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Analysis of rainfall and return periods to assess flood risks in hilly areas of Nepal

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Abstract

The study analyzed rainfall data for 30 years from 17 meteorological stations to determine flood risk in the hilly areas of Nepal. The probability of occurrence and return period were used as the methods to calculate the flood event. Probability of occurrence was calculated from seven different methods: Chegodayev, Blom, California, Weibull, Gringorten, Hazen and Sevruk and Geiger method and mean probability was taken from these methods. The mean probability was then used to calculate the return period. The common application of these methods involves the ranking of the rainfall data and calculated as a ratio of the ranked values to the length of the samples i.e. number of years. There turn period is an estimation of the expected return of the annual observation i.e. extreme rainfall associated events and the probability determines the chances of occurrence of these events in terms of percentage. The Pansayakhola station and year 1999 has a higher return period of 24 years and 42 years, but the least probability of occurrence (4.13%) and (2.36%) respectively. While, the station Nepalthok and year 1992 has a return period of one year time interval corresponding to the lowest average rainfall, but have more than 95% of probability of occurrence. The study also reported that the highest return period (42 years) was observed in the month of July and least in November. Return periods with higher probability need robust mitigation measures for the occurrence of frequent flood events. Hilly regions of Nepal is highly vulnerable to flood pertaining to a higher share of land coverage and concentration of dense population which demands a pragmatic approach to reduce the risk of floods or hydrological events.

Keywords: Food, flood management, probability of occurrence, rainfall, return period.

Introduction

Investigating spatial and temporal variability of rainfall and intensity, volume, and duration is an important method to determine the occurrence of hydrological events. Hydrological events, including floods, landslides, extreme runoff, etc., can be catastrophic, causing fatalities and economic losses[1]. Subramany and Chettri & Kumar state that variation in rainfall is the key cause of many hydrological events such as flood and droughts[2,3]. Understanding such events is important in early preparedness and reduction of the potential risk to life and property. The past records of rainfall data is used for assessment of future probabilities of occurrence of hydrological events. The comprehensive study of the past data is indispensable for water resource assessment which is in turn prerequisite for planning and designing of developmental activities. Sabarish et al.[4] suggested that the estimation of rainfall data and its reoccurrence period from historical record is an important application in water management systems. In hydrology, one of the methods to assess the extreme events is estimating the return period and the probability of occurrence. Therefore, the study used the probability of occurrence and return period as the methods to assess flood event. The rainfall data for 30 years from 1987 to 2016 were used. The Return period is also applicable to calculate the likelihood occurrence of extreme events such as landslide and river discharge flow. The standard procedure for return period involves estimation of the probability of occurrence which applies mathematical formula. Total of seven methods of the probability of occurrence was used: Chegodayev, Blom, California, Weibull, Gringorten, Hazen and Sevruk and Geiger method. The mean probability of occurrence was then taken to calculate return period. Return period (Tx) is calculated as the probability expressed in terms of reciprocal value[5].

$$T_x = \frac{1}{P_x}$$

The study of the magnitude of rainfall amount accounted for probable occurrence of event is essential for the design of irrigation and other hydraulic structures[4]. The main analysis of the probability of exceedance and return period is to indicate what amount of rainfall can cause the damages to the projects. Chettri and Kumar pointed out that hilly region is prone to drought and flooding, therefore, analysis of rainfall pattern in hilly areas is an important matter[3]. Nepal is highly vulnerable to floods with the entire land area of the country prone to natural flooding. The vulnerability is significant as more than 70% of the population depends on agriculture[6] for livelihood and the sector account for one third of the gross domestic product[7]. The paper highlights the importance of probabilities of extreme rainfall events and determines the return periods in the hilly regions of Nepal. The results will help to develop strategies such as early preparedness to reduce the impact and securing any loss from the possible hazards. The other studies lack the assessment of temporal variability of rainfall particularly across the hilly region of Nepal[8]; therefore, it also calculated the monthly and annual rainfall pattern important for understanding return period within 30 years.

