Rainfall Spatial Distribution in Sumber Jaya Watershed, Lampung, Indonesia

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Abstract: As part of a larger hydrology study related to agroforestry in Sumber Jaya, West Lampung, Indonesia, the spatial distribution of rainfall within a 729 km^2 area was investigated. Manual rain gauges were set of 200 m, 1 km, 2-3 km and 8 km distances apart; other gauges were distributed at the fringe of the watershed at distances of 3.5 to 13.95 km from the centroid. River discharge was measured at three locations at distances ranging from 3.9 to 37.7 km from the centroid. Rainfall data were statistically analyzed to quantify various aspects related to the spatial distribution of daily and monthly catch at different locations in the area. Daily rainfall (mean = 25.66 mm/day) from rain gauges located 200 m from each other in a particular location showed that rainfall was homogenous; coefficients of correlation (r) between the gauges ranged from 0.85 to 0.93. Data from gauges separated by a distance of 1 km (17.69 and 19.93 mm/day) were also homogenous (r = 0.83). When rain catch was separated by distances of 2 to 3 km (14.31 mm/day), correlation coefficient was low (r = 0.23) and became progressively lower (r = 0.13) for gauges separated by 8 km (25.66 mm/day). All daily rainfall followed a gamma distribution, but the scale parameter (α) was different for the gauges located 8 km apart. Monthly rainfall followed a normal distribution: for different distances, mean rainfall was not significantly different, but variances were different. Rainfall in gauges separated by distances below 10 km in the center of the watershed were better correlated (r >0.7) compared with gauges separated by >10 km, and the highest correlation coefficient (0.88) was for stations separated by 3.5 km. Monthly rainfall and river discharge data were not highly correlated regardless of the distances.

Keywords: *Probability density function*

1. INTRODUCTION

Sumber Jaya is a large (729 Km^2) watershed in West Lampung, Sumatra, Indonesia that experienced rapid land use change in the past 20 years. Agroforestry systems are being introduced in the area to solve environmental problems caused by recent land use changes. To evaluate these effects, a research project is underway to evaluate the effects of these land use changes on watershed functions; part of this project is designed to investigate hydrological processes changes related to different land uses.

Rainfall heterogeneity obviously needs to be considered in a study of hydrological process in larger catchments area since it influences: runoff volume, peak flow, and hydrograph regime and infiltration dynamics (Bacchi and Kategoda, 1995; Connoly, 1998; Arnaud et al, 2002). However, some hydrology studies still rely on small numbers of point scale rainfall measurements and the problem of limited rainfall gauges is common in many watershed investigations, especially in developing countries (Goodrich et al, 1995; Grimes et al, 1999).

Therefore, prior to investigating watershed functions in Sumber Jaya, we examined the spatial attributes of rainfall in the area based on existing data.

2. RAINFALL DISTRIBUTION

Spatial distribution of rainfall is critical in mountainous watersheds like Sumber Jaya where weather systems interact with local topography resulting in highly non-uniform rainfall over the area (Michaud et al, 1995; Loukas and Quick, 1996; Arnaud et al, 2002). Topographic effects on rainfall vary seasonally. Most studies have found a linear or non linear relation between rainfall and station elevation - e.g., southwestern U.S.A. (Michaud et al.,1995) southwestern Bristish Columbia (Loukas and Quick, 1996) and Israel (Ben-Gai, 1998). However, there are indications that precipitation distribution does not always increases with topographic profiles such as studies by Daly et al (1994) in the Columbia Gorge of the Pacific Northwest U.S.A. Hatfield et al. (1999) in Central Iowa, U.S.A. and Wotling et al (2000) on the island of Tahiti.

Statistical analysis is commonly used to investigate rainfall patterns. Loukas and Quick (1996) used correlation coefficient for statistical association between the precipitation series at any two stations.

