5.

Table-5: Results of seasonal rainfall t-test statistic at a 95 % confidence interval

Stations	Seasons	Difference in mean	Slopes	Trends	P-value	Significance of trends
Ranipauwa (M. Nath)	Spring	29.0232	0.3438	+ve	1.6290	Not Significance
	Autumn	7.3466	-0.4057	-ve	0.1214	Not Significance
	Summer	45.9262	1.4304	+ve	2.5246	Not Significance
	Winter	111.1644	-6.6943	-ve	3.3486	Not Significance
Dumkibas	Spring	43.5665	-1.8919	-ve	0.5532	Not Significance
	Autumn	105.9178	-7.2530	-ve	1.4287	Not Significance
	Summer	47.1333	10.5942	+ve	0.4186	Not Significance
	Winter	49.7155	9.5391	+ve	0.1754	Not Significance
Damauli	Spring	24.6511	1.4304	+ve	1.8631	Not Significance
	Autumn	8.4488	0.1494	+ve	0.1927	Not Significance
	Summer	103.2933	-3.7920	-ve	1.7799	Not Significance
	Winter	217.3978	-5.6847	-ve	1.4085	Not Significance
Baglung	Spring	107.5377	-3.2565	-ve	0.092	Not Significance
	Autumn	32.6500	0.5231	+ve	0.085	Not Significance
	Summer	21.5600	-3.2150	-ve	1.23	Not Significance

Stations	Seasons	Difference in mean	Slopes	Trends	P-value	Significance of trends
	Winter	357.4666	1.5632	+ve	0.68	Not Significance
Bobang	Spring	53.4288	3.6598	+ve	1.32	Not Significance
	Autumn	102.3200	0.6396	+ve	2.21	Not Significance
	Summer	56.2100	2.9664	+ve	1.63	Not Significance
	Winter	364.6666	1.3021	+ve	0.96	Not Significance
Ranghkhani	Spring	101.1733	-3.2645	-ve	1.3268	Not Significance
	Autumn	98.2500	-3.2100	-ve	1.6821	Not Significance
	Summer	64.9500	2.0364	+ve	0.983	Not Significance
	Winter	17.5000	1.2678	+ve	0.9214	Not Significance
Chame	Spring	57.4649	0.6398	+ve	0.85	Not Significance
	Autumn	32.6400	9.6598	+ve	1.23	Not Significance
	Summer	45.9700	0.6321	+ve	0.98	Not Significance
	Winter	353.6925	6.3241	+ve	0.045	Significant
Manang Bhot	Spring	23.6111	3.2678	+ve	0.65	Not Significance
	Autumn	102.3400	2.1645	+ve	0.049	Significant
	Summer	65.2100	-2.3216	-ve	0.7012	Not Significance
	Winter	39.0888	6.3215	+ve	0.3256	Not Significance
Bandipur	Spring	38.7444	8.2134	+ve	1.3265	Not Significance
	Autumn	32.6500	-0.6321	-ve	3.2651	Not Significance
	Summer	21.5600	0.6321	+ve	1.9821	Not Significance
	Winter	220.0666	1.3046	-ve	0.6541	Not Significance
Kharinitar	Spring	73.8022	2.3264	+ve	3.2162	Not Significance
	Autumn	56.9700	1.0236	-ve	2.1564	Not Significance
	Summer	56.3200	-3.2165	-ve	1.5698	Not Significance
	Winter	317.6333	2.0365	+ve	2.3154	Not Significance
Ramjakot	Spring	73.8022	1.2564	+ve	1.2658	Not Significance
	Autumn	103.6300	2.3215	+ve	0.985	Not Significance
	Summer	65.9800	0.6356	+ve	1.3658	Not Significance
	Winter	274.9333	-6.3265	-ve	2.3651	Not Significance
Benibazar	Spring	21.2622	0.9654	+ve	0.6523	Not Significance
	Autumn	89.5600	0.3265	+ve	1.2365	Not Significance
	Summer	56.5400	0.2185	+ve	0.6598	Not Significance
	Winter	174.9555	0.1156	+ve	0.7165	Not Significance
Darbang	Spring	98.8600	-2.5232	-ve	2.3264	Not Significance
	Autumn	103.6300	1.3596	+ve	2.6985	Not Significance
	Summer	40.2100	0.9654	+ve	1.9658	Not Significance
	Winter	264.2666	2.5215	+ve	0.6598	Not Significance
Tatopani	Spring	44.5666	1.3033	+ve	0.3267	Not Significance
	Autumn	65.4500	2.7895	+ve	1.2689	Not Significance
	Summer	71.2100	-2.3215	-ve	1.6794	Not Significance
	Winter	288.5000	1.6325	+ve	2.4319	Not Significance
Chapkot	Spring	44.2333	0.9861	+ve	2.3497	Not Significance
	Autumn	50.3000	0.6897	+ve	1.6597	Significant
	Summer	21.4500	1.3024	+ve	0.9654	Not Significance
	Winter	63.3200	-2.3620	-ve	0.9632	Significant
Syangja	Spring	60.4400	0.9861	+ve	1.3267	Not Significance
	Autumn	59.6700	2.3156	+ve	2.6597	Not Significance
	Summer	51.3200	-5.3200	-ve	2.6534	Not Significance
	Winter	149.6666	0.3498	+ve	1.3269	Not Significance
Waling	Spring	78.3386	1.9564	+ve	0.8564	Not Significance
	Autumn	75.5600	2.6532	+ve	0.7932	Not Significance
	Summer	85.2100	1.2689	+ve	1.2379	Not Significance
	Winter	132.6000	-1.2365	-ve	2.3679	Not Significance
Dumkauli	Spring	37.8800	0.6321	+ve	0.6597	Not Significance
	Autumn	85.4500	0.7891	+ve	0.6321	Not Significance
	Summer	102.6500	1.2365	+ve	2.6794	Not Significance
	Winter	218.6000	-2.3265	-ve	0.7698	Not Significance
Gharedhunga	Spring	21.4377	0.6000	+ve	1.3264	Not Significance
	Autumn	74.3200	0.6548	+ve	2.3641	Not Significance