Materials and methods

Study area: Geographically, Nepal is divided into three regions: terai, hilly, and mountain region. Terai is a low-lying plain suited at southern part; hilly areas are middle region with hills, valleys and lakes. Mountain regionlies in the northern part that covers mountainous area including the world's highest peak Mt. Everest[7]. The study focuses in hilly areas which consist of the largest land area of the country. The region is relatively densely populated with about 43.1 percent of population as it is comprised of numerous attractive peaks, fertile valley, and habitable areas such as Kathmandu and Pokhara valley. The region is recorded with high to low rainfall ranging from 3000 mm to 800mm annually with the highest rainfall observed in July. The vegetation in the hilly region is mostly dominated by temperate deciduous forest.

Data: The rainfall data from 17 meteorological stations over the period of 30 years from 1987 to 2016 were collected from the Department of Hydrology and Meteorology, Nepal. The monthly rainfall records were collected and it was converted into annual rainfall data for the year wise analysis. The rigorous analysis of monthly rainfall was carried out to find out the least and the highest rainfall month. The separate station and year wise data were analyzed as per the scope of the study. All the 17 sites are stationed in the hilly areas with altitude varied from 200 masl to 2273 masl.

Estimation of the probability of occurrence or exceedance (Px): The probability of exceedance is defined as the probable occurrence of a rainfall amount or depth (intensity) that exceeds or is higher than given rainfall value recorded previously[5]. When such amount of rainfall is exceeded the hydrological events such as flood and landslide is expected to occur.

Firstly, it involves the ranking of the rainfall data based on the rainfall depth from the number of observations (number of years or stations). The serial rank numbers are assigned from 1 to n^{th} number of observations. Secondly, the probability was determined from rank numbers and number of observations allotted to each of the rainfall depth. It is denoted as Px and expressed in the form of percentage in a scale range from 0 to 100%. Initially, the probability was calculated from individual method, then average of seven methods were used to determine the return period (Table-2).

