GUIDELINES FOR ESTIMATION OF AVERAGE DEPTH OF PROBABLE MAXIMUM PRECIPITATION (PMP) OVER BAGMATI BASIN OF NEPAL

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Abstract

The Bagmati basin of Nepal is located over the central part Nepal and its head water originates from the Capital Kathmandu. The basin have been hovered by the most extreme disaster rainstorm in July, 1993, which claimed the life of about two thousand people, along with large number of animals and public properties. Heavy damages have been experienced in the Bagmati river barrage at Karmaiya and in the Kulekhani Hydropower plant also several bridges were washed away. The maximum rainfall recorded was 540 mm a day with night time rainfall at the rate of 65 mm/hour at station Tistung (Inside Bagmati basin). In the meantime, the river discharge was greatest in many rivers of Nepal, even greater than the design discharge of major infrastructure of Nepal.In this connection, the estimation procedure of PMP is urgent in Nepal and the guidelines for PMP over Bagmati basin have been prepared using July, 1993 storm rainfall and other hydro-meteorological parameters during the storm. For the preparation of guidelines, hydro-meteorological method has been adopted and the mathematical models have been developed for hourly rainfall and Depth area duration curve. The digital elevation model and a geographic information system (GIS) have been used to assess the drawing of isohyets and DAD curve. Finally, a combined set of equations have been developed for the guideline.

Keywords: DAD, Average depth of PMP, Hyper- Tangent model, MMF

INTRODUCTION

The monsoon is the seasonal wind, actually a southern hemisphere wind moving across the Equator and north wards to the Tropic of Cancer. The heavy spells of rainfall in monsoon is mainly due to the formation and direction of movement of depression or cyclonic storms which originates in the Bay of Bengal and also sometimes in the Arabian Sea. Most of the extreme floods formation in Nepal is due to the result of concentrated spells of heavy monsoon rain. In Nepal, 70-80% of annual rainfall occurs during monsoon period. The extra tropical disturbances, popularly known as "Western Disturbances," (December to April), travel eastwards which originates somewhere around the Mediterranean Sea. Their track is north of latitude 45^0 N but comes down to as low as 30^0 N during the winter period. These disturbances do not bring heavy precipitation as to cause floods. They generally bring light rain of about 20 to 30 mm in months of December to April over Nepal.

The significance of high precipitation for hydraulic design in Nepal was realized in mid 1930s. The hydro-meteorological parameters for design depend on the purposes for which they are required and Probable Maximum Precipitation (PMP) is one of them. The uppermost limit of probable precipitation depth is known as Probable Maximum Precipitation (PMP), which can be defined in various ways. According to American Meteorological Society, 1959; PMP is defined as “the theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage area at a certain time of year”. Another definition of PMP more operational in concept is “the steps followed by hydro-meteorologists in arriving at the answer supplied to engineers for hydrological design purposes" (WMO, 1973). The more convenient definition is 'theoretically the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of year" (Hansen et al., 1982) and this definition is appropriate and adopted for the computational procedures.

PURPOSE OF STUDY

The purpose of this study is estimation of average depth of PMP of Bagmati basin of Nepal with the help of available extreme storm data and traditional hydro-meteorological method. The procedures for estimating PMP require knowledge of meteorology. No attempt has been made to define or discuss basic meteorological terms or procedures. The paper is written in sufficient detail to permit a hydro-meteorologist or an engineer to assess the parameters required for the estimation of PMP with the application of this guideline so as to solve the problems on estimation of PMF.

STUDY AREA

Geometrically Nepal has roughly a rectangular outline located between latitude 26^0 22' and 30 ^{0} 27' and longitude between 80 ^{0} 04' and 88 ^{0} 12' with average east-west extension of 880 km and north-south extension of 193 km. The study area is Bagmati basin which is situated in central Nepal. The total catchment area of study area is around 2800 sq.km. Kulekhani, Bishnumati, Nakhu and Marin rivers are main tributaries of Bagmati main stream. The studies on climate and topography have been carried out for the PMP estimates within the study area.

HIGHEST ONE DAY EXTREME RAINFALL IN NEPAL

The central region of Nepal was hit by storm of July 1993. The violent storm was due to "Break Monsoon". The axis of monsoon trough was situated over central Nepal on 19th July 1993 and remained so till 21st July. The resulting effect of the storm was heavy precipitation causing devastating floods in and around Bagmati basin. This particular storm was most violent storm ever hit or recorded in Nepal. The storm disaster claimed the life of about two thousand people, along with large number of animals and loss of property amounting to hundreds of millions of rupees. Heavy damages have been experienced in the Bagmati river barrage at Karmaiya and in the Kulekhani hydropower plant. Also several bridges were washed away along Prithivi Highway. The maximum rainfall recorded was 540 mm a day with night time rainfall at the rate of 65 mm/hour at station Tistung (Kulekhani basin – sub basin of Bagmati basin). In the meantime, the river discharge was greatest in many rivers of Nepal, even greater than the design discharge of major infrastructures of Nepal. The rainfall received at Tistung, i.e., 540 mm/24 h was highest ever recorded 24 hour rainfall of Nepal. The highest ever storm in Nepal is depicted in table 1.