Stations	Seasons	Difference in mean	Slopes	Trends	P-value	Significance of trends
	Summer	56.3200	1.2365	+ve	0.7192	Not Significance
	Winter	47.1666	2.3265	+ve	0.6594	Not Significance
Kuncha	Spring	8.3333	0.6665	+ve	2.1364	Not Significance
	Autumn	30.3200	0.6321	+ve	1.2364	Not Significance
	Summer	56.9800	-0.8546	-ve	1.9641	Not Significance
	Winter	27.4500	0.80231	+ve	2.3232	Not Significance
Gorkha	Spring	56.6111	-1.3025	-ve	1.6891	Not Significance
	Autumn	97.3200	2.3164	+ve	0.7594	Not Significance
	Summer	12.3200	0.2678	+ve	0.9213	Not Significance
	Winter	48.2000	0.6897	+ve	0.6321	Not Significance
Jagat (setibas)	Spring	26.3933	-2.3654	-ve	2.3164	Not Significance
	Autumn	103.5200	0.3564	+ve	2.3148	Not Significance
	Summer	56.9800	2.3156	+ve	1.2691	Not Significance
	Winter	198.6333	1.3021	+ve	1.3497	Significant
Larke samdo	Spring	159.6533	0.6321	+ve	1.5946	Not Significance
	Autumn	66.6600	-1.5640	-ve	2.3648	Significant
	Summer	71.5200	1.2356	+ve	0.559	Not Significance
	Winter	418.6000	2.2156	+ve	0.679	Not Significance
Jomsom	Spring	10.6022	1.2348	+ve	0.3264	Not Significance
	Autumn	97.4100	0.6324	+ve	0.05	Significant
	Summer	106.1200	-0.7589	-ve	0.0659	Not Significance
	Winter	172.3333	0.6598	+ve	0.6314	Significant
Lete	Spring	59.9000	-1.2364	-ve	2.3497	Not Significance
	Autumn	99.9900	0.3265	+ve	1.6795	Not Significance
	Summer	106.5400	1.8790	+ve	1.6497	Not Significance
	Winter	238.8000	2.3468	+ve	2.3197	Not Significance
karki Neta	Spring	73.0333	-3.2514	-ve	3.2678	Not Significance
	Autumn	54.6200	6.3248	+ve	0.7854	Not Significance
	Summer	32.5800	0.9864	+ve	1.3033	Not Significance
	Winter	1206.9666	1.2487	+ve	2.9564	Not Significance
Kushma	Spring	9.4600	1.3264	+ve	1.6585	Not Significance
	Autumn	103.6200	0.6321	+ve	0.6597	Not Significance
	Summer	70.6500	-1.4587	-ve	1.6352	Not Significance
	Winter	78.5200	0.6321	+ve	2.9865	Not Significance
Lamachaur	Spring	78.9800	0.8975	+ve	2.9854	Not Significance
	Autumn	63.3300	-1.2647	-ve	0.048	Significant
	Summer	66.9600	0.6314	+ve	1.2154	Not Significance
	Winter	1206.9666	0.9647	+ve	2.5412	Not Significance
Lumle	Spring	60.8400	0.3024	+ve	3.6598	Not Significance
	Autumn	103.6500	-9.3241	-ve	2.6597	Not Significance
	Summer	69.5100	3.2154	+ve	1.6597	Not Significance
	Winter	47.9333	3.2145	+ve	0.049	Significant
Pokhara Airport	Spring	75.8266	-1.6794	-ve	0.6597	Not Significance
	Autumn	20.3000	0.3265	+ve	0.7495	Not Significance
	Summer	64.6600	-2.5678	-ve	1.2333	Not Significance
	Winter	289.8000	0.6614	+ve	0.9636	Not Significance