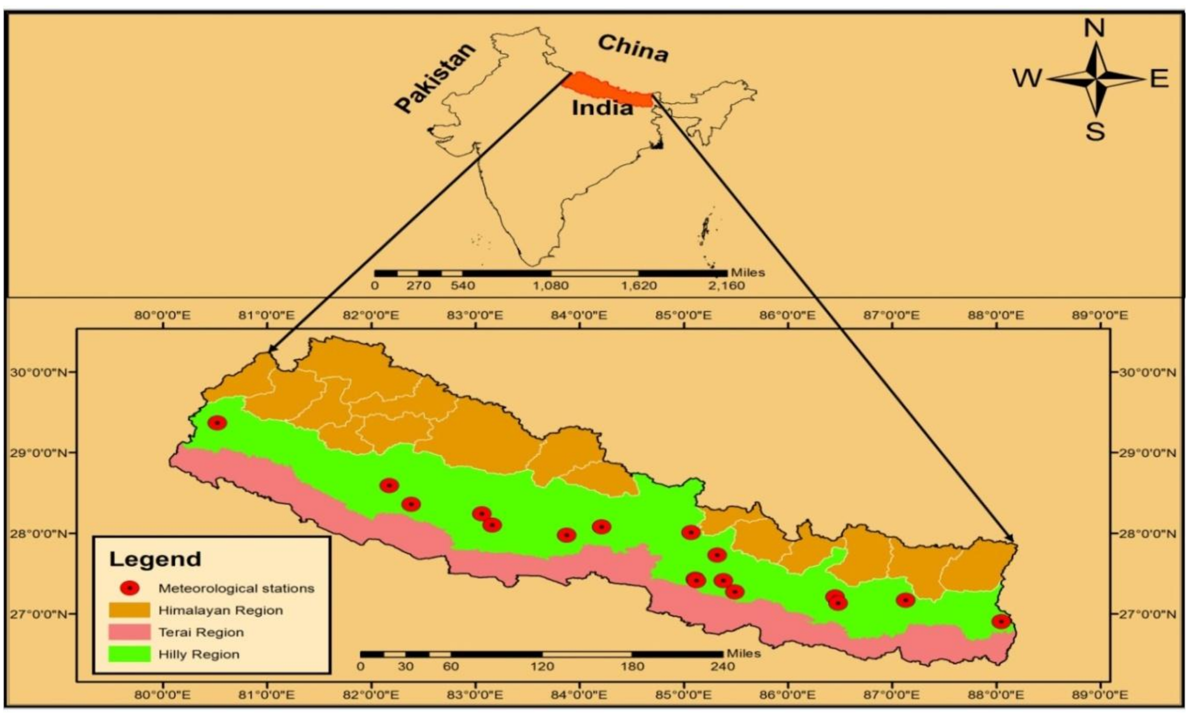


Figure-1: Map showing study area and meteorological stations.

For instance, if 3000 mm is the annual average rainfall depth of meteorological station X in 30 years, which is the highest of all the stations (ranked 1), it is about 3.5% probability that same amount would reoccuror exceed in a given return period. The rainfall amount is inversely proportional to the probability of exceedance as evident from Figure-3 and 4. The probability of occurrence was studied for station and year wise.

Table-1: Formulae used for the probability of occurrence or exceedance[16].

Methods	Estimation of probability of occurrence or exceedance
California[9]	$P(X \geq x_m) = \frac{M}{n} \times 100$
Chegodayev[10]	$P(X \geq x_m) = \frac{m-0.3}{n+0.4} \times 100$
Blom[11]	$P(X \geq x_m) = \frac{m-0.375}{n+0.25} \times 100$
Weibull[12]	$P(X \geq x_m) = \frac{m}{n+1} \times 100$
Gringorten[13]	$P(X \geq x_m) = \frac{m-0.44}{n+0.12} \times 100$
Hazen[14]	$P(X \geq x_m) = \frac{m-0.5}{n} \times 100$
Sevruk and Geiger[15]	$P(X \geq x_m) = \frac{(m-\frac{3}{8})}{(n+\frac{1}{4})} \times 100$

Where, m is rank of the rainfall data and n = length of the sample (no. of years).

Return period (Tx) and the probability of occurrence: The return period estimates the occurrence or expected return of the annual observation[5]. The annual observation is regarded as an annual rainfall and associated events attributed to it. Therefore, return period is synonymously referred to as recurrence of these events. Denoted as Tx, the return period is calculated as the probability expressed as reciprocal value in terms of fraction which is the period expressed in number of years[5].

$$T_x = \frac{1}{P_x}$$

For instance, a 3.5% probability of exceedance (Px=0.35) has a return period of 3 (1/Px=1/0.35) years. It is explained as on average once every 3 years for the period of 3 decades, the rainfall will be exceeded or larger than 3000mm in a given station. The rainfall that is expected to reoccur is assessed to cause the flood events. The return period was studied for station and year wise.

Results and discussion

Probabilities of annual rainfall and return period: Station wise: Table-3 shows an annual average rainfall of the 30 years period from 1987 to 2016. The ranking of average rainfall of 17 stations was in accordance to its amount in descending order and the corresponding probabilities of occurrence were calculated from the mean of seven different methods. The averaged probabilities of occurrence were used for calculating the return period.

The probability of occurrence varies from 4% to 97% and the return period from 1 year to 24 years. The stations with less than 1600 mm of average annual rainfall have a return period of one year with more than 65% of the probability of occurrence. This indicates that possibility of flood events in those stations is more than 65% higher. The highest return period of 24 years was observed at Pansayakhola station with an average rainfall of 3015 mm and 4.13% of probability of occurrence. The lowest average rainfall of 832.79mm had occurred at Nepalthok with a return period of 1 year and has the highest probability of occurrence of 96.71%.