Michaud et al (1995) used regression model of local rainfall related to elevation, while Wotling et al. (2000) used rainfall intensity distribution and principal component analysis (PCA) to asses the complexity of the terrain in addition to the elevation. In general, differences in rainfall pattern may involve a combination of two statistical outcomes: a shift in the mean and a change in the scale of the distribution functions; the gamma distribution is a popular choice for fitting probability distributions to rainfall totals because its shape is similar to that of the histogram of rainfall data (Ben-Gai, 1998).

3. SUMBER JAYA

Sumber Jaya is located in West Lampung, South Sumatra, Indonesia ($4^o55'$ to $5^o10'$ S and $104^o19'$ to $104^o34'$ E). The entire study area is 729 km^2 and elevation ranges from 780 to 1700 m above sea level. Monthly rainfall in Sumber Jaya ranges from 329 to 1098 mm, with dry seasons from May to October and the rainy seasons from November to April. Topography of this area ranges from 0-8 % (35.09 % of the area); 8-15% (24.44% of the area); 15-25% (21.93% of the area); 25-40% (22.39% of the area) and >40% (1.53%of the area) (Sihite, 2001).

Rainfall stations were distributed inside the watershed (Figure 1) and additional rainfall gauges were set in some research plots in Bodong, Simpang Sari and between Simpang Sari and Bukit Rigis. Length of data collection and distances of the gauges are presented in Table 1.

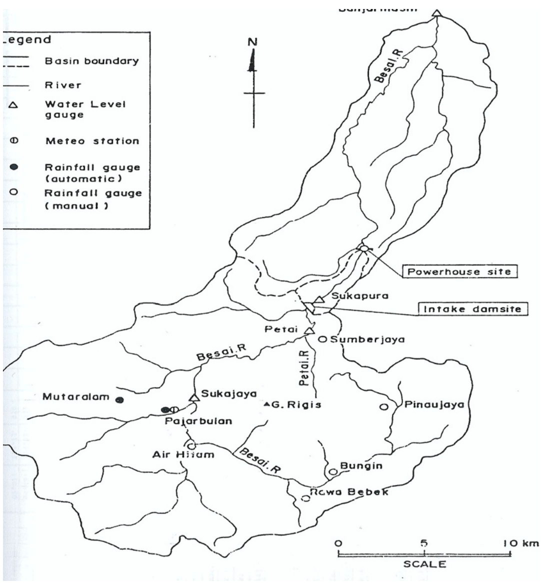


Figure 1. Rainfall and water level gauges locations In Sumber Jaya watershed

Table 1. Locations, length of data records and distances of rainfall gauges in Sumber Jaya Watershed.

Locations and elevation (m above sea level)	Length of data records	Distance from catchment center (km)
a. at fringe and center of the watershed	*Monthly*	
1 Air Hitam (805)	1974 - 1988	0
2 Pajar Bulan (810)	1974 - 1988	3.5
3 Bungin (820)	1974 - 1988	7.4
4 Rawa Bebek (812)	1974 - 1989	8.14
5 Sumber Jaya (720)	1973 - 1989	11.6
6 Pinau Jaya (825)	1973 - 1989	11.6
7 Sekincau (1000)	1973 - 1989	13.95
. At research plots in northern part of the watershed	*Daily*	
1 Simpang Sari	1984 - 2002	0
2 Laksana	2002	2
3 Tepus	2002	3
4 Bodong	1996 – 1998 2001 – 2002	8
c. Water level gauges	*Monthly*	
1 Suka Jaya (760)	1983 – 1988	3.9
2 Petai (720)	1974 – 1989	11.63
3 Sukapura (710)	1974 - 1989	13.9
4 Banjarmasin(701)	1972 – 1988	37.7

4. STATISTICS ANALYSIS OF SUMBER JAYA RAINFALL

4.1. Measures of Central Tendency, Dispersion and Symmetry

The most common indicator of the central tendency of a random variable (x) such as rainfall is its mean or average value (μ_x). The mean can be estimated as the arithmetic value $\overline{x}$ calculated as

$$\overline{x} = \sum_{i=1}^{n} xi \;/\; n \qquad (1)$$

where n is the number of observations.

