

LONG TERM RAINFALL TREND OF THE BRANTAS CATCHMENT AREA, EAST JAVA

Edvin Aldrian

edvin@webmail.bppt.go.id

UPT Hujan Buatan – BPPT, Jl. MH Thamrin No 8, Jakarta 10340

Yudha Setiawan Djamil

UPT Hujan Buatan – BPPT, Jl. MH Thamrin No 8, Jakarta 10340

ABSTRACT

Spatial and temporal rainfall analyses of the Brantas Catchment Area from 1955 to 2002 based on 40 daily rainfall stations has been performed. To identify the climate pattern for the last five decades, we used the Empirical Orthogonal Function (EOF) followed by the Fast Fourier Transform. By using EOF, we found the monsoonal pattern as the most dominant, which explains about 72% of all variances. The interannual pattern shows a negative trend of the monsoonal strength. From the monthly isohyets for each decade, the rainfall amount appears to decrease significantly during the last five decades, indicated by wider low rainfall amount areas and the orographic effect is detected, indicated by always greater amount in highlands. From rainfall data in mountain and coastal areas, dry periods had been increasing, mainly in lowlands. Thus, the continued imbalance of the dry and wet period is one cause of the monsoonal strength decrease during the last five decades.

Key words: spatial rainfall trend, Brantas, EOF, climate change

INTRODUCTION

According to the IPCC report [IPCC, 2001], the surface temperature of the earth will raise steadily during the post industry era of the 19th century. Some of the impact of the global climate change is a change of rainfall pattern on a local or a regional scale. Global or worldwide assessment of the impact of global climate change has been done by using global climate model, a tool relatively available as public domain. On the regional scale, the study of local and regional impact of rainfall pattern change is quite rare, especially for Indonesian rainfall. Study of the character of Indonesian rainfall characteristics has been performed by *Aldrian* and *Susanto* [2003] and the regional rainfall climate modeling study has also been performed by *Aldrian et al.* [2004]. While studying on the characteristics of Java

rainfall has also been discussed [Anzhar, 1996]. It is interesting to see past changes of the rainfall pattern during previous decades not from the model result but from the real observed data. One of the interesting areas for such a study is the Brantas catchment area in east Java province. The data from this area has been collected daily for quite a long time (almost five decades). With a good spatial and temporal coverage, those data is a valuable source of information of the local climatic changes could be assessed. The result of this study will be useful in understanding the local impact of the global climate change. Besides, spatial assessment of climate impact and its trend is relatively a new topic for rainfall study in Indonesia. On a local scale, climate pattern change is important for farmers in deciding their plantation period and plantation area.

The Brantas catchment covers about 12.000 km² or about 25% of the area of East Java Province. The total length of the river is 320 km, which goes around an active volcano the Mount Kelud, while the Brantas River itself is the second largest river in Java. The annual average of rainfall amount reaches 2000 mm and about 80% of those falls during the rainy season. Total potency of surface water reaches 12 billion m³, while total reservoir capacity in the area is only 2.6 – 3 billion m³ yearly. People live in the Brantas basin was about 13.7 million in 1994 (about 16 million nowadays) or about 43.2% of total East Java population. The population density over the basin area is about 1.5 times of the provincial average.

Considering the importance of the Brantas catchment area to the local and regional economy, a study of long-term climatic trend is essential. This study will focus on rainfall data collected over the catchment area and the long term spatial, temporal and trend of the climate over the Brantas catchment area. Such a study is important for understanding the water potency at the surface and in the atmosphere. Whether there are changes of climatic behavior in recent decades temporally or spatially is important for future projection of the water management. The study is limited to temporal analyses from monthly to decadal. Climate factor for higher frequency from daily up to intraseasonal will be disregarded in this study. In doing so, the outline of the study is divided into following; the next section will discuss the data and method of analyses follows by some results. Then we will discuss some topics related to various result and the final section will conclude by some highlights found here.

Rainfall Data

We used daily rainfall data from 40 rain gauge stations over the catchment area or an area bounded from 07.2°S to 08.4°S and from 111.5°E to 113.0°E (see Fig. 1). Those data is managed and collected by the Brantas catchment authority or Perum Jasa Tirta I. The analyses are conducted to rainfall data from 1955 in to 2002. Since we are dealing with long-term climate trend, thus we rearrange the data from daily into monthly data. Before we change the data type into monthly, we check the data consistency and missing data. There were some missing data on

daily data, but using spatial gridding method, the missing data could be disregarded spatially.