Year wise: Table-3 indicates the probabilities of occurrence and return period for three decades. Out of 30 years, 15 years have more than 50% of probability of occurrence and the return period for 1 to 2 years. The probability of occurrence ranges from 2% to 98% and a return period from 1 year to 42 years. From three decades of rainfall data, the year 1999 was recorded with the highest average rainfall of 2233.14 mm with 2% of probability and the highest return period of 42 years.

The lowest average rainfall had occurred in the year 1992 with the highest probability of occurrence of 98.12% with a return period of 1 year.

Highest monthly rainfall of probabilities of occurrence and return periods: The graph (Figure-2) represents the maximum average rainfall, probability of occurrence, and return period of the month of July. Figure-2 (A) represents the highest average rainfall of 820.086 mm with the highest return period of 24.20 years at the Pansayakhola station whereas Figure-2(B) of year wise represented that year 1987 has the highest average rainfall of 644.1mm with the highest return period of 42 years. When there is an increase in the probability occurrence of rainfall in the month of July has reduced in return period of rainfall.

Lowest monthly rainfall of probabilities of occurrence and return periods: The graph (Figure-3) demonstrates the lowest average rainfall, probability, and return period of the month of November. The probability of occurrence and return period was calculated for the month and station rainfall data. Graph (Figure-3A) provides information about the station wise *i.e.* Mainagaun with the highest average rainfall of 13.97mm and highest return period of 24 Years. The lowest average rainfall was observed at Musikot with 3.25mm. Figure-3B indicates that the year 2016 has a high probability of occurrence of 96.70% with a return period of 1 year while, the year 1995 has lowest average rainfall of 77.81mm with the lowest return period of 42 years.

Table-2: Station wise annual rainfall of probabilities of occurrence/ exceedance with return period.

Estimate of probability Ranked of exceedance (Px)											
Name of station	Average rainfall (mm)	Rank	California	Chegodayev	Hazen	Weibull	Gringorten	Sevruk & Geiger	Blom	Average Probability of occurrence	Return Period (years)
Pansayakhola	3015.04	1	5.88	4.02	2.94	5.56	3.27	3.62	3.62	4.13	24.21
Kunchha	2607.52	2	11.76	9.77	8.82	11.11	9.11	9.42	9.42	9.92	10.08
Himaligaun	2362.44	3	17.65	15.52	14.71	16.67	14.95	15.22	15.22	15.70	6.37
Bobang	2333.34	4	23.53	21.26	20.59	22.22	20.79	21.01	21.01	21.49	4.65
Musikot	2321.77	5	29.41	27.01	26.47	27.78	26.64	26.81	26.81	27.28	3.67
Pipalkot	2203.07	6	35.29	32.76	32.35	33.33	32.48	32.61	32.61	33.06	3.02
Aisealukhark	2193.52	7	41.18	38.51	38.24	38.89	38.32	38.41	38.41	38.85	2.57
Chapkot	1869.83	8	47.06	44.25	44.12	44.44	44.16	44.20	44.20	44.63	2.24
Mainagaun	1848.86	9	52.94	50.00	50.00	50.00	50.00	50.00	50.00	50.42	1.98
Rukumkot	1798.85	10	58.82	55.75	55.88	55.56	55.84	55.80	55.80	56.21	1.78
Thankot	1716.7	11	64.71	61.49	61.76	61.11	61.68	61.59	61.59	61.99	1.61
Kakerpakha	1688.41	12	70.59	67.24	67.65	66.67	67.52	67.39	67.39	67.78	1.48
Dhunibesi	1568.11	13	76.47	72.99	73.53	72.22	73.36	73.19	73.19	73.56	1.36
Diktel	1451.13	14	82.35	78.74	79.41	77.78	79.21	78.99	78.99	79.35	1.26
Gausala	1306.64	15	88.24	84.48	85.29	83.33	85.05	84.78	84.78	85.14	1.17
Tumlingtar	1270.05	16	94.12	90.23	91.18	88.89	90.89	90.58	90.58	90.92	1.10
Nepalthok	832.79	17	100.00	95.98	97.06	94.44	96.73	96.38	96.38	96.71	1.03

Table-3: Year wise annual rainfall of probabilities of occurrence/exceedance with return period.

