RAINFALL DURATION-FREQUENCY CURVE FOR UNGAGED SITES IN THE HIGH RAINFALL, BENGUET MOUNTAIN REGION IN THE PHILIPPINES

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The motivation of this study was to determine whether or not the typhoon-related rainfall that occurred in October 1998 in Bakun, Benguet is a *force majeure* event, that is, an event associated with a significantly large recurrence interval or return period. Since there is no rainfall data in this particular location, this translates into an ungauged site estimation problem. Based on gauging stations around this mountain region, a regional rainfall-duration-frequency (RDF) equation was first developed as a function of mean annual precipitation, elevation and station location (longitude and latitude). Then, this regional RDF equation was used to develop the RDF curve at the Bakun site, and subsequently to estimate the return period associated with the October 1998 typhoon rainfall event at this site. An attempt to measure rainfall in Bakun in October 14, 1998 was made but unfortunately the 1000 mm raingauge overflowed. In any case, even at 1000 mm, the computed return period for this 1-day rainfall is 554 years thus signifying a *force majeure* event. The regional RDF equation developed in this study can likewise be used to calculate the RDF curve at ungaged sites in the vicinity of the Benguet mountain region in the Philipines.

INTRODUCTION

In October 1998, a typhoon locally called *Iliang* hit the mountain region of Benguet causing major landslides, loss of lives and especially delaying the completion of a hydropower project in Bakun, Benguet. Due to the delay in the hydropower project, a question arose whether or not the typhoon-related rainfall event is a *force majeure* event, that is, an event associated with a significantly large return period or recurrence interval.

The purpose of this study is to estimate the return period or recurrence interval of the rainfall associated with typhoon *Iliang* around Bakun, Benguet. Typhoon *Iliang* occurred during the period October 12 through 14, 1998, with intense storm activity in Bakun on October 14, 1998. In this study, the recurrence interval or return period of the storm rainfall is estimated based on rainfall-duration-frequency (RDF) analysis and modeling. Since there is no long-term rainfall data available in Bakun, Benguet, the approach is to develop a regional RDF equation for the study area based on the rainfall data of stations in Benguet and adjacent areas around Bakun. Then, the regional RDF equation developed is used to infer the rainfall frequency of typhoon *Iliang* at the specific location of Bakun, Benguet.

RAINFALL DATA USED

Figure 1 shows the location of 10 rainfall gaging stations around the Bakun area which were considered in the study. The data available in 9 of the 10 stations are on a daily basis. Data from the synoptic station in Baguio City are available in shorter time intervals (5 min, 10 min, etc), Because of this, it was decided to perform the rainfall analysis using daily time intervals. Since typhoon *Iliang* lasted less than 3 days, the rainfall analysis is performed at 1-day, 2-day and 3-day time intervals or durations. For the specific purpose of rainfall-duration-frequency analysis, only the annual rainfall maxima are used. The annual rainfall maxima are the maximum 1-day, maximum (consecutive) 2-day and maximum (consecutive) 3-day precipitation for each year of data.

Table 1 shows pertinent information of the rainfall gaging stations available in this study. This table shows the station elevation, location in longitude and latitude and the mean annual precipitation and years of record available.

METHODOLOGY

A summary of the analysis and modeling procedures involved in estimating the recurrence interval of the storm rainfall associated with typhoon *Iliang* are as follows:

First is to perform probability analysis and modeling of the rainfall data at each station for the different durations of 1-day, 2-day and 3-day. After selecting the most appropriate probability model to represent the rainfall data, the rainfall quantiles can be calculated at different rainfall durations and return periods (or frequencies). These calculated quantiles essentially constitute the historical rainfall-duration-frequency (RDF) curves.

Second is to develop station-specific rainfall-duration-frequency (RDF) equation which a parametric function fitted to the historical RDF curve for each station.

Third is to develop the regional RDF equation by regionalizing the parameters of the station-specific RDF equation as a function of mean annual precipitation, the elevation and spatial coordinates longitude and latitude. Note that the regional RDF equation is essentially developed for purposes of estimating an RDF curve for an ungaged site.