The most common measure of dispersion about the mean is the variance or standard deviation. The standard deviation is calculated as:

$$\sqrt{\left(\sum x_i^2 - \sum x_i^2 / n\right) \big/ n-1} \qquad (2)$$

Many distributions are not symmetrical. They may tail off to the right or to the left and as such are said to be skewed. A relative measure of skewness can be obtained by dividing the difference in the mean and the mode by the standard deviation. The measure of sample skewness can be calculated as:

$$3(\bar{x} - x_{md})/s \qquad (3)$$

where x_{md} is the sample median and s is standard deviation. The mean, standard deviation and coefficient of skewness of Sumber Jaya rainfall data are summarized in Table 2 for various areas and periods of record.

Monthly rainfall mean values from stations around Air Hitam did not differ significantly from this central station based on t-test ($\alpha = 0.05$). However, all stations but one station (Bungin) had significant differences in variances compared to Air Hitam based on chi-squared test ($\alpha = 0.05$). Similarly, daily rainfall means from Laksana, Tepus and Bodong did not differ significantly from Simpang Sari (near the center of these stations) but variances were significantly different. The positive coefficients of skewness for all data indicated that data are skewed to the right. The higher skewness coefficients for daily data indicated that these distributions were less symmetric than monthly values.

Table 2. Central tendency, dispersion and symmetry of Sumber Jaya rainfall

Locations	Total (mm)	Average (mm)	S Dev	Coeff Skew
Monthly				
1Air Hitam	2691.05	224.25	115.60	0.64
2 Pajar Bulan	2556.81	213.07	119.94	0.50
3 Bungin	2479.79	206.65	91.63	0.28
4Rawa Bebek	2360.34	209.81	116.92	0.51
5Sumber Jaya	2422.99	215.38	133.44	0.09
6 Pinau Jaya	2768.04	261.43	158.61	0.41
7 Sekincau	2239.28	199.05	118.80	0.36
Daily				
Inside				
Bodong	3156	25.66	0.71	1.48
Bodong	2021.66	26.26	18.14	1.08
Tepus	2530.64	19.93	20.75	2.55
Laksana	2670.45	17.69	18.15	2.11
Simpang Sari	2289.86	14.31	14.52	2.38
Simpang Sari				
1984 –1989	12896.09	14.69	16.48	2.23
1990 –1994	13675.93	12.94	14.00	1.80
1995 –1999	13089.21	13.48	14.23	2.17
2000-2002	7460.81	13.97	14.51	1.63
1996-1998				
Bodong	3976.60	14.10	15.13	1.82
S Sari	3864.99	14.82	15.96	2.19

Changing pattern in rainfall can be shown by a shift in the frequency distribution rather than just in mean values (Ben-Gai et al, 1998); therefore we further analyzed the frequency distribution.

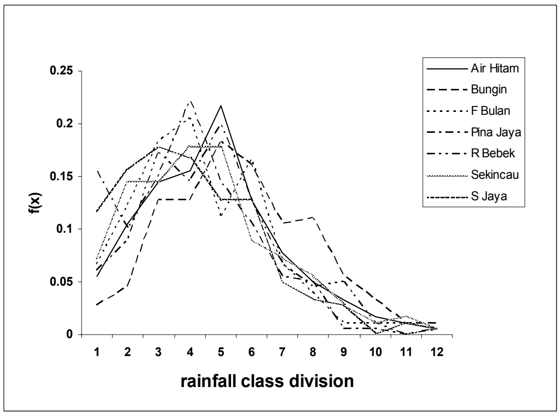
4.2. Probability Distribution

The most widely used and important continuous probability distribution is the Gaussian or normal distribution. Many statistical analyses rely on the assumption of normality and this assumption remains approximately valid when moderate shifts from normality occur (Haan, 1986).

The normal probability density function is generally written as (Chaw et al, 1988):

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(\frac{(x-\mu)^2}{2\mu^2}\right) \qquad (4)$$

When skewness coefficients for the monthly data were near zero, the probability distribution of the monthly rainfall is approximately normal (Figure 2), and this can be tested by using the chi-square testing of goodness of fit.



