Pattern of Spatio-Temporal Rainfall Distribution

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Abstract

Series of rainfall dataset have been analyzed to determine spatial and temporal rainfall distribution through statistical and wavelet analysis. Both methods were introduced to bring information of rainfall pattern in Tana Toraja Regency based on rainfall dataset collected from 4 climatology stations of Tana Toraja during 1991- 2000. Temporal and spatial distribution was determined from statistics calculation of monthly rainfalls, meanwhile wavelet analysis was used to analyze the pentad and monthly rainfalls.

Results of statistical analysis for temporal distribution show an equatorial climatic pattern. This pattern was more-likely generated due to orographic conditions at the west side causing rainfall delay during the west monsoon. Consequently monthly rainfall reaches its maximum in April and is intensified by enough radiation as the sun locates near the equator during the period. While the output of wavelet analysis pointed that the dominant is period of 64 pentads and annual. Period of 64 pentads and annual can be associated as monsoon effect. On the other hand, statistical analysis result plotted in monthly rainfall contour from January to December shown rainfall distribution is increase to north and east which dominated by mountainous area vice versa. Annual distribution shows that annual rainfall tends to increase toward northeast. This pattern arises due to the difference in air temperature between mountainous region and surrounding lowland.

I. Introduction

Pattern and dynamic of rainfall distribution of the region has its own local variation. Both are interesting to study due to their important contribution in regional planning, especially in agriculture.

Agriculture and tourism potentials of Tana Toraja Regency can be expanded when they are supported by optimal land-use and infrastructure plans. Knowledge of climate and other aspect could be involved in the decision management to realize these plans.

The rainfall data was chosen due to its random fluctuation from time to time. In parallel with its characteristics, wavelet transformation has been employed, instead of Fourier transformation as a tool for analysis. It can cover the transient and fluctuation over time.

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The basic data in this study was obtained from the daily rainfall recorded in the climate station. The data was selected based on their completeness and continuity. The consistency test was applied to test their quality.

The scope of the study is limited to the investigation of spatial and periodical patterns of rainfalls using wavelet transformation. The Morlet wavelet was used as mother wavelet. The purpose of the study was as follows:

1. To investigate the spatial and temporal patterns of monthly and annual rainfall in Tana Toraja.
2. To investigate the periodicity of daily and annual rainfall in Tana Toraja.

II. Literatur Review

1. Rainfall Pattern in Indonesia

In general the rainfall pattern can be categorized into three patterns:

(1) Monsoon Pattern

Monsoon pattern was characterized by pattern shape of unimodal (one peak rainy season). Monsoon occurs due to alternate appearance of high and low pressure cell at the Asian and Australian Continent. The period of December-January-February (DJF) is the winter season in the northern atmosphere and induces the high pressure cell in the Asian Continent, and at the same time, the summer season appears in the southern atmosphere and induces low pressure cell in the Australian Continent. The difference of the air pressure betweem both continents in DJF period results in the wind blows from the high pressure cell in Asia toward the low pressure cell in Australia. This wind was called west monsoon or north-west monsoon. In contrary, in the period of June-July-August (JJA), low pressure cell appears in Asia and high pressure cell appears in Australia. This phenomena induces east monsoon or south-east monsoon.

In the transition period between west and east monsoon which was in March-April-May (MAM) and September-October-November (SON), the wind direction will be fickle and weak. These transition periods are called '*pancaroba*'.

The west monsoon is usually more humid than the east monsoon. This difference could be attributed to (1) the air goes down during the east monsoon and goes up during the west monsoon, and (2) during the east monsoon, the air current goes up within short distance of the sea. Meanwhile, during the west monsoon, the air current goes up over long distance of the sea and consequently absorbs enough vapor.

(2) Equatorial Pattern

Equatorial pattern is characterized by bimodal shape (two peaks of rainfall) which occurs around March and October. In these periods, the sun is approaching the equator. The Equator pattern related to the movement of convergence zone to the north-south direction follows the pseudo-movement of the sun.