Fourth is to calculate the return period of the rainfall associated with typhoon *Iliang* for certain rainfall durations using the regional RDF equation for the Bakun area.

PROBABILITY ANALYSIS AND MODELING OF RAINFALL

Six candidate probability models are fitted to the rainfall data. These probability distribution models are: normal; lognormal; Pearson Type III (3-parameter gamma); log-Pearson Type III; Gumbel; and, general extreme value. Using maximum likelihood estimation and in some cases method of moments, the six probability models were fitted to the annual rainfall maxima data of each of the 10 rainfall stations for the three rainfall durations of 1-day, 2-day and 3-day.

The best fitting probability distribution functions were selected based on graphical comparison of empirical and fitted cumulative distribution functions as well as the chi-square and Kolmogorov-Smirnov goodness-of-fit-tests. Based on these tests, the Pearson Type III distribution fits most data sets, followed by both Gumbel and log-Pearson Type III and then the lognormal and general extreme value and the least is the normal distribution. From these results, it was decided that the Pearson Type III probability model be adopted to represent all data sets. The Pearson Type III distribution is written as:

$$f(x) = \frac{1}{|\alpha|\Gamma(\lambda)} \left[\frac{x - x_0}{\alpha} \right]^{\lambda - 1} \exp\left[-\frac{x - x_0}{\alpha} \right] \tag{1}$$

where x_0 is the location parameter, α is the scale parameter and λ is the shape parameter.

As mentione earlier, the Pearson Type III probability model is used to calculate the rainfall quantiles at different rainfall durations and return periods to form the historical rainfall-duration-frequency (RDF) curves for each station.

STATION-SPECIFIC RAINFALL-DURATION-FREQUENCY CURVES

The station-specific rainfall-duration-frequency (RDF) equation is essentially a parametric function fitted to the historical RDF curves computed earlier. The station-specific RDF equation adopted in this study is written as:

$$R_{T,D} = A_1 T^{A_2} D^{A_3} \tag{2}$$

where $R_{T,D}$ is the total rainfall (in mm) for a specific return period (in years) T and duration (in days) D ; and $[A_1, A_2, A_3]$ are model parameters.

This sation-specific RDF equation may be useful in smoothing the computed rainfall quantiles due to sampling variabilities or it can be used for extrapolation or interpolation purposes. The station-specific RDF equation can also be regionalized to estimate RDF curves for ungaged sites. The regional RDF equation is presented in the next section.

Using least squares method, the estimates of the parameters of $[A_1, A_2, A_3]$ of Eq. (2) are shown in Table 2. Note that Table 2 also includes the standard error SDe^2 of the model residuals (difference of observed and predicted rainfall quantiles).

To backforecast or predict the rainfall quantiles, Eq. (2) is rewritten to correct for bias (underestimation of predicted value) due to the use of logarithmic transformation in the least squares method. In this case, the prediction equation form of Eq. (2) is:

$$R_{T,D} = A_1 T^{A_2} D^{A_3} \exp [SDe^2 / 2] \qquad (3)$$

where the same notations are used as in Eq. (2) but with the additional term containing the standard error of the model residuals SDe.

For illustration, Figure 2 shows the plots of the predicted rainfall quantiles using the fitted station-specific RDF equations given in the form of Eq. (3) for Baguio City. Actually, the predicted values using Eq. (2) are very much similar to predicted values using Eq. (3) since the bias-correction factor $\exp [SDe^2 / 2]$ is almost equal to unity. Generally, the rainfall quantiles calculated using the station-specific RDF equations fairly reproduced the historical rainfall quantiles computed from the fitted Pearson Type III distribution.

REGIONAL RAINFALL-DURATION-FREQUENCY CURVES

To estimate the rainfall-duration-frequency (RDF) curve at an ungaged site, one can make use of the RDF curve developed from a nearby station provided that such station can be qualified so that information at that gaged site is transferrable to the ungaged site of interest. Transfer of information are made on the basis of proximity, similarity in topographic features, as well as homogeneity in climatic regions including geophysical factors. In the study area in particular, the RDF curves of the nearby rainfall stations namely Mt. Data, Adaoay and Atok, may be transferrable (utilized) to represent the RDF curve of Bakun, Benguet.