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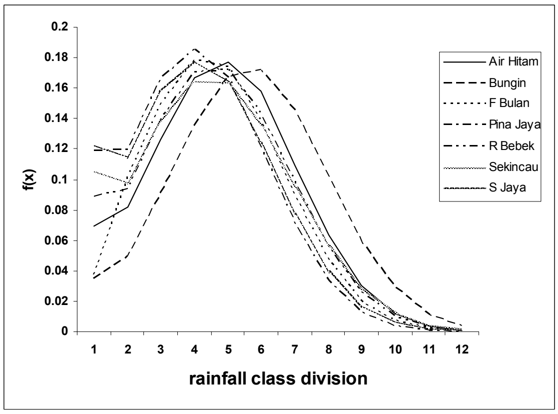


(b)

Figure 2. Comparison of probability distributions of monthly rainfall data from stations in Sumber Jaya watershed: (a) calculated and (b) the normal distribution

High skew coefficients (>1.0) for daily rainfall indicated that these data like most hydrological variables, followed exponential distribution.

A gamma distribution, sum of n exponentially distributed random variables, and has been applied to describe the distribution of precipitation depth. The probability density function for the gamma distribution can be expressed as (Gottschalk and Weingartner, 1998):

$$f(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \tag{5}$$

The expected value, the variance and the coefficient of skewness for this distribution are calculated from:

$$m_r = E(R) = \alpha\beta \tag{6}$$

$$\sigma_R^2 = Var(R) = \alpha\beta^2$$

$$C_s = 2/\sqrt{\alpha}$$

where α is the shape parameter, expressing the extent of the symmetry around the mode and β is the scale parameter, the area covered by the distribution.

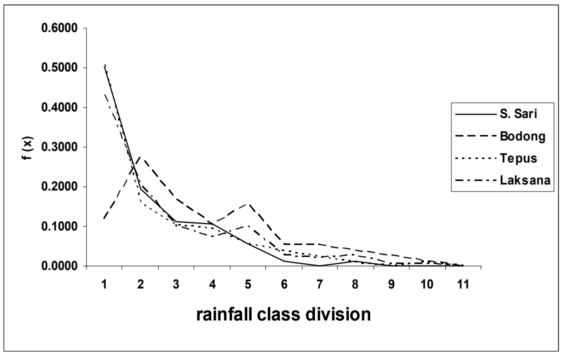
Table 3. Distribution parameters and correlation coefficients of calculated and predicted daily data.

Stations	α	β	r
Gamma 01-02			
1 Bodong	4.23	8.82	0.45
2 Tepus	1.18	19.13	0.91
3 Laksana	1.51	14.76	0.83
4 Simpang Sari	0.97	14.78	0.98
Exponential	λ		
1 Bodong	0.03		0.74
2 Laksana	0.06		0.98
Gamma 96-98			
1 Bodong	0.83	17.49	0.98
2 Simpang	1.21	13.76	0.98
Simpang Sari Gamma			
1984 –1989	0.80	18.41	0.99
1990 –1994	1.23	12.57	0.93
1995 –1999	0.85	15.42	0.99
2000-2002	1.51	11.81	0.86
exponential	λ		
2000-2002	0.07		0.98

Based on correlation coefficients between the calculated and predicted probability, Tepus and Simpang Sari best fit to the gamma distribution while Bodong and Laksana best fit the exponential distribution (also presented in Figure 3). These results showed that for distances of 2 km (S Sari-Laksana), daily rainfall distributions started showing differences, it was more obvious for distances of 8 km (Bodong to Tepus, Simpang Sari and Laksana).

The possibility of temporal changes in rainfall patterns can be analyzed using two locations that have longer daily records, Simpang Sari and Bodong (lower part of Table 2 and 3). For Simpang Sari both the mean and variance of daily rainfall in later years were not significantly different from the period of 1984-1989. All probability distribution were fit to a gamma distribution, although the period of 2000-2002 fit an exponential distribution better (Figure 4).

Bodong area, however, showed a significant difference from the period of 1996-1998 compared to the period of 2001-2002, both for means and distribution parameters (Figure 5). Thus it follows that Simpang Sari and Bodong (8 km away) should have different rainfall patterns.