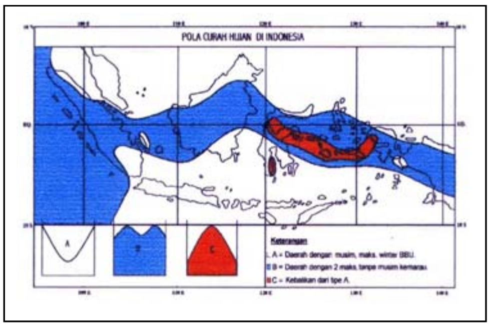


Figure 1 Rainfall Patterns in Indonesia
(Source: Geophysics & Meteorology Agency)

(3) Local Pattern

This pattern is characterized by unimodal shape (one peak rainfall) but opposite to the monsoon pattern. The local pattern was strongly influenced by local condition. The governing factor is inclination of the air to the high land or mountain, and the unbalanced local heat [Bayong 1999]. According to Langitan [2002], mountainous region is physically affected by the air movement. Orographic rain occurs through the condensation process when moist air is pushed upward and cooled. The rainfall intensity of windward side will be high and the lee ward will be very low.

2. Topography and Climate Pattern of Tana Toraja

Tana Toraja lies in the mountainous area ranging from 150 to 3000 msl., consisting of 40% mountainous, 20% high land, 38% lowland and 2% river and swamp (www.toraja.go.id).

The climate type of Tana Toraja is A type (wet tropical) with 11 wet months and annual rainfall distributes from 1500~2000 mm (19.37%), 2000~2500 mm (23.03%), 3000~3500 mm (13.79%), 3500~4000 mm (20.95%) to more than 4000 mm (9.36%) (www. bppmd-sulsel.go.id).

3. Rainfall Data Analysis

(1) Consistency Test

The rainfall data is a valuable source if it is used to a certain specific purpose. However, before it is used for hydrological analysis, it is necessary to check the data. Some error can arise from several factors: human, equipment and location. If error occurs, then the data should be claim as inconsistent. The consistency test means testing the truth of the data. The rainfall data can be said to be consistent means when the measured and calculated data is accurate and valid following the natural phenomena [Soewarno 2000]. In this study, the least square method was adopted, and the consistency of the data was determined by linear relationship between the data of a particular station and those obtained at its neighbors.

(2) Descriptive Analysis

The daily rainfall was accumulated as monthly rainfall and further it can be collected as annual rainfall. The monthly rainfall gives a unique feature for the climate characteristic of a certain area. Statistical record of daily, monthly and annual rainfall can be composed according to time series to give return period and its anomaly through the fluctuation of the record over time.

(3) Wavelet Analysis

Wavelet was the mathematical function which divides the data into frequency component with the resolution according to certain scale. Comparing to Fourier method, wavelet has advantages to be applied in the signal which has discontinuity and strong transient fluctuation [Grapps 1995].

Wavelet analysis uses mother wavelet as a basic function to derive other functions. In the application, many wavelets can be applied. In this study, the Morlet wavelet have been chosen as a basic wavelet, which has been commonly used in geophysics. Morlet wavelet consists of exponential complex forming from sinusoid wave by Gaussian function. The equation of the mother wavelet for the Morlet wavelet is:

$$\psi_0(\eta) = \pi^{-1/4} e^{i\omega_0 \eta} e^{-\eta^2/2} \qquad (1)$$

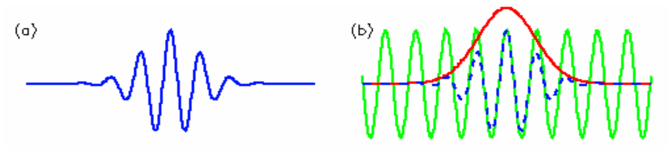


Figure 2
(a)Morlet Wavelet (b)The governing morlet wavelet from the sinusoidal wave (source:http://paos.colorado.edu/research/wavelets/)

Where ψ was dimensionless at η and ω_o was wave number, we choose $\omega_o = 6$, which gives oscillation and the overall average was zero.

Wavelet analysis through wavelet transformation is recent mathematical tools. It suits to the study of multi-scale non-stationare process in time and spatial domain. If we assumed X as *time series with* data x_n at index n and every x was divided into constant interval time δt, then the wavelet transformation can be calculated in the Fourier 'manner':

$$W_n(s) = \sum_{k=0}^{N-1} \hat{x}_k \hat{\psi}^*(s\omega_k)\, e^{i\omega_k n \delta t} \qquad (2)$$

By previously doing the Fourier transformation of the time series X_n :

$$\hat{x}_k = \frac{1}{N} \sum_{n}^{N-1} x_n\, e^{-i2\pi k n/N} \qquad (3)$$

Fourier transformation of the function $\psi(\eta)$ in the continue limit given by $\hat{\psi}(s\omega)$

where $\omega_k = \dfrac{2\pi k}{N\delta t}$ (4)

k = 0 ... $N-1$ frequency index

ω_k positive for $k \leq N/2$ and ω_k negative for $k > N/2$, and the sign ^ representing Fourier transformation.