Analysis of variability

In this study results of seasonal as well as annual variability and reliability is calculated and compared. Results from the seasonal coefficient of variation found that the largest value of variability is observing during the summer season at Ranipauwa (M. Nath) i.e. 123.73%. This implies that there is little rainfall in this region during the summer season; also, high variability confirms that rainfall is less reliable. Furthermore, the lowest variability found in the winter season at Jomsom this implies that the winter season rainfall of Jomsom is more reliable. All the outcomes of results are as shown in the given Table 3.

Similarly, results from the annual coefficient of variation and Reliability in a pictorial form represented by ArcGIS Map as shown in Figure 8 (a) and 8 (b) respectively.

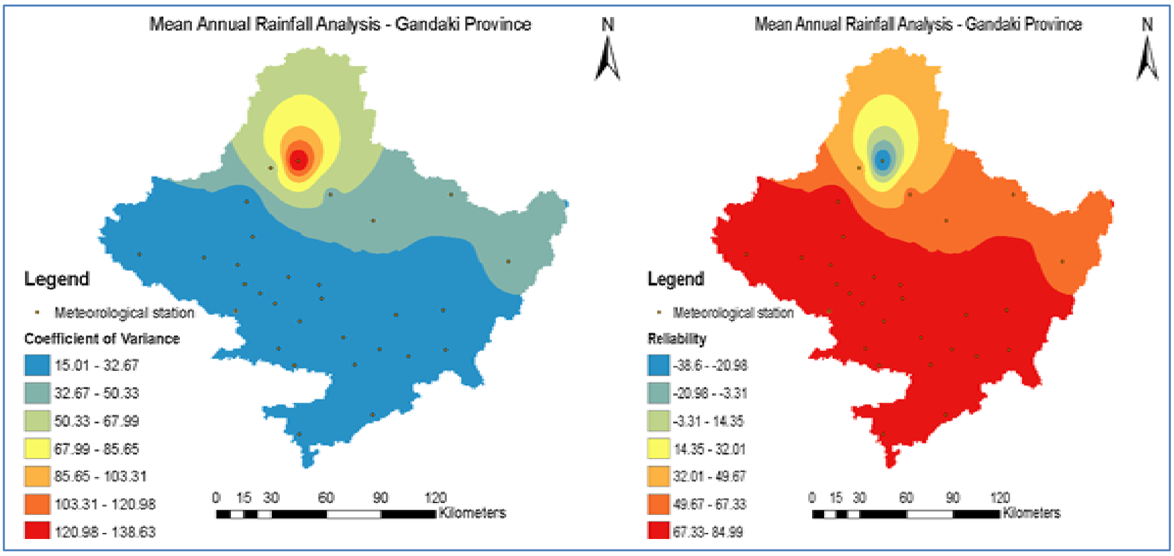


Fig-8: The spatial pattern of the coefficient of variation (%) (a) and reliability (b) for the annual rainfall

Also, results from the Season wise coefficient of variation are represented by ArcGIS Map as shown in Figure 9 (a) to 9 (d) respectively. Results show that almost all Himalaya region of Gandaki Province is facing the low reliability rainfall event in all season. Similarly, except some of the stations like; Karki Neta, Parbat in particular season of Mountainous region is getting somewhat constant range of rainfall variation event.