Year	Average (mm)	Rank	California	Chegodayev Formula	Hazen	Weib ull	Gringorten	Sevruk & Geiger	Blom Formula	Probability of occurrence (%)	Return periods (year)
1999	2233.14	1	3.33	2.30	1.67	3.23	1.86	2.07	2.07	2.36	42.37
1998	2224.65	2	6.67	5.59	5.00	6.45	5.18	5.37	5.37	5.66	17.66
2000	2173.32	3	10.00	8.88	8.33	9.68	8.50	8.68	8.68	8.96	11.16
1995	2122.96	4	13.33	12.17	11.67	12.90	11.82	11.98	11.98	12.27	8.15
2002	2080.64	5	16.67	15.46	15.00	16.13	15.14	15.29	15.29	15.57	6.42
1990	2065.19	6	20.00	18.75	18.33	19.35	18.46	18.60	18.60	18.87	5.30
1987	2055.88	7	23.33	22.04	21.67	22.58	21.78	21.90	21.90	22.17	4.51
1988	2052.79	8	26.67	25.33	25.00	25.81	25.10	25.21	25.21	25.47	3.93
2013	2050.78	9	30.00	28.62	28.33	29.03	28.42	28.51	28.51	28.78	3.48
2016	2041.08	10	33.33	31.91	31.67	32.26	31.74	31.82	31.82	32.08	3.12
2001	2030.24	11	36.67	35.20	35.00	35.48	35.06	35.12	35.12	35.38	2.83
2003	2017.79	12	40.00	38.49	38.33	38.71	38.38	38.43	38.43	38.68	2.59
2007	1999.06	13	43.33	41.78	41.67	41.94	41.70	41.74	41.74	41.98	2.38
1996	1984.38	14	46.67	45.07	45.00	45.16	45.02	45.04	45.04	45.29	2.21
1989	1980.74	15	50.00	48.36	48.33	48.39	48.34	48.35	48.35	48.59	2.06

2011	1973.62	16	53.33	51.64	51.67	51.61	51.66	51.65	51.65	51.89	1.93
1993	1905.38	17	56.67	54.93	55.00	54.84	54.98	54.96	54.96	55.19	1.81
1997	1870.87	18	60.00	58.22	58.33	58.06	58.30	58.26	58.26	58.49	1.71
2010	1866.98	19	63.33	61.51	61.67	61.29	61.62	61.57	61.57	61.79	1.62
1991	1770.84	20	66.67	64.80	65.00	64.52	64.94	64.88	64.88	65.10	1.54
2004	1758.33	21	70.00	68.09	68.33	67.74	68.26	68.18	68.18	68.40	1.46
1994	1756.39	22	73.33	71.38	71.67	70.97	71.58	71.49	71.49	71.70	1.39
2008	1728.15	23	76.67	74.67	75.00	74.19	74.90	74.79	74.79	75.00	1.33
2012	1723.52	24	80.00	77.96	78.33	77.42	78.22	78.10	78.10	78.30	1.28
2006	1684.94	25	83.33	81.25	81.67	80.65	81.54	81.40	81.40	81.61	1.23
2014	1663.52	26	86.67	84.54	85.00	83.87	84.86	84.71	84.71	84.91	1.18
2009	1618.12	27	90.00	87.83	88.33	87.10	88.18	88.02	88.02	88.21	1.13
2015	1605.43	28	93.33	91.12	91.67	90.32	91.50	91.32	91.32	91.51	1.09
2005	1573.21	29	96.67	94.41	95.00	93.55	94.82	94.63	94.63	94.81	1.05
1992	1543.47	30	100.00	97.70	98.33	96.77	98.14	97.93	97.93	98.12	1.02