To ensure that the wavelet transformation in each scale s was comparable with others, the wavelet function at each s scale was normalized into energy unit:

$$\hat{\psi}(s\omega_k) = \left(\frac{2\pi s}{\delta t}\right)^{1/2} \hat{\psi}_0(s\omega_k) \qquad (5)$$

To give an overall view of the Power Spectrum (PSW), the local spectrum was averaged to time at certain period for all PSW, which gives Global Spectrum:

$$\overline{GS} = \frac{1}{N} \sum_{n}^{N-1} \left| W_n(s) \right|^2 \qquad (6)$$

GS was used to show the dominant period of the PSW and the fluctuation of the PSW in a certain band can be determined through averaging the PSW at scale s_1 and s_2 as follow:

$$\overline{PSW}^2 = \sum_{j-j_1}^{j_2} \frac{\left|W_{(s,\tau)}\right|^2}{s_j} \quad (7)$$

$\overline{PSW}$ was the average period of the time series at a certain band. PSW can be used to show the modulation of a time series to others or modulation of a frequency to others in the same time series.

III. Methodology

1. Location

In this study the rainfall data was collected from 4 stations in three district: Rindingallo, Sesean and Saluputti in Kabupaten Tana Toraja. Those 4 stations were: Pangala/Rindingallo Station (119° 48' 34.95" EL and 2° 51' 37.32"SL), Toa'o/Rindingallo Station (119° 48' 6.55" EL and 2° 53' 55.01" SL), Parappo/Saluputti Station (119° 46' 51.18" EL and 3° 4' 42.38"SL), and Rantepangli/Sesean Station (119° 56' 35.98" EL and 2° 55' 40.90"SL). The 10 years daily rainfall data record was used as a basic data.

2. Data Testing and Analysis

(1) Consistency Test

Before consistency test was executed, the daily rainfall was composed to get the monthly and annual rainfall. The consistency test was employed by comparing two variables, say X and Y, in which Y was the annual rainfall data of the considered station and X was the average of the annual rainfall of the surrounding stations.

(2) Descriptive Analysis

In the descriptive analysis, the daily rainfall was composed to get the monthly and annual rainfall over years. To get a spatial picture of rainfall distribution, the contour of the rainfall intensity was drawn according to the monthly and annual rainfall.

(3) Wavelet Analysis

The daily rainfall was composed to get pentad (five days) and monthly rainfall. Those time series were transformed using Fourier transformation (by eq. 3). After selecting the initial scale, the wavelet transformation was executed by using eq. (2), and normalized by eq. (5). The process can be repeated for different scale by using eqs. (2) and (5).

IV. Results and Discussions

1. Results of the Consistency Tests

The consistency test resulting in the determinant of approaching almost to 1 (see Table 1), indicated a linear relation between the considered station and its surroundings. It means that the data of all stations have a good consistency.

Table 1 Results of the Consistency Tests

Station	Determinant (R^2)
Pangala	0,9984
Toa'o	0,9988
Parappo	0,9968
Rantepangli	0,9969

2. Temporal Analysis of the Rainfall

Results of statistical calculation as shown in Figure 3 indicates that the maximum rainfall of all stations in Tana Toraja occurs around March and April (more than 300 mm/month) and its minimum occurs around August and September (less than 100 mm/month). This pattern of rainfall was influenced by local and geographic effects.

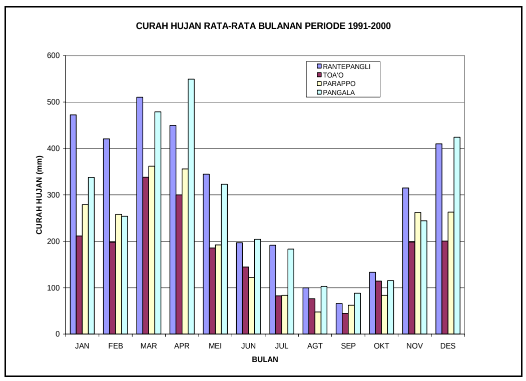


Figure 3 Average annual rainfall (1991-2000)

