Reliability of rainfall intensity prediction method for mine dewatering design in tropical region

Rudy Sayoga Gautama

Department of Mining Engineering
Institut Teknologi Bandung
Jl. Ganesha 10, Bandung 40132, Indonesia
Tel. +62-22-250 2239; Fax. +62-22-250 4209
E-mail : r_sayoga@mining.itb.ac.id

Abstract. Convective rainfall type which is very common in most mines in tropical region is characterized by its high intensity in short duration. For mine dewatering design purposes it is necessary to analyze the extreme rainfall intensity for a certain return period. Extreme value type I probability distribution is the most common used method for storm rainfall analysis. In this paper, the 2-year return period rainfall intensities are calculated for various data series and time periods. The results are compared to the observed rainfall data to see whether the prediction is considerably in line with the actual rainfall.

Background

Rainfall is derived from atmospheric water. The condensation is generated by dynamic or adiabatic cooling due to the vertical transport of air masses. According to the conditions that generate vertical air motion precipitation may be classified into three categories, e.g. convective, orographic and cyclonic. Convective rainfall is typical of the tropics and characterized by high intensity rainfall in a short duration. The heated air expands with a resultant reduction in weight, increasing quantities of water vapor are taken up, the warm moisture-laden air becomes unstable and vertical currents are developed. Dynamic or adiabatic cooling takes place, causing condensation and precipitation. Orographical precipitation results from the mechanical lifting of moist horizontal air currents over natural barriers such as mountain ranges. Both rainfall types commonly occur in tropical regions like Indonesia.

With a rainfall rate of 2000 mm to 5000 mm per annum, rainwater is the main water problem in almost all open pit mines in tropical regions like Indonesia. The tropic climate of Indonesia is influenced by the monsoon which divides the yearly season into dry and rainy seasons. At most mine sites the rainfall type is convective and in some mines orographic.

In a mining area the high intensity of convective rainfall will significantly reduce the effective working hours of mining operation. Certain rainfall intensity will cause muddy conditions, particularly in mining fronts, and the slippery haul roads. Due to operational and safety reasons the operation in such conditions is usually delayed. Data of November 2001 in Bukit Asam Coal Mining Area shows that total delay time due to rainfall and slippery haul road condition is 184.75 hours and it is 25.7% of the scheduled monthly working time.

To minimize the impact of rainwater on the mining operation it is necessary to define the appropriate design parameter for mine dewatering facilities. The main parameter is a predictive rainfall intensity with a certain level of probability of occurrence which accounts the hydrologic risk of dewatering facilities.

Storm Rainfall Analysis

Rainfall is considered as a random event and it varies geographically, temporally and seasonally. In designing the mine dewatering facilities it is necessary to understand the rainfall characteristics of the mining area. The most important characteristic is the extreme rainfall intensity and its probability of occurrence.

The method of storm rainfall analysis has been described in Chow et al (1988), Viessman Jr et al (1977) and Gautama (1997). Using historical rainfall data design rainfall intensity for a certain return period could be determined by applying extreme value probability distribution analysis (Chow et al, 1988; Kite, 1977). The data analyzed are assumed to be independent identically distributed, and the storm rainfall system is considered to be stochastic, space-dependent and time-independent.

The extreme value type I (EVI) probability distribution function (Chow et al, 1988) is

$$P(x<x_T) = F(x) = \exp(-\exp[-(x-u)/\alpha]) \qquad (1)$$

$$\alpha = \sqrt{6}.\ s/\pi \qquad (2)$$

If u = mode of distribution or point of maximum probability density,

$$u = \bar{x} - 0.5772\ \alpha \qquad (3)$$

A reduced variate *y* can be defined as

$$y = (x-u)/\alpha \qquad (4)$$

If reduced variate of the return period T is :

$$y_T = -\ln[\ln\{T/(T-1)\}] \quad (5)$$

for the EVI distribution, x_T is related to y_T by Eq. (4), or

$$x_T = u + \alpha\, y_T \quad (6)$$

Case study : Bukit Asam Coal Mining Area

Bukit Asam Coal Mining Area is one of the primary coal mining areas in Indonesia. It is located at the southern part of Sumatra Island in a transition zone between lowland in the west and Bukit Barisan mountainous range in the east. The area characterized by a hilly morphology with an elevation range between 50 to 300 m above sea level.