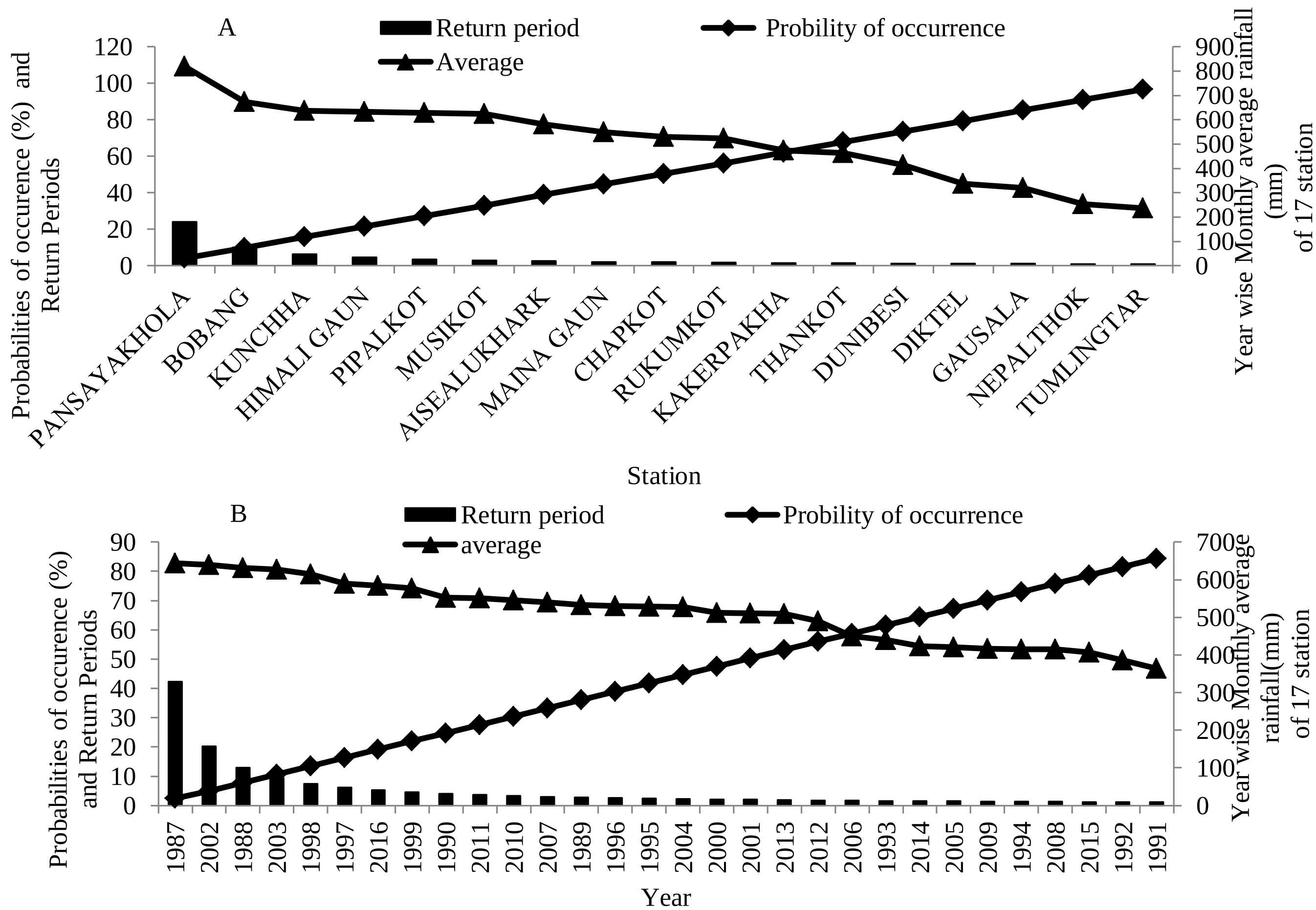
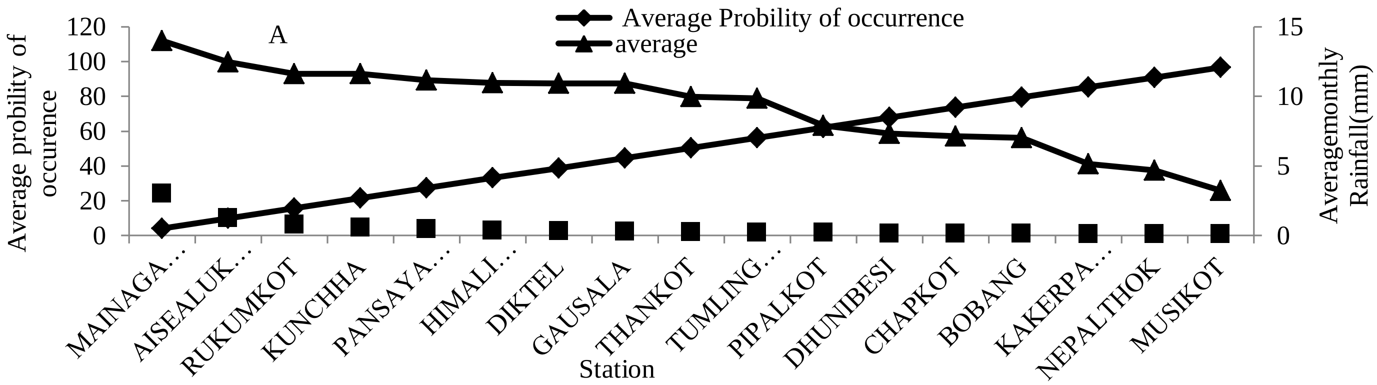