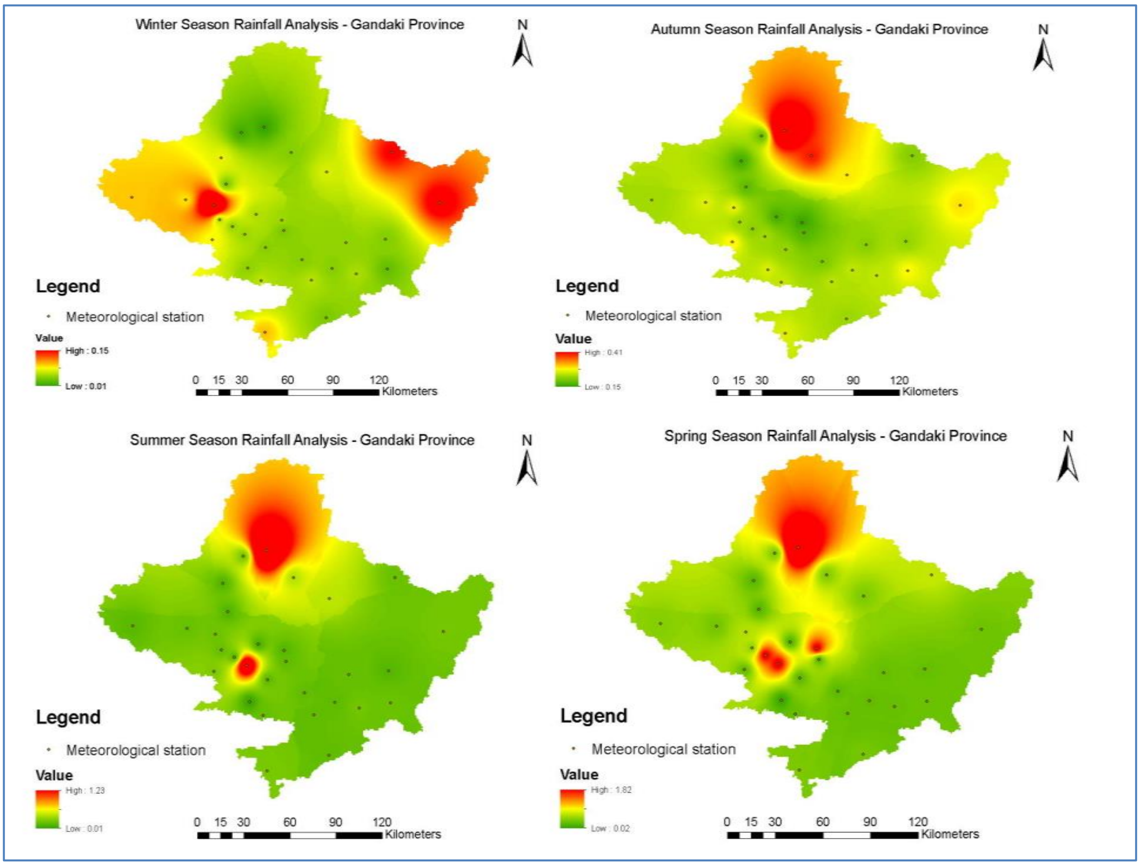


Fig-9: The Season wise pattern of the coefficient of variation (%) (a): winter, (b): Autumn, (c): Summer; and (d): Spring

Spatial analysis

In this study, we determine the mean annual rainfall of 30 years indicating that the Beni Bazar, Myagdi region has the highest rainfall and Ranipauwa, Mustang the least. For the case of Beni bazar, this is possibly due to the availability of moisture content around those locations. Similarly, the Ranipauwa 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. The results are represented in Figure 10.