Table 1 24h Extreme rainfall 19-20 July 1993, (Bagmati Region)

S.N	Station Name	19-20 rainfall(mm)	20-21 rainfall(mm)
1	Markhu	386	43.6
2	Daman	373	240
3	Tistung	540	39
4	Thankot	111.2	69.3
5	Ghantimadhi	482.2	116.3
6	Kulekhani	376.8	52.4
7	Patharkot	38	473
8	Dhunibesi	194	30.2
9	Chisapanigadh	294	65

METEOROLOGICAL NETWORK AND DATA AVAILABILITY

There is a moderate network of precipitation stations within the study area. Mostly, the data from these stations are collected by the Department of Hydrology and Meteorology.

Besides, few separate stations are available belonging to Department of Irrigation, Nepal Electricity Authority, Non governmental organizations etc.

The most responsible authority for meteorological data is Government of Nepal, Department of Hydrology and Meteorology (DHM). There are all together 309 Precipitation, 68 Climatological, 15 Synoptic, and 22 Agro-meteorological, and 6 Aeronautical stations (DHM, pub.1995). Among these the stations are heavily concentrated around Bagmati basin. For the study on PMP the required available data from DHM publications and data from Department of Soil Conservation and Watershed Management have been used.

METHODOLOGY

There are several methods for estimation of PMP out of which hydro-meteorological method looks more convenient as it shows the extreme rainfall distribution with area. Statistical method is also used for the estimation but useful only for point PMP. In order to estimate probable maximum flood at ungauged location, the average depth of PMP is required and it can be best derived from storm DAD

Hydrometeorological method

The three main steps in the hydro-meteorological approach in estimating maximum precipitation are to transpose storm values, transpose maximum values, maximize storm values, and then envelope the transposed maximum values. Initially, several parameters can be maximized to determine PMP. The simple and convenient way of storm maximization is moisture maximization. The first step in moisture maximization is to determine the maximum atmospheric moisture that may be expected in the region during storm. A method satisfactory for most localities is to survey a long record of surface dew point or vapor pressure measurement at several stations. Moisture maximization of storms in place is the multiplication of observed storm rainfall by the ratio of maximum precipitable water indicated for the storm reference location to the maximum precipitable water estimated for the storm. If the storm elevation is not at mean sea level, some adjustment may be required for the elevation correction. If the elevation of storm is less than 300m, it is not necessary to adjust storm elevation [Hart 1982, Schreiner and Riedal, 1978.] This decision is based on the distance to the moisture source and the storm characteristics and the topography of the region. If the basin topography is rough and series of intervening barriers, an adjustment on barrier is also required. In this study, all the possible corrections have been made for the estimation of moisture maximization factor (MMF).

Hydrometeorological Analysis

All the storm hourly and daily rainfall data are collected. Most of the stations are of non recording type. Thus, only 24 hours total rainfall data are available instead of hourly. So, relation is developed between hourly storm rainfall and 24 hours total rainfall of same storm with the help of data from few automatic stations within Nepal.

The relationship between 24 hours and lower duration precipitation depths developed from the available hourly rainfall data of some specified storm period is presented in
Fig. 1and the best fitted equation is

$$\frac{P_t}{P_{24}} = Sin\left(\frac{\pi \cdot t}{48}\right)^{0.4727}, \quad (1)$$

where "t "is time in hours.

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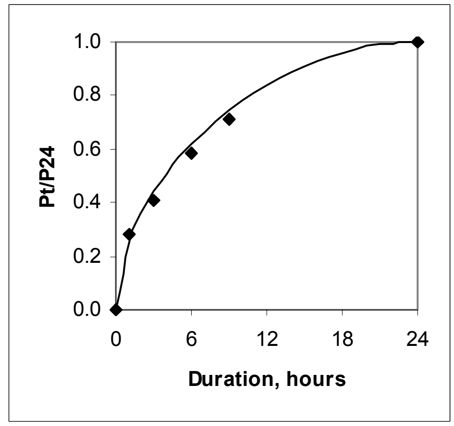

Fig. 1 The relationship between rain intensity and duration

New approach for the construction of Depth Area Duration curve (DAD)

The best fitted depth-area-duration (DAD) curves during the storm are worked out with the help of digital elevation model (DEM) of the Nepal with the cell size equal to 0.0083 degree, which in case of Equal-Area Cylindrical Projection corresponds to 930 m.

The capabilities of ArcView® Geographic Information System (GIS) and mapping package Surfer® have been intensively used for the analysis. The Hyper-Tangent model fitted best for all DAD plots in Bagmati. This new approach for Bagmati Basin is presented in this paper. The storm rainfall is presented in Fig.2.