Rainfall Characteristics

The climate is influenced by a monsoon system. The annual rainfall for the last 12 years varies from 1577.5 mm/year to 3341.3 mm/year with an average of 2732.4 mm/year (see Fig. 1).The extremely low annual rainfall in 1997 is believed as the impact of El Nino phenomena.

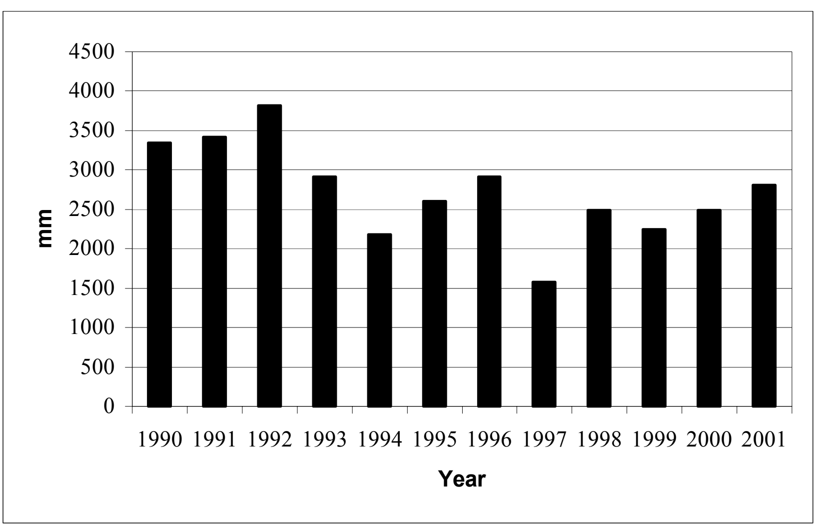

Fig. 1. Annual rainfall of Bukit Asam Coal Mining Area from 1990 - 2001

The monthly rainfall distribution which shows the maxima, minima and average monthly rainfall is given in Fig. 2. Considering the average values May to September are considered as dry months with rainfall less than 150 mm/month. The maxima values show that the monthly rainfall rate during rainy season, October to April, may be more than 500 mm.

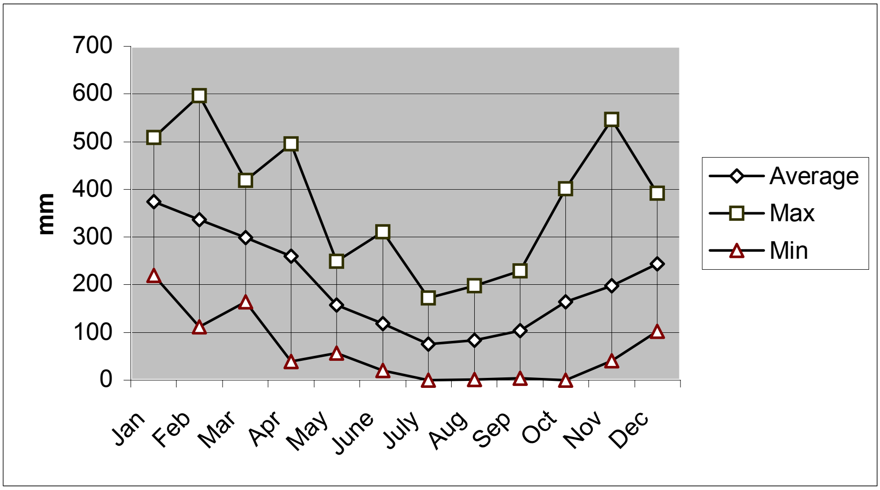

Fig. 2. Monthly Rainfall Distribution of Bukit Asam Coal Mining Area (data 1990-2001)

Rainfall Intensity Analysis

Using data derived from automatic rainfall recorder since 1990 storm rainfall for Bukit Asam Coal Mining Area has been analyzed. For the purpose to study the reliability of rainfall intensity prediction method, different types of data series and range have been chosen to determine the rainfall intensity of 2-year return period. Those are :

- Annual data series of 1990-1994
- Annual data series of 1995-1999
- Annual data series of 1990-1999
- Partial duration data series of 1990-1994
- Partial duration data series of 1995-1999
- Partial duration data series of 1990-1999

In hydrological analysis it is suggested to use annual data series to determine an extreme event with a defined recurrence period. But the problem faced by most of mines in Indonesia is the availability of long term rainfall data because the mines are developed in remote and undeveloped areas where usually no rainfall station available in the nearby area. In some mines the rainfall station was first installed during the construction phase.