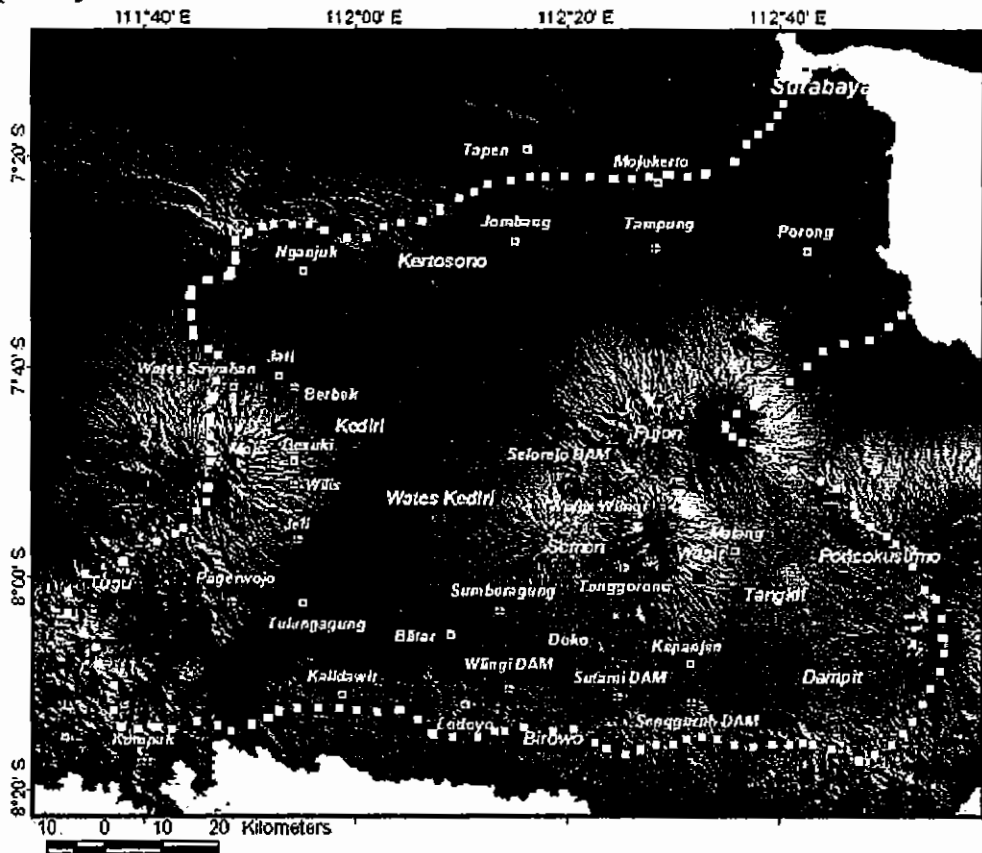


Figure 1. Catchments Area of the Brantas River basin, East Java (dashed line represents the catchment border) and rain gauge stations used in this study.

For the data consistency, there is a problem of data before and after 1991. Before 1991, all rain gauge station recorded manual data from each rain gauge taken once daily in the morning. Since beginning of 1991, data were recorded automatically, thus the record will measure instantaneous data not once a day. With such different measurement method, there was a consistency problem from data before and after 1991. In the daily data before 1991, the total daily evaporation is not taken into account. As a result there is about 40% differences between monthly rainfall before and after 1991, where the later data is higher. In order to adjust the data before 1991, we used the result of a regional model simulation over the area [Suwarman and Aldrian, 2004] to obtain the daily evaporation information. According to their simulation result, the Brantas catchment has the average evaporation rate of 5 mm/day. We assume that the same amount is missing daily in the manual record. we then added 5 mm/day total evaporation to the daily rainfall data on the day with rain record above zero. Then the accumulated daily rain data

after adjustment is collected into a monthly data. In the next step, we perform gridding process of the rainfall data in the study area using the Cressman Objective [Cressman, 1959] gridding method. The grid system uses a spatial resolution 0.08° or about 8.9 km^2 and has 26 grid cell longitudinally and 16 grid cell latitude for our area of study. Although the data period of each station is not the same, however, after the gridding process, we could fill all grid cell homogenously and similar period from January 1955 to December 2002. The latter fact is essential to run the EOF method (explained later), otherwise that method will not work. Also with the gridding system we applied, the spatial problem of station data location inconsistency before and after 1991 has not been arisen.