Figure-2: Highest rainfall month (July) with probability occurrence and return period of station (A) and year(B).



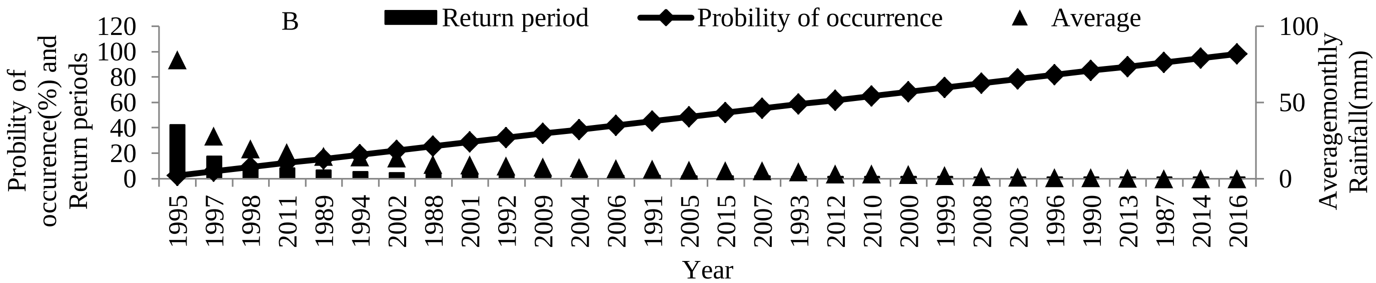


Figure-3: Lowest rainfall month (November) withthe probability of occurrence and return period of station (A) and year (B).