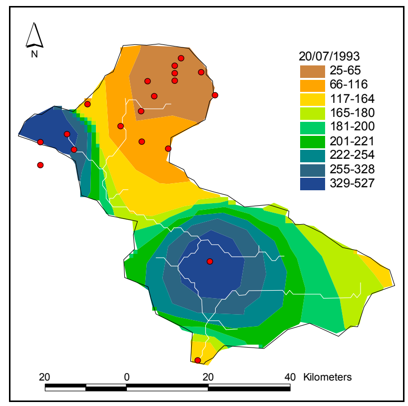

Fig. 2. The pattern of 24 hours rainfall over Bagmati river basin

Bagmati Basin

Extreme storm periods in Bagmati basin is:

- 19-20/07/1993

The depth-area-duration (DAD) curves are constructed based on the GIS numerical methods of map analysis. The relationships between average storm precipitation depth (Y-axis) and area (X-axis) for corresponding rainfall events are shown on Fig 3.

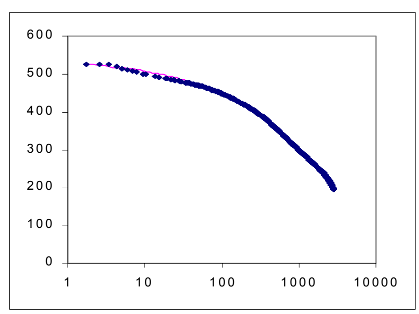

Fig. 3 The DAD relationship of 24h storm precipitation, mm (Y-axis) versus area ,sq.km (X-axis, logarithmic) for different rainfall events

The best curve for DAD has been worked out and the linear equation with hyper-tangent model was found to be the best. The fitted equation has been presented in equation 2. This equation has been applied to obtain relationships between average precipitation layer of 24-h (P_{24}) and corresponding area (A, km²):

$$P_{24} = a\frac{1+\tanh\left(\frac{\ln(A)-c}{d}\right)}{2}+b, \qquad (2)$$

Where, *a,b,c,d* are the parameters and tanh is hyperbolic tangent, for any x it can be calculated as follows:

$$. \tanh(x) = \frac{e^{x}-e^{-x}}{e^{x}+e^{-x}}$$

The new approach has been applied for the study area and the results are depicted in table 3. The calculation of MMF is depicted in table 4.

Table 3 The parameters for best fitted curves

Date	a	b	c	d	s, mm	Recommended area limits, km^2
1	2	3	4	5	6	7
			Bagmati Basin			
20/07/1993	-1020.98	541.0	9.4276	4.2248	3.2	1-2800

Table 4 Calculation of MMF

Area limits	Average Elevation of Meteorological Stations,m	Storm average 9 am dry bulb Temperature (T'd)	Maximum dew point temperature (T_M) (1000hPa)	Precipitable Water at Ts (Rs)	Precipitable Water at T_M (R_M)	R_M / Rs = MMF
			Bagmati Basin			
0.1-2800	1600	19.6	28.3	73	107	1.46

Guidelines for estimation of PMP

The quick point PMP can be estimate from statistical methods using historical extreme rainfall data of the meteorological station. The more reasonable PMP estimate for PMF is hydro-meteorological method and the computation procedure using this approach is

$$P_t = [\underbrace{a\frac{1+\tanh\left(\frac{\ln(A)-c}{d}\right)}{2}+b}_{X}]\times[\underbrace{Sin\left(\frac{\pi\cdot t}{48}\right)^{0.4727}}_{Y}]\times[\underbrace{MMF}_{Z}]$$

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An example for Kulekhani basin is presented below.

Estimation of PMP over Kulekhani basin

The study area within Kulikhani Watershed is limited to existing dam site and the total watershed area above dam-site is 126 km^2. The watershed is sub-basin of Bagmati and exposed to moisture bearing wind direction. The elevation of damsite is about 1300 m above mean sea level

For the computation of X, the coefficients a,b,c,d are taken from table.3. The MMF is taken from table 4. The estimation of hourly PMP are tabulated in table 5.

Table 5 The estimation of hourly PMP

Duration(t) hours	$Y = Sin\left(\frac{\pi \cdot t}{48}\right)^{0.4727}$	$Z = \frac{R_M}{R_S}$	$X = a\frac{1 + \tanh\left(\frac{\ln(A) - c}{d}\right)}{2} + b$	PMP, mm
9	0.702	1.46	436.7	447.5826
12	0.778	1.46	436.7	496.0388
15	0.837	1.46	436.7	533.6561
18	0.882	1.46	436.7	562.3473
24	1.000	1.46	436.7	637.582

CONCLUSIONS

This new approach within hydro-meteorological method for the estimation of average depth of PMP over the basin is very useful as only 24 hours data were available in Nepal. The general formula for PMP estimation can be obtained by combining equations 1and 2 along with MMF. The point PMP (24h) of Bagmati basin is around 900 mm. However, the average depth of PMP of specified duration is more essential rather than point PMP for the estimation of PMF.

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