THE METHODS

In order to classify the climate trend for the last five decades, we separate monthly data into decadal data of five groups, 1955–1964, 1965–1974, 1975–1984, 1985–1994 and 1995–2002 and one dataset covering the whole data 1955–2002 (interannual data). We will look at isohyets of each data group and compare it with the whole time series (non decadal). Isohyets are spatial lines showing the same amount of rainfall in a certain area. Thus, we will have the average spatial pattern of each decade and the total time series. After we classified data into their decadal groups and as a whole, we performed the Empirical Orthogonal (EOF) and Fast Fourier Transform (FFT) analyses on each data group in order to obtain dominant spatial patterns as well as their long time behavior and frequency distribution of the principal component of the dominated spatial pattern, respectively.

Empirical Orthogonal Function (EOF)

The Empirical Orthogonal Function (EOF) method [Lorenz, 1956] is a part of the multivariate statistic method to extract the most dominant component of the variances that has an orthogonal character from one to the other of a multi series dataset. This method computes eigen values (λ) and eigen vectors (e_m) of the data using matrix operation. An eigen vector is a subset (can be time series or matrices, i.e. spatial patterns) of the whole dataset, while an eigen value represents the dominance of a certain subset against the whole dataset. One of the disadvantage of this method is the choice of the subset area, sometimes, inappropriate choice of the subset domain may lead to wrong conclusion, i.e. too large or too small domain [Dommenget and Latif, 2001]. Similar application of this method to local climate data includes Jamaluddin [1991], Sumantri [1996], Ratnawati [2002] and Tugiono [2003].

$$|R - \lambda I| = 0 \quad (R - \lambda I)e_m = 0$$

R = data input matrix

I = identity matrix

λ = eigen values

e_m = eigen vectors

According to this method, for our rainfall data, three outputs can be derived: a) Variances, an eigen value from one of the dominant component in comparison to the whole variances; b) Eigen map, the spatial plot of an eigen vector that show spatial correspondence to the respective principal component; c) Principal component, temporal pattern of any eigen value shown in a time series as a result of a dot product operation between any eigen value and the real dataset. It shows the evolution of eigen map dominances during the whole time series.

$$f_n = \sum_{m=1}^M c_{nm} e_m$$

f_n = principal component
 c_{nm} = input data matrix
 e_m = eigen vectors

Fast Fourier Transform (FFT)

The FFT is the best tool to analyze the frequency spectrum of any time series data. In this study, we performed the FFT analyses for each Principal Component data of the dominant spatial pattern of any decadal and the whole data series. After that, we will compare the result of each data series and see the change in frequency spectrum in intensities and frequencies. Several local applications of the spectral method include *Ratnawati* [2002] and *Tugiono* [2003].

$$F(\omega) = \int_{-\infty}^{\infty} f(t)e^{-i\omega t} dt$$

RESULTS AND DISCUSSION

The average annual rainfall pattern (period of 1955 – 2002) as shown in Fig. 2 clearly show monsoonal behavior in the Brantas catchment area with high intensity rainfall from October to April. By definition of the Indonesian Bureau of Meteorology and the confirmed proof by *Suwarman* and *Aldrian* [2004], the above normal or wet month is when a ‘dasarian’ or 10 days period passes with a rainfall amount exceeding 50 mm or about 150 mm/month.

Moreover, we also see that the mountain area always has a bigger amount of rainfall than other area. High mountainous area seems to preserve high rainfall amount all year round and even during the peak of the rainy season, the mountainous area receive more rainfall. In fact, the increase of rainfall over the mountainous area is more than the increase of rainfall amount in the lowland area. The propagation of the wet area on the onset of the wet season and its retreat begins from the mountainous area down to the coastal area. Hence, the lowland, especially the coastal area is more susceptible to dryness than the mountainous area. After looking at the annual spatial pattern, we are interested in the spatial trend changes

occur during the past five decades. Then we choose December and May as months representing the wet and the dry season, respectively.