Discussion: The study found that higher return period is associated with maximum average rainfall, but the minimum probability of exceedance as indicated in both year and station wise record. It is understood as the probability of flood occurrence in that particular place is expected with large time interval, but higher severity (huge rainfall). For instance, the Pansayakhola station has a return period of 24 years, but least probability of occurrence (4.13%). While, the station Nepalthok has a return period of one year time interval corresponding to the lowest average rainfall, but have more than 95% of probability of occurrence. The relationship shows that increase in rainfall amount is related to increase in return period and decrease in probability of exceedance. Such relationship was also observed by Urias et al.[17]. About 35% of total stations have a return period of one year with the probability of occurrence ranging from 67% to 97% and rainfall varied from 800mm to 1900mm (Table-3). This indicates that the risk of flood occurrence in those places is 67% to 90% chance every year. This can be because the climate of Nepal is dominant by monsoon as studied by Shrestha and Sthapit[8]. While flood events in other stations are expected with a larger gap of time period and risks associated is higher. The estimated return periods with such high probability of occurrence pose a high risk to vulnerable areas of Nepal and undertaking appropriate actions in order to mitigate the serious consequences is an immediate need. The flash flood in the hilly areas is primarily due to an extreme rainfall amount[1].

In respect to the monthly pattern of rainfall, July was reported with the highest return period (42 years) observed in the year 1987 (644mm).Therefore, it is predicted that such amount of rainfall is likely to occur in this range of time period and associated flood events. It also shows July is highly sensitive to flood occurrence due to high rainfall amount. Kansakar et al. studied spatial pattern of rainfall dominant regime in Nepal and reported a similar finding[18]. Several studies[3,8,19,20] supported that Monsoon in Nepal starts from June to September and receives 80% of annual rainfall during this season with the highest rainfall recorded in July. This is a clear indication that people must be more alert from rainfall related events during this season and the government should take a greater role in its mitigation.

The higher probability of occurrence with a lesser return period is related to flood events occurring more frequently. The higher rainfall data relates to the magnitude of extreme events and more destructive, though the frequency of occurrence is expected to be relatively low. Assessment of hydrological events from the shorter time period i.e. monthly data needs to adopt strategic planning and strong flood management system accordingly.

Nepal is characterized by extreme lands which receive a different amount of rainfall from stations to stations which significantly influence the spatial variation. The geographic condition such as non-uniform rugged terrain influences the spatial variation of rainfall[21]. Shrestha *et al.* found that both spatial and temporal variability of rainfall show increase in rainfall amount in monsoon and significant decrease in the post-monsoon, pre-monsoon and winter in the most of the zones of Gandaki River Basin of Nepal[22]. The 17 stations varied with altitude from 200 masl to 2273 masl. Daly and Goovaerts

(2000) observed that elevation is an important predictor for precipitation[23,24]. Chettri and Kumar stated that climate and rainfall period determines the variability such that drier climate and shorter length of rainfall duration leads to larger variation of rainfall[3]. Such variation in rainfall pattern imposes higher associated risks such as frequency of flood, landslide, drought, runoff and demands better management. Alam et al. argued that geographical location and surrounding environment also influences the variation of the rainfall pattern[1]. Variation and intensity of rainfall are responsible for causing many hydrological problems such as floods, drought, and landslides in the hilly region[25].

Conclusion

Thirty years of rainfall data from 17 field stations were analyzed. The risks of flood events were assessed by means of seven different methods of probabilities of exceedance and return period. The study concluded that higher return period was associated with higher rainfall amount, but a lesser probability of occurrence and vice versa. More than 35% of stations were found to have the risk of flood occurrence every year with the probability of 67% to 90%, though; the risk is expected low with less rainfall amount. Other stations were associated with the occurrence of flood events with larger time interval and severity with rainfall depth. The study also reported that July is potentially sensitive to flood event with November being the least sensitive. The probability of occurrence and the return period were calculated for a better understanding of the data which are deciding factors in determining long-term risks. The finding of the study is vital for the risk assessment, encourage to develop better risk models, and significantly, reduce the destruction from rainfall related catastrophe. It will help the government to plan and frame appropriate policies and implement to mitigate the risks.

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