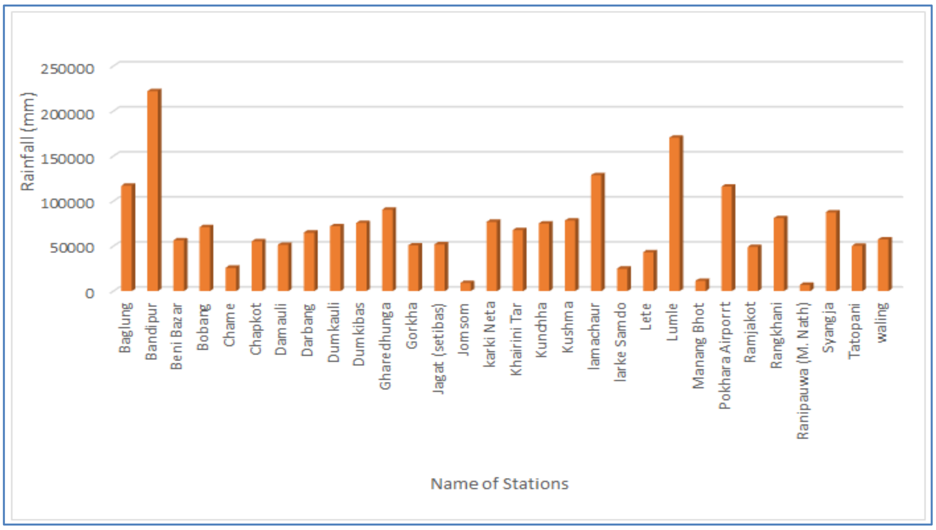


Fig-10: The spatial distribution of mean annual rainfall from 1991-2020

Data validation

Firstly mean annual rainfall of three different decades for three different stations were determined and result is depicted in Fig. 11. For the year 1991-2000, Beluwa station was selected. Similarly, Malepatan and Naar station were selected from the year 2001-2010 and 2011-2020 respectively. At the same time interpolation was also done for the respective station to know the interpolated value of mean annual rainfall from given value of considered stations. Results from interpolated rainfall value of those stations which were not considered for analysis and the rainfall value from the analysis part lies within the range. For example Mean annual rainfall of the Beluwa station carry the mean annual rainfall range between (2071.92-2719.43) mm. Similary, other two stations also has depicted the same result as represented in Figure 11 (a), (b) and (c).

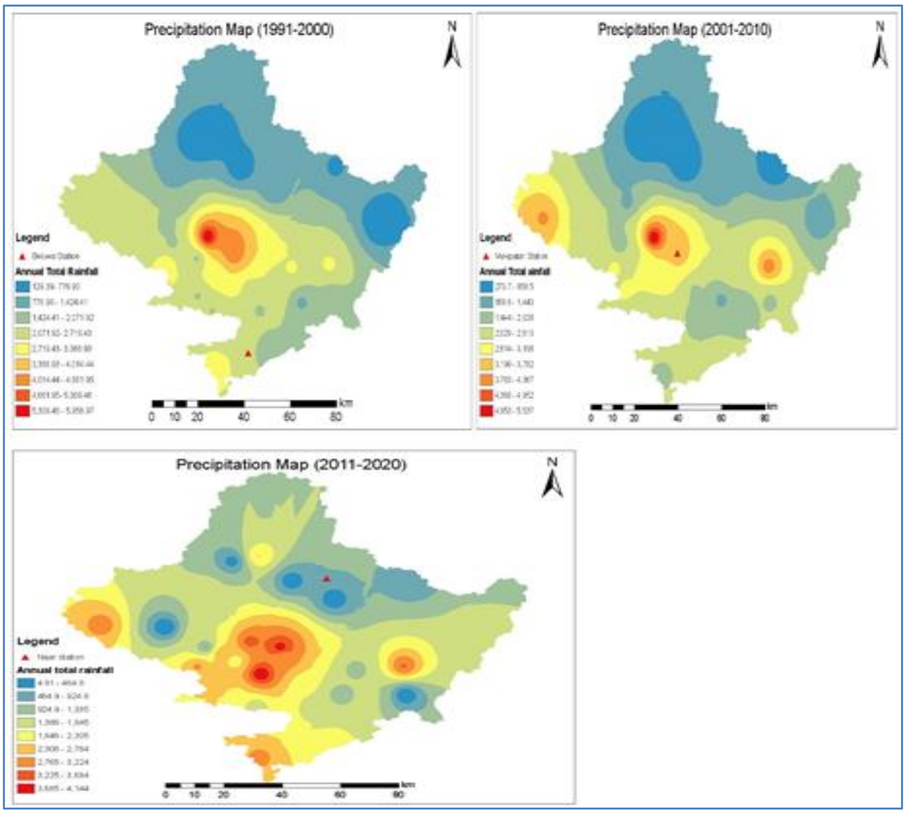


Fig-11: The Mean annual rainfall validation of (a): Beluwa, (b): Malepatan and (c): Naar station