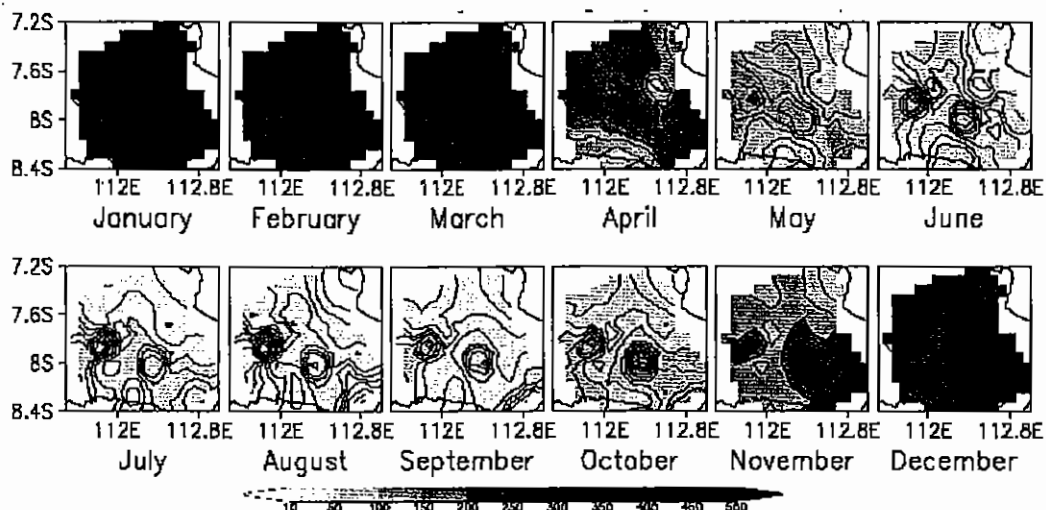


Figure 2. The average annual isohyets pattern between 1955 and 2002

The decadal spatial pattern changes as shown in Fig. 3 illustrate a regular trend on certain months like January (not shown), May and December. Those spatial patterns show greater expansion of the dry area in latter decades indicating the decrease of the yearly amount of rainfall for the last five decades. The pattern shows that such phenomena occur in the lowland as well as in the mountainous areas. Besides, the decrease happens during the dry and the wet period. Thus, we expect in recent years of a greater intensities and longer dry period.

EOF analyses

The result of EOF analyses for six data groups as defined above is given in Table 1. From that table we notice dominance of the first eigen vector (eigen map), which always explains more than 69% of all variances or about 12 times more than other eigen maps. From the principal component data of each eigen map, we find out that the first eigen map corresponds to the annual or monsoonal pattern, which is the most dominant climate pattern in this catchment area. The second and the third eigen map seems to have no order of pattern according to the principal component data. It is also interesting to see the decadal evolution of the first eigen map during the last five decades and the strength of dominance seems to decrease on the latter period except for the last eight year. The discrepancies seem to attribute to less data of the latter part, only eight year in comparison to ten-year data of other data groups.