Another approach is the use of *regionalized* RDF equation defined within the region with say similar hydrometeorologic, topographic features or geophysical features. Then, this regional RDF equation can be used to estimate the RDF curve for an ungaged site. In this study, the regional RDF equation is based on regionalizing the parameters of the station-specific RDF equations in Eq. (2). Specifically, prediction (regression) equations are developed relating the $[A_1, A_2, A_3]$ parameters to extraneous (independent variables) information such as mean annual precipitation MAP, elevation EL, and the site coordinates longitude $LONG$ and latitude LAT. A linear regression model is adopted herein such that say the parameter A_1 is a linear function of one or more of independent variables. Various combinations of independent variables were tried. Based results of regression analysis, the model form selected for each parameter is given by:

$$A_i = \beta_0 + \beta_1 \, MAP + \beta_2 \, EL + \beta_3 \, LONG + \beta_4 \, LAT \qquad (4)$$

where A_i is i-th station-specific RDF equation model parameter and $[\beta_0, \beta_1, \beta_2, \beta_3, \beta_4]$ are the model parameters. Table 3 shows the values of the estimated parameters $[\beta_0, \beta_1, \beta_2, \beta_3, \beta_4]$ and coefficient of determination R^2.

For an ungaged site, the mean annual precipitation MAP is also needed in the estimation parameters of the RDF curve in Eq. (4). The MAP can actually be estimated based on contour maps of MAP in the study area if available. However, one can also develop a regional regression of MAP in a given region. Using multiple linear regression, the regional model of MAP adopted here is given by:

$$MAP = \beta_0 + \beta_1 \; EL + \beta_2 \; LONG + \beta_3 \; LAT \tag{5}$$

The parameters estimated for Eq. (5) are also given in Table 3.

For the Bakun site, the return periods for a given rainfall amount and duration can be estimated using the regional RDF equation in the form of Eq. (3) but with estimates of its parameters given by Eq. (4) as well as the MAP by Eq. (5). Specifically, the regional RDF equation parameters for Bakun site with elevation of 1500m, longitude of 120.6533 and latitude of 16.7864 (see Table 1), results in the following: MAP = 3536.29, A_1 = 322.835, A_2 = 0.178964 and A_3 = 0.554811. For these parameters, the return period in the Bakun site for 1-day rainfall amounts of 900, 950, 1000, 1050 and 1100 mm are 308, 416, 554, 728 and 944 years, respectively. Figure 3 shows the plot of the rainfall-duration-frequency curves of Bakun for the 1-day, 2-day and 3-day rainfall durations.

CONCLUSIONS

With regard to storm rainfall event associated to typhoon *Iliang*, in October 14, 1998, the observed 1-day rainfall at Bakun must be more than 1000 mm since the rain gage at that site overflowed and the gage can only measure up to a maximum of 1000 mm. In any case, even with 1000 mm rainfall, the return period associated with this storm rainfall depth at the Bakun site is 554 years thus signifying a *force majeure* event. It may be noted that the rainfall depth observed in Baguio City during the height of the storm in October 14, 1998 was 994 mm with an estimated return period of about 123 years. In La Trinidad, the observed rainfall during that day was 1116 mm which corresponds to a return period of 1147 years.

This study presented a methodology for ungaged site estimation as well as a regionalization technique of an RDF curve. In particular, the regional RDF equation developed in this study can be used for RDF curve computations at ungaged sites in the vicinity of the Benguet mountain region of the Philipines.