Rainfall erosivity

To indicate the rainfall erosivity, daily rainfall risk frequency was considered. It shows the early warning potential in that area with coverage of 25Km radius. The analysis mainly based on the number of daily rainfall amount which is more than 20mm/day (Roslan and Twe, 1997). Figure 12 shows the monthly rainfall erosivity risk for the Gorkha district by considering all the station from (2016-2020) AD. Gorkha district has higher flood risk probability according to the report Geonet Connection Pvt. Ltd. in 2019.

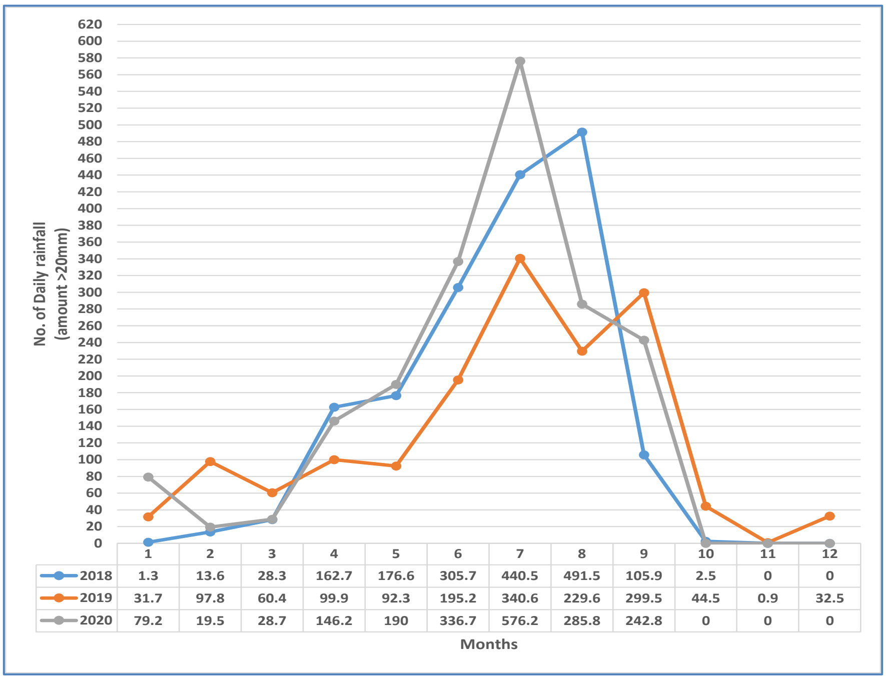


Fig-12: Monthly erosivity risk for Gorkha District

From Figure 12 it can be seen that highest possible rainfall erosivity risk based on the daily rainfall event were in the months of March to September and lowest were almost on the month November to February.

Based on the seasonal rainfall data collected, it can be seen that highest possible rainfall erosivity based on the daily rainfall amounts are in the lower elevated region of Gandaki Province i.e. in the Syangja, Tanahun, Nawalpur and some parts of Gorkha, Lamjung, Kaski, Parbat, Myagdi and Baglung and very small affects was in the upper region like Manag and Mustang as shown in Figure 13.