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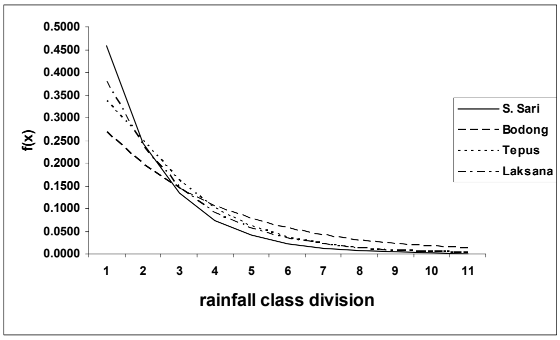
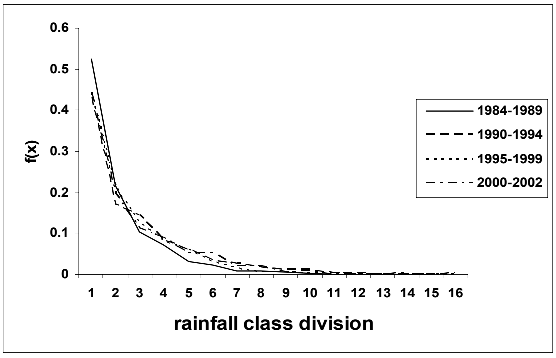


(b)

Figure 3. Comparison of probability distribution of daily rainfall data from research plots in Sumber Jaya Watershed, (a) calculated and (b) the gamma distribution.

Spatial distribution could also be investigated from correlations between distances and rain catch. Matrices in Table 4 showed that except for Pina Jaya that showed no correlations with any station, all stations with distances < 10 km from each other has correlation coefficients >0.7, the highest coefficient was 0.88 for stations with distance of 3.5 km.

For daily data, distances clearly affected the correlation coefficients. Gauges 1 km apart were highly correlated (≥ 0.83); correlation coefficients dropped to 0.22 -0.50 when stations were 5 km apart and to 0.13 were 8 km apart.



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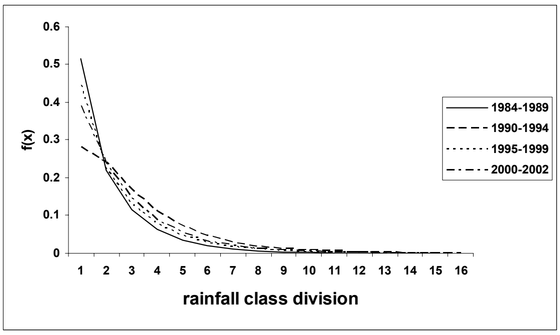
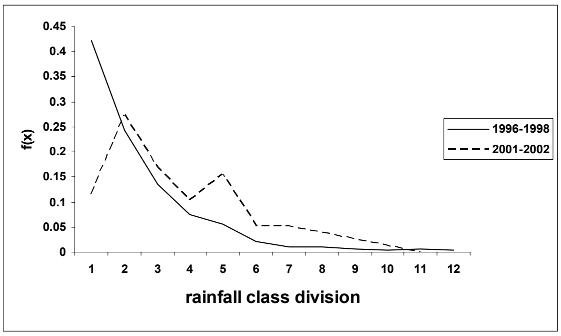


(b)

Figure 4. Comparison of probability distribution of daily rainfall data in Simpang Sari in different periods: (a) calculated and (b) the gamma distribution.



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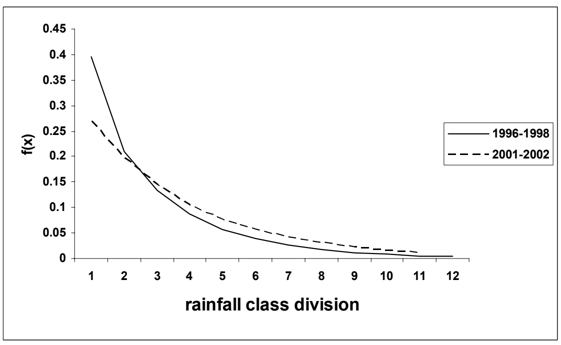

(b)

Figure 5. Comparison of probability distribution of daily rainfall data in Bodong in different period of years (a) calculated and (b) the gamma and exponential distribution.