Table 1. List of gaging stations and pertinent rainfall data-related information

Station Name	*Elev (m)*	*Longitude*	*Latitude*	*MAP**	*Records**
Baguio City	1482	120.6000	16.4167	3810.2	1949-1997
Adaoay	1120	120.8250	16.6428	2215.7	1982-1992
Ambuklao	735	120.7417	16.4611	2088.4	1950-1996
Atok	1500	120.6667	16.5000	3271.7	1950-1981
Bauko	1290	120.8667	16.9936	2256.9	1964-1994
Cervantes	1370	120.6700	16.9753	3693.5	1979-1995
Itogon	914	120.6833	16.3667	3345.9	1961-1996
Mt. Data	2340	120.8667	16.8667	3102.7	1970-1995
Tubao	100	120.4167	16.3500	2520.0	1966-1997
La Trinidad	1400	120.5833	16.4500	3755.4	1976-1995
Bakun	1500	120.6533	16.7864	---	---

**MAP* = mean annual precipitation in mm, **Records* = years of data available

Table 2. Parameters $[\ A_1\ ,\ A_2\ ,\ A_3\ ]$ and standard error SDe^2 of the station-specific RDF equation [see Eq. (3)]

Station Name	A_1	A_2	A_3	SDe^2
Baguio City	453.817	0.1630	0.3969	0.000880966
Adaoay	122.122	0.2424	0.4878	0.002142424
Ambuklao	225.674	0.1498	0.5151	0.001064910
Atok	239.324	0.1622	0.6201	0.001861440
Bauko	207.313	0.1931	0.3259	0.002704658
Cervantes	329.618	0.2032	0.7205	0.008584515
Itogon	364.425	0.1511	0.4798	0.001388074
Mt. Data	214.459	0.1656	0.4949	0.001423200
Tubao	169.893	0.0987	0.8973	0.008265363
La Trinidad	404.441	0.1440	0.4046	0.001058567
MEAN	273.109	0.1673	0.5343	0.008809660

Table 3. Estimated parameters $[\ \beta_0\ ,\beta_1\ ,\beta_2\ ,\beta_3\ ,\beta_4\ ]$ of the regionalized parameter model in Eq. (4) of the regional RDF equation parameters $[\ A_1\ ,A_2\ ,A_3\ ]$ including those for *MAP* regional equation in Eq. (5). Also shown are the coefficient R^2 of determination of the fitted parameter models.

	β_0	β_1	β_2	β_3	β_4	R^2
A_1	-0.5286E+05	0.2035	-0.1021	450.0	-100.0	0.815
A_2	-0.1844E-06	-0.1244E-04	0.1787E-04	-0.008258	0.07104	0.406
A_3	-0.1053E-04	0.8171E-04	-0.0002304	-0.02433	0.2113	0.337
MAP	0.5379E+06	1.127	-4443.0	0.4996	---	0.754