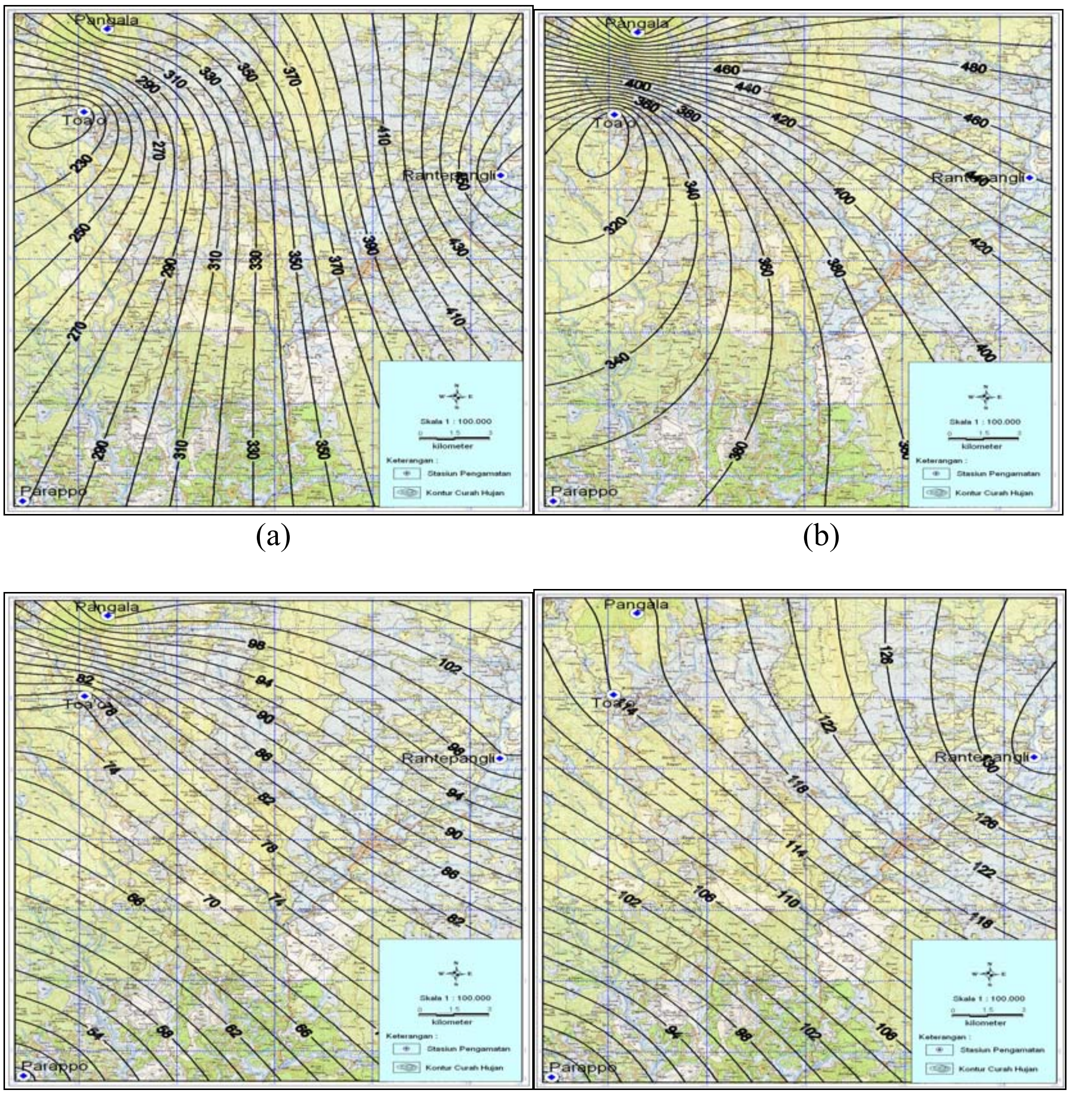
The highland which surrounds the Tana Toraja region gives significant effects on the rainfall in this area. The surface relief along the northern and north-eastern sides is mountainous with heavy forest vegetation. The orography on the west side functions as physical barrier in the west monsoon season. Consequently, the peak of rainfall in this area occurs around March-April-May (MAM), which is actually the transitional period from the west monsoon to the east monsoon. The geographic position which is close to the equator also influences the quantity of the rainfall. As the period of high radiation take place every 6 months during the transitional period, the equatorial pattern is formed with bimodal rainfall pattern.