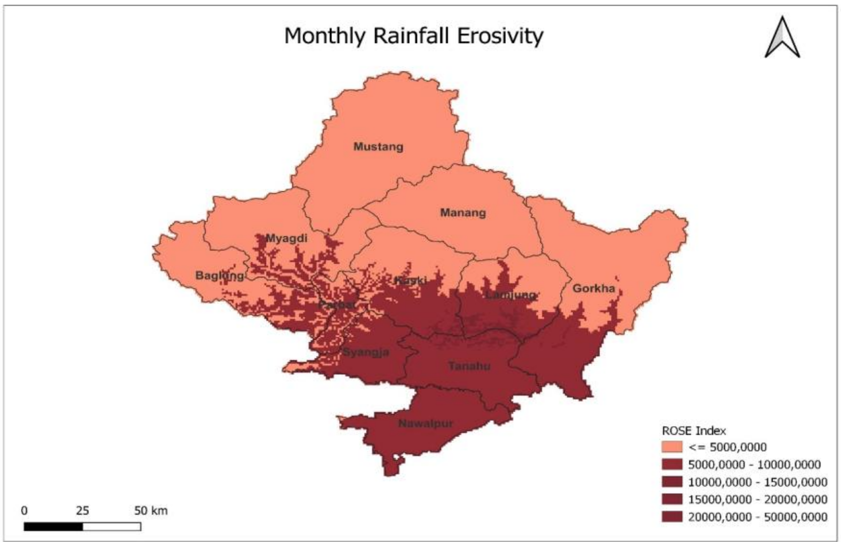


Fig-13: Monthly rainfall erosivity as per 'ROSE' index parameter

Similarly, as per standard criteria of threshold value of 'ROSE' index, calculated was done and graph was obtained based on that critical value. Red vertical line in the Figure 14 shows the critical value of 'ROSE' index which covers value greater that 20000MJ.mm/ha.hr. although value greater than 5000MJ.mm/ha.hr is also lies under the category starting with minor to major risk zone as per rainfall erosivity value but Figure 14 is based on critical risk which mainly cover the stations Baglung, Kushma, Larke Samdo and Bobang.

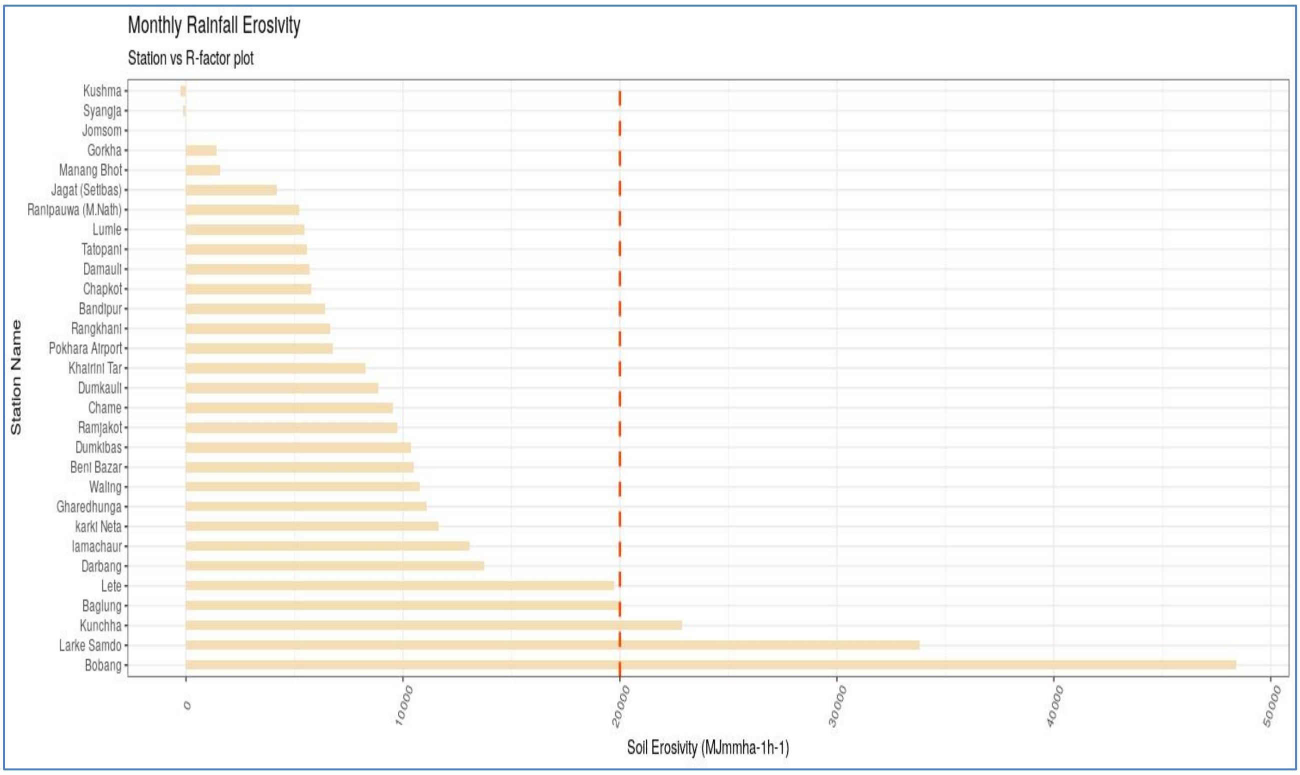
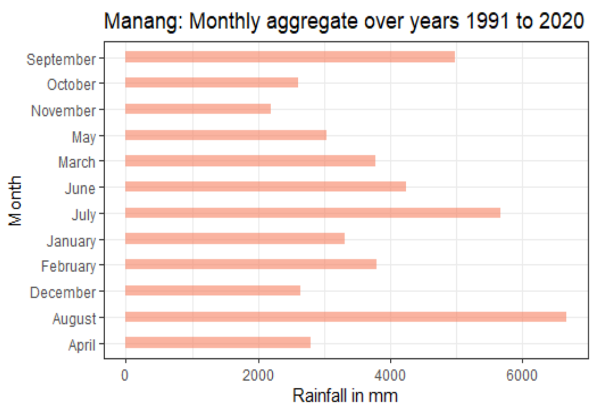