Three types of annual data series will be compared to each other as well as to partial duration data series. The predefined base value for partial duration data series is the lowest annual maximum value of the records. The data analyzed is 60-minute-duration rainfall recorded at weather station in Bukit Asam Coal Mining Area.

The calculated 60-minute 2 year return period rainfall using Eqs. (2), (3), (4), (5) and (6) for various data series are shown in Table 1 as well as the respective sample size (n), mean ($\bar{x}$) and standard deviation (s) of the sample.

Table 1. 60-minute Duration Storm Rainfall Analysis of Bukit Asam Coal Mining Area

Data Series	Sample size, n	Mean, $\bar{x}$	Standard deviation s	2 year return period rainfall, x_T
Annual series of 1990-1994	5	71.82	24.90	67.73
Annual series of 1995-1999	5	56.66	5.19	55.81
Annual series of 1990-1999	10	64.24	18.75	61.16
Partial duration series of 1990-1994	18	61.76	15.08	59.28
Partial duration series of 1995-1999	13	54.79	4.29	53.54
Partial duration series of 1990-1999	34	58.23	11.85	56.29

Reliability Analysis and Discussion

The reliability of the results of frequency analysis depends on how well the assumed probabilistic model applies to a given set of hydrologic data.

Annual data series

The calculated 2-year return period rainfall of annual data series of 1990-1994 is 67.73 mm/hr which is the highest compared to the results of other annual data series and of partial duration data series. It is related to the high rainfall years as well as annual maximum values which can be seen from $\bar{x}$ and s of the sample (see Table 1). The exceedence of the 2-year return period rainfall intensities of annual data series for various time periods is given in Table 2.

A 2-year return period rainfall intensity means that the event has the probability to be equaled or exceeded once in two years or twice in four years. It may be noted that the 2-year return period rainfall intensity of 1990-1994 data series is over predicted during time period of 1995-2001 since it is never being equaled during that period. On the other hand the 2-year return period rainfall intensity of

1995-1999 annual data series is less than the predicted model because it has been exceeded twice by the annual maxima in 2 years (2000-2001). The best fit to the predicted model is the calculated rainfall intensity of annual data series of 1990-1999.

The exceedences by annual maxima are between 0.11 % and 0.58% of the total rain days of the respective time periods. The total exceedences are in general twice as much as the exceedence by annual maxima (see Table 2).

Partial duration data series

As in annual data series, the calculated rainfall intensity of partial duration data series of 1990-1994 is higher than the other partial duration data series because of higher rainfall intensities measured during this period as it is shown by the $\bar{x}$ value in Table 1. The calculated 2-year return period rainfall intensity of 1990-1994 partial duration data series is exceeded three times by annual maxima during 1995-2001 (see Table 2). It means that the frequency of occurrence of observed extreme rainfalls during that period is approximately as predicted by the model. The result of 1995-1999 and 1990-1999 partial duration series are under predicted since they have been exceeded 5 times in 7 years (1995-2001) and twice in 2 years (2000-2001) respectively.

The exceedences by annual maxima lie between 0.24% and 0.58% of the total rain days of the respective time periods. The total exceedences are between 0.36% and 1.46% of the total rain days (see Table 2).

Annual vs. Partial Duration Series

As it is shown in Fig. 3, the annual data series give higher results than partial duration data series. Comparing the results between annual and partial duration series of 1990-1994 during the time period of 1995-2001, it can be seen that the 2-year return period rainfall calculated from partial duration data series has the better prediction than that of annual data series. But for the 2-year return period rainfall of 1995-1999 data series, both series show a similarity in the results during the period of 2000-2001.

In term of exeedence by the annual maxima both annual and partial duration series are in general showing a similarity. But the total exceedences of the results derived from partial duration series are higher than those derived from annual series.