Monthly river discharges were not significantly correlated to monthly rainfall based on different locations of gauges. Table 5 shows that except for Pina Jaya, which always had low coefficients, the correlation coefficients were just between 0.5 – 0.7.

5. CONCLUSIONS

Spatial variations in rainfall distribution in Sumber Jaya watershed were noted. Daily rainfall showed different deviations and low correlation over distances of about 2 – 3 km, while the distributions were different for distances of about 8 km. Monthly rainfall showed low correlations for location with distances > 10 km. The geographical positions of those stations have significant influence on the rainfall distribution; however, this preliminary study had not been able to cover that part. Monthly rainfall was not highly correlated with monthly river discharge; daily discharges might be more sensitive to rainfall but the data were not available at this time. These analyses suggest that hydrology studies in this area need denser rain gauges networks and the low correlation between rainfall and river discharges might indicate that the land use factors need further investigation.

6. ACKNOWLEDGEMENTS

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Table 4. Stations distances (km, in parentheses) and correlation coefficients of rainfall monthly data between stations in Sumber Jaya

Stations	Air Hitam	Bungin	Fajar Bulan	Pina Jaya	Rawa Bebek	Sekincau	Sumber Jaya
Air Hitam	**1.0** *(0)*	**0.72** *(7.5)*	**0.73** *(3.5)*	**0.12** *(11.6)*	**0.75** *(8.14)*	**0.70** *(13.95)*	**0.58** *(11.6)*
Bungin	**0.72** *(7.5)*	**1.0** *(0)*	**0.72** (9.8)	**0.13** *(6.04)*	**0.87** *(3.49)*	**0.65** *(22.79)*	**0.60** *(10.70)*
Fajar Bulan	**0.73** *(3.5)*	**0.72** *(9.8)*	**1.0** *(0)*	**0.12** *(12.56)*	**0.68** *(10.47)*	**0.63** *(12.33)*	**0.56** *(10.47)*
Pina Jaya	**0.12** *(11.6)*	**0.13** *(6.0)*	**0.12** *(12.56)*	**1.0** *(0)*	**0.16** *(8.60)*	**0.12** *(23.95)*	**0.13** *(6.51)*
Rawa Bebek	**0.75** *(8.14)*	**0.87** *(3.49)*	**0.68** *(10.47)*	**0.16** *(8.60)*	**1.0** *(0)*	**0.65** *(21.39)*	**0.56** *(13.26)*
Sekincau	**0.70** *(13.95)*	**0.65** *(22.79)*	**063** *(12.33)*	**0.12** *(23.95)*	**0.65** *(21.39)*	**1.0** *(0)*	**0.53** *(20.70)*
Sumber Jaya	**0.58** *(11.6)*	**0.60** *(10.70)*	**0.56** *(10.47)*	**0.13** *(6.51)*	**0.56** *(13.26)*	**0.53** *(20.70)*	**1.0** *(0)*
Daily	Simpang Sari	Laksana	Tepus	Bodong			
Simpang Sari	1						
Laksana	0.22						
Tepus	0.23	0.83					
Bodong	0.13	0.50	0.48				
Inside Bodong	0.85-0.93						

Table 5. Coefficient correlations between monthly rainfall and river discharge from rain and water level gauges in Sumber Jaya watershed

	Air Hitam	Bungin	Fajar Bulan	Pina Jaya	Rawa Bebek	Sekincau	Sumber Jaya
Suka Jaya	0.57	0.63	0.58	0.29	0.62	0.64	0.60
Petai	0.65	0.70	0.67	0.41	0.64	0.64	0.60
Suka Pura	0.65	0.70	0.67	0.39	0.64	0.64	0.62
Banjar Masin	0.67	0.64	0.57	0.55	0.58	0.53	0.64