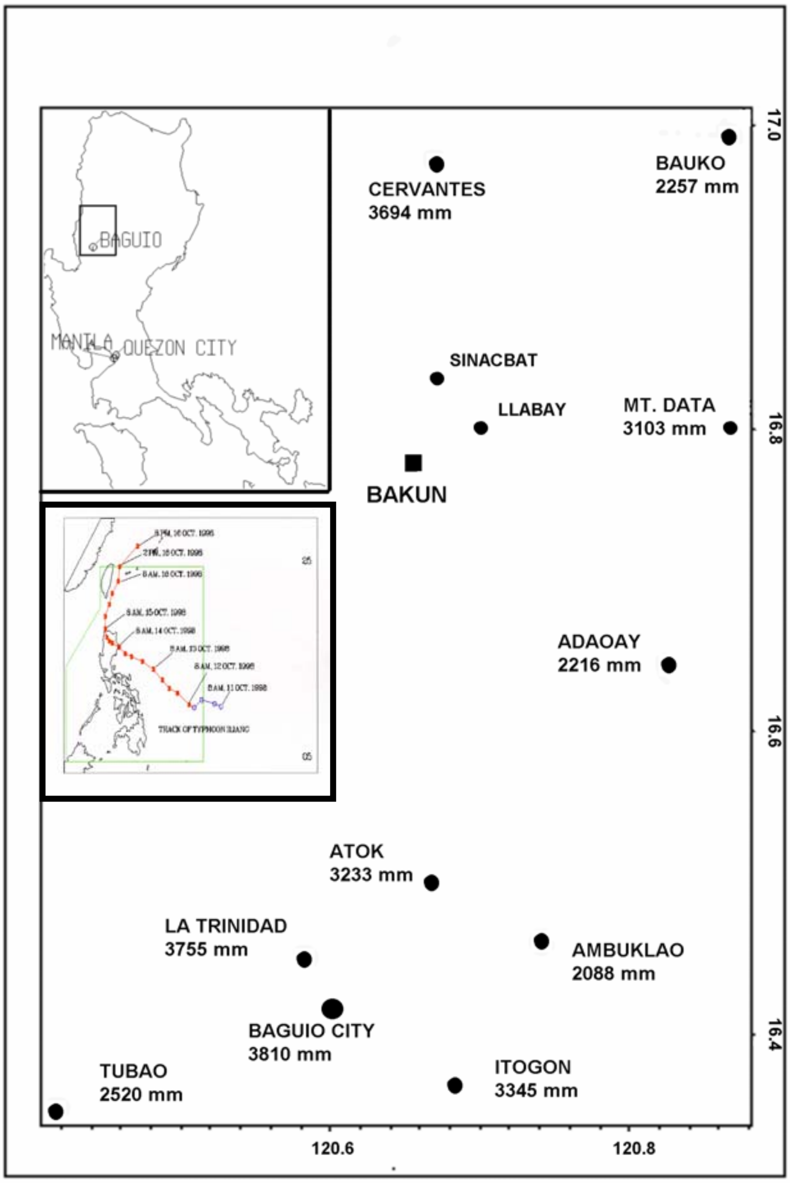

Figure 1. Location map of study area and rainfall gaging stations around Bakun, Benguet

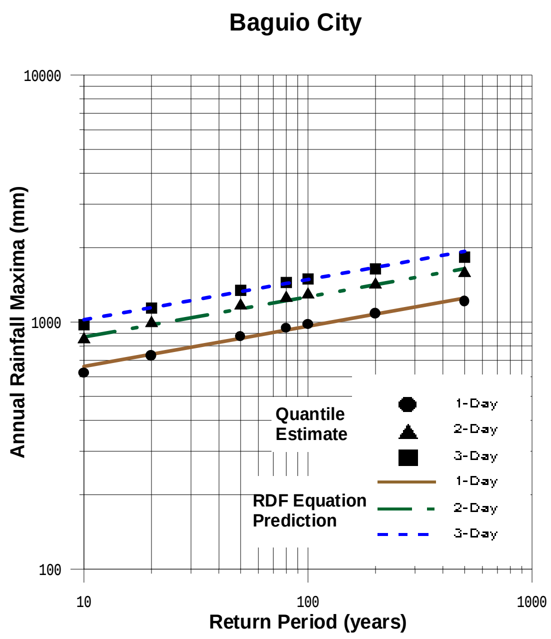

Figure 2. RDF curves for Baguio calculated from the station-specific RDF equation

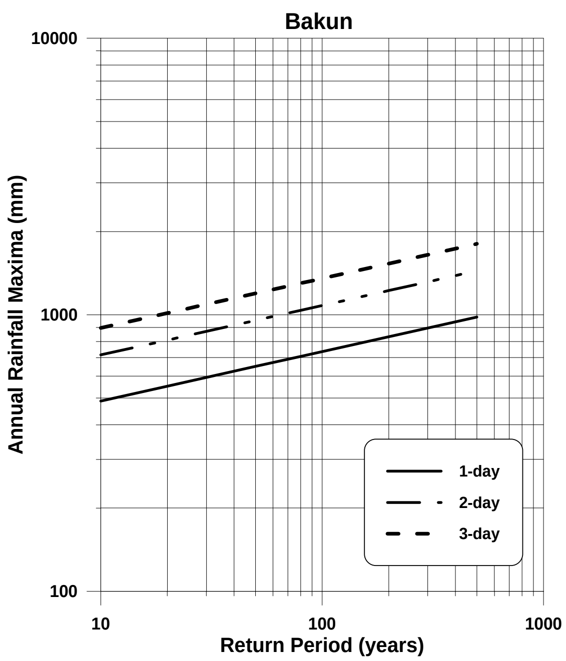

Figure 3. RDF curves for Bakun calculated from the regional RDF equations