3. Spatial Analysis of the Rainfall

(1) Distribution of Monthly Rainfall

The spatial distribution of the monthly rainfall in Tana Toraja can be shown through series contour (see Figure 4). In January, the rainfall in Tana Toraja was in the range of 220 mm/month to 470 mm/month. The lowest rainfall was recorded at Toa’o station (220 mm/month) and the highest was recorded at Rantepangli station (470 mm/month). The rainfall in this month tends to increase toward the east direction. The same trend also occurs in February.

The rainfall in April was the highest in the Tana Toraja, and it ranges from 310 mm/month to 540 mm/month. It forms a minimum closed closure around Toa’o station and a maximum closure around Pangala station in the north. It tends to increase toward north direction. The same pattern was also observed in March, a tendency of increasing from the southwest side (Parappo station) toward maximum area in northern side (Pangala station). In August, the rainfall intensity was relatively low, ranging from 48 mm/month to 104 mm/month. The pattern showed the declining one from the maximum area in the northern side (Pangala station) to the minimum area in the northwest (Parappo station).



(c) (d)

Figure 4 Monthly rainfall map of Tana Toraja
(a) January, (b) April, (c) August, and (d) October

The pattern of spatial distribution changes its direction to east-west in October. It moves from Parappo station to Rantepangi station. The rain intensity was in the range of 86 to 132 mm/month. The similar tendency also occurs in November, but the minimum rainfall was observed at Toa’o station. In December, the rain turns to the north with the minimum area being similar to November.

The spatial pattern moves uniformly in each month. It moves to the north and turns to the south during a certain period. This movement also followed by movement of maximum closure from the east to west and movement of the minimum closure from the west to northwest, alternately. West monsoon wind does not so significantly influence the west side due to the mountainous barrier. Consequently, in the west area (Toa’o and Parappo stations), which becomes the lee area in this season, receives less rainfall.

In the east/southeast monsoon and the transitional periods, the rainfall moves to the northern direction in this area. This phenomena was affected by local temperature circulation. The temperature of highland in the northern area (2000-3000 msl) decreases as the increase of the altitude.

(2) Spatial Pattern of Annual Rainfall

During 1991 to 2000, the annual rainfall intensity in the western area was relatively low and tended to increase toward southwest, ranging from 2200 mm/year to 3600 mm/year (see Figure 5). The minimum rainfall intensity was observed at Toa’o station (2200 mm/year) in the west and the maximum was at Rantepangli station (3600 mm/year) in the east side.

The average temperature in the highland such as mountainous area is lower compared with lowland. It is due to the change in the atomospheric pressure, because the air in higher land can not keep more heat in comparison with lower land. This situation induces the movement of the air from the lowland to the highland and causes relatively wide cloud cover which increases the probability of rainfall in mountainous area. The increase of elevation along the western to the northwestern area is closely related to the quantity of the rainfall. This fact is also found from the annual rainfall map of South Sulawesi as shown in Figure 6. It moves from the north to teh southwest direction.

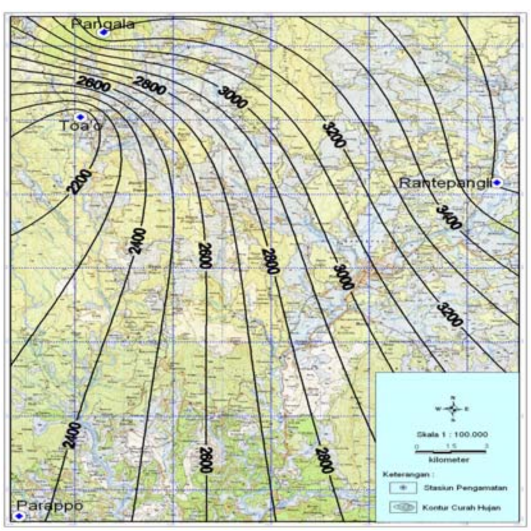


Figure 5 Map of Annual Rainfall in Tana Toraja (1991-2000)