Fig-14: Monthly rainfall erosivity based on the critical zone

District wise Monthly aggregate

For the consistency of rainfall, monthly aggregate of each district was done. Here almost all districts other than Manang show the inconsistency of rainfall event. Manang shows the consistency of monthly rainfall greater than 2000mm in each month. Similarly comparing it to the Kaski district there was the very inconsistency of rainfall events i.e. greater than 100000mm in the month of July and very few in the month of December i.e. less than 3000mm. Results from both the events are represented in Figure 15 (a) and (b).



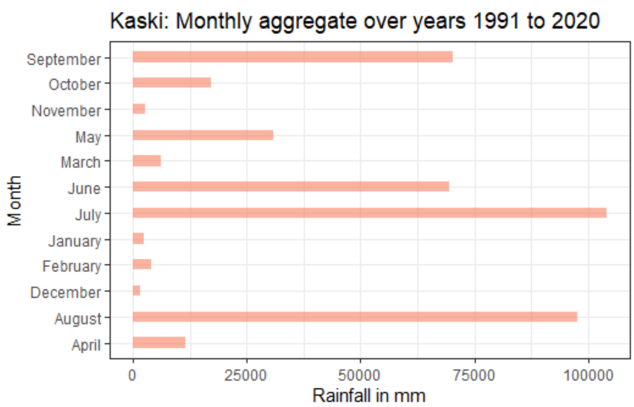


Figure 15: The Monthly total rainfall of (a): Manang district (b): Kaski district

CONCLUSIONS

The spatial and temporal variation on precipitation around Gandaki Province 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. Here, we have analyzed the rainfall data of different time-domain at different stations using mean-ratio method, graphical and statistical approach, IDW techniques, and significant t-test to obtain the temporal and spatial variability of rainfall of Gandaki Province. The temporal characteristic shows that peak month of rainfall are in July and August for all the regions. Considering Total Annual, the maximum value is at Beni Bazar i.e. more than 200000mm and least in the Ranipauwa i.e. less than 10000mm. Similarly, trend analysis shows that there are increasing (+ve), decreasing (-ve) and somewhat constant trends for the different stations. Furthermore, results from variability and reliability data shows that that Ranipauwa has the highest annual variability (138.86%) and Lumle has the least annual variability (15%) in which in turn implies that the rainfall at Lumle is more reliable than other areas. This may be due to the rain shadow effect of this region. Furthermore, results from spatial analysis indicate that rainfall is much higher in the regions close to water bodies or higher catchment. 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. Except few of the stations 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 season wise 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 Ranipauwa has the largest variability value, which indicates it has less reliable rainfall event.

During the buffering process for the selection of the station, some of the station near Himalayan range lies outside the standard criteria which means there should be establishment of some more stations so that data analysis can be done easily. Similarly, erosiveness of rainfall intensity reflects the river bank erosion on the basis of rainfall erosivity assessment. It can be used as a indicating tool for the river bank erosion and mitigation measures can also be done based on the erosivity assessment along major river bank of Gandaki province.

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