Table 2. Number of exceedence of the 2-year return period rainfall intensity

Remarks	X, T=2 yr	1990-1994		1995-1999		1990-1999		1995-2001		2000-2001	
		am	a	am	a	am	a	am	a	am	a
Total raindays (days)		933		838		1771		1181		343	
Annual series											
Period 1990-1994	67.73	2	3	0	0	2	3	0	0	0	0
% exceedence of total raindays		0.21	0.32	0	0	0.11	0.17	0	0	0	0
Period 1995-1999	55.81			3	6			5	10	2	4
% exceedence of total raindays				0.36	0.72			0.42	0.85	0.58	1.17
Period 1990-1999	61.16					3	5			1	2
% exceedence of total raindays						0.17	0.28			0.29	0.58
Partial duration series											
Period 1990-1994	59.28	3	6	2	3	5	9	3	5	1	2
% exceedence of total raindays		0.32	0.64	0.24	0.36	0.28	0.51	0.25	0.42	0.29	0.58
Period 1995-1999	53.54			3	7			5	12	2	5
% exceedence of total raindays				0.36	0.84			0.42	1.02	0.58	1.46
Period 1990-1999	56.29					7	15			2	4
% exceedence of total raindays						0.40	0.85			0.58	1.17

Notes : am = exeedence by annual maxima; a = total exeedence by extreme rainfalls

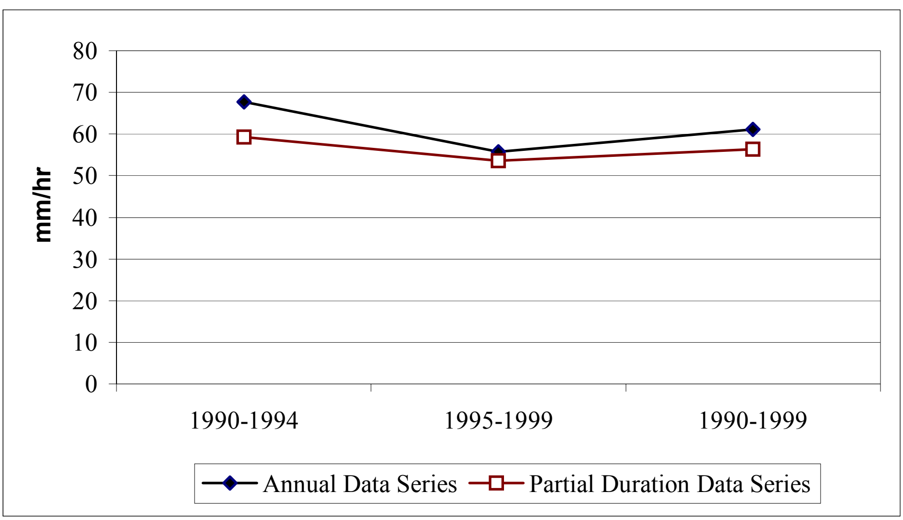

Fig. 3. Comparison of 2-year return period rainfall intensity for various data time period and data series.

Design parameter of mine dewatering facilities

The calculated 2-year return period rainfall intensity may be used as design parameter of mine dewatering facilities such as drainage ditches and pit collecting sump. As shown in Table 2, for the best prediction the use of annual data series with a sufficient record length is suggested. Big difference in magnitude between data series of 1990–1994 and 1995–1999 gives a significant difference in the results. It seems that minimum ten year data is required to make a good prediction so it can consider the climate variations.

If sufficient data is not available, for instance the data time period is less than 5 years, partial duration data series may be used. It is suggested, if possible, that the base value selected is the lowest annual maxima of the respective time period. Before using the calculated rainfall intensity for the design of mine dewatering facilities, it is advised to study the regional climate characteristics for a better prediction of the probability of exceedence in the future.

References

Chow V.T, Maidment D.R. and Mays L.W.(1988) Applied Hydrology, McGraw-Hill Book Company

Gautama R.S. (1997) Storm Rainfall Analysis : An Important Factor in Designing Mine Dewatering Facilities in Tropical Region, Mine Water and The Environment, Proceedings of 6th International Mine Water Association Congress, Bled, Slovenia, 235-242

Harto S (1993) Analisis Hidrologi, Penerbit PT Gramedia Pustaka Utama, Jakarta

Kite G.W (1977) Frequency and Risk Analysis in Hydrology, Water Resources Publication, Fort Collins, Colorado

Viessman Jr W, Knapp J.W, Lewis G.L & Harbaugh T.E (1977) Introduction to Hydrology, Dun-Donnelley Publisher, New York