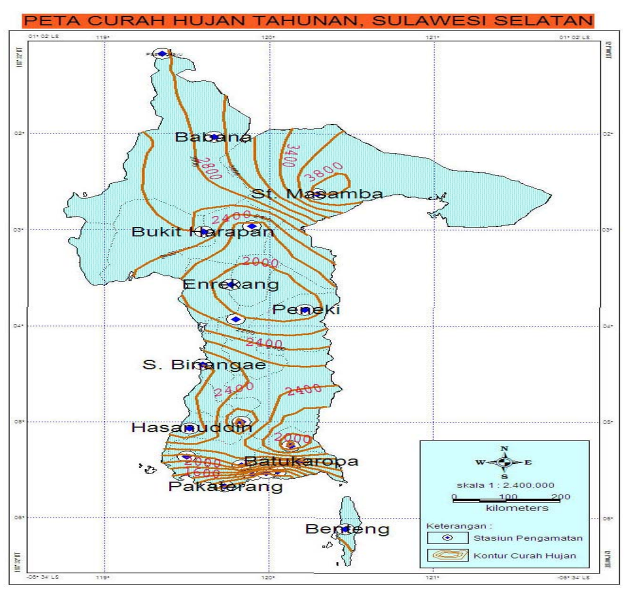


Figure 6 Annual Rainfall Map in South Sulawesi in the period of 1984-2002 (*source:Ferawaty,2005*)

3.Periodicity Analysis

Periodicity spectrum of the rainfall of all stations in Tana Toraja shows the similar pattern, which was 64 pentads or 1 year. As shown in Fig. 7c, Rantepangli station gives the period of 64 pentads or 320 day (input data in pentad). The same trend was also shown in Fig. 8c for input time series, in which monthly rainfall gives dominant period of 1 year. This indicates that Tana Toraja is influenced by west monsoon every year in the period of DJF.

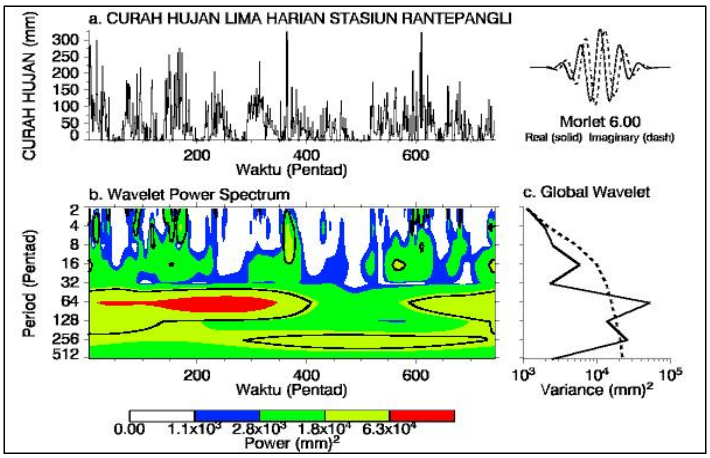


Figure 7 Periodicity spectrum of daily rainfall recorded at Rantepangli station **a)** Pentad rainfall. **b)** Wavelet Power Spectrum. The black contour line was 10% significant c) The dash line: Global Wavelet 10% significant

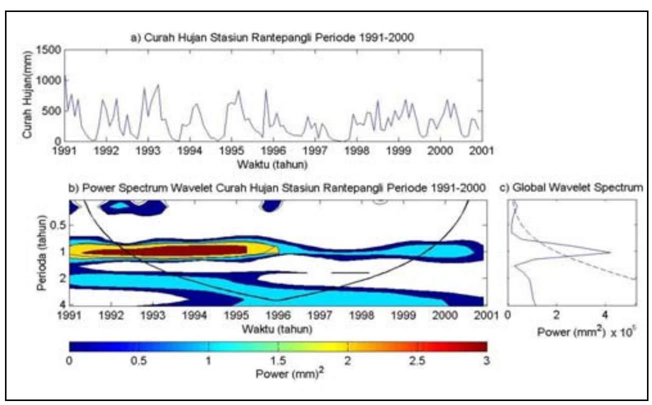


Figure 8 Periodicity spectrum of monthly rainfall recorded at Rantepangli station **a)** Pentad rainfall. **b)** Wavelet Power Spectrum. The black contour line was 5% significant. c) The dash line: Global Wavelet 5% significant

V. Conclusion

Conclusions obtained from this study are as follows:

1. The spatial pattern of the monthly rainfall is relatively uniform which has a tendency to move to the north and the east in highland. The annual rainfall moves from the west to the southwest. This distribution can be attributed to the differences in air temperature between highland and lowland in the area.
2. The periodicity of 64 pentads (320 day) or 1 year in this area indicates that the rainfall is influenced by the west monsoon.

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