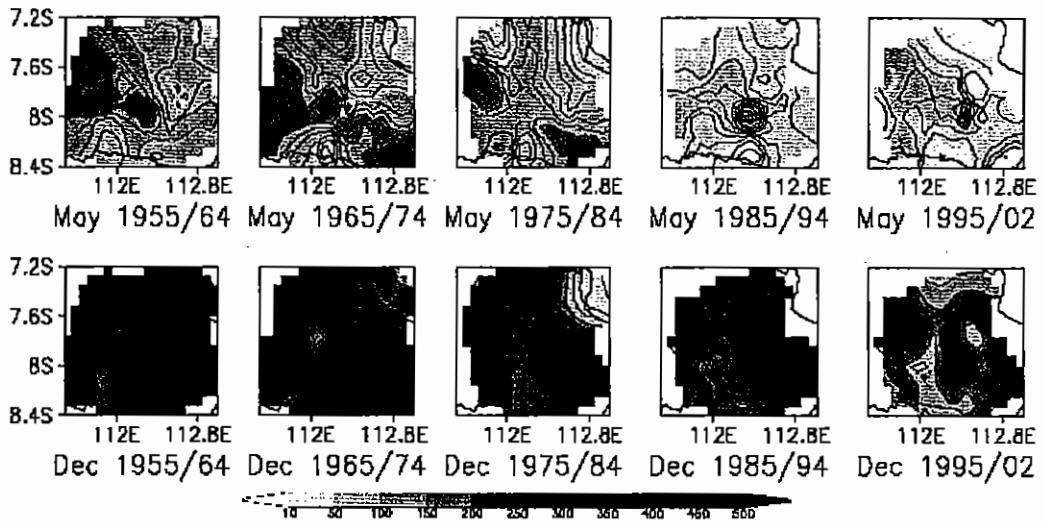


Figure 3. Decadal spatial pattern changes on May (above) and December (below)

Table 1. Decadal and Interannual Variances of Eigen Maps

Years	1955-64	1965-74	1975-84	1985-94	1995-02	1955-02
Eigen map 1	74.180%	71.490%	75.500%	69.090%	75.110%	72.270%
Eigen map 2	5.894%	5.379%	5.760%	6.573%	5.766%	4.546%
Eigen map 3	3.866%	4.225%	3.100%	4.772%	3.786%	3.083%

The eigen map of the first pattern (PC1) of the interannual data in Fig. 4 always shows positive values that indicate similarity of the whole study area to follow the same annual or monsoonal pattern. Moreover, this eigen map contour follows the land morphology or contour of the catchment area. The significant values on the mountain area are higher than the coastal area, which explain the change of the rainfall intensity over mountain areas is higher than coastal area or more contrast between rainy and dry season over this area than over the low land area. This contrast comes from the persistent orographic effect during the dry period in the mountain area.

The principal component time series of the first pattern (PC1) from the interannual data as illustrated in Fig. 5 shows a clear one-year period or the monsoonal pattern with the maximum values that has negative trend of the maximum rainfall intensity from 1955 to 2002. In the year 1991, there is a significant increase but then decrease again along the latter years. This condition is in favor of the idea we made before about the evapotranspiration problem with the rainfall data after 1991 caused by the application of a telemetric observation system. That figure shows principal components of the original data and after the

evaporation adjustment. The result after adjustment shows better variability with better view of negative trend of the maximum rainfall amount. This fact also indicates that the method we use for adjustment the evapotranspiration on rainfall data before 1991 is quite unrepresentative, but still can be analyzed base on an assumption we made about the rainfall data before 1991.

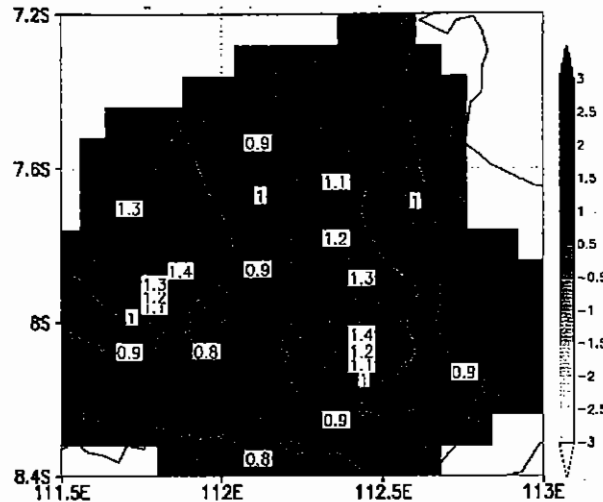


Figure 4. The first eigen map of the Brantas catchment area for 1955 – 2002

After the principal component analyses, we used the PC data for their spectrum analyses and investigate the strength of their component. As we understand before, the most dominant pattern is the annual or monsoonal pattern. From Fig. 6 we show the spectrum of the first PC of the decadal dataset. Beside the one-year period, there is no other clear pattern in lower (above one-year period) and higher frequency (below one-year period). There is a decreasing trend of intensities of one-year period from the first to the latter decade.

Fast Fourier Transform Analyses

For the last decade (1995-2002) the graphic shifts the dominant period from one to 1,25 year period. This condition comes from numerous missing data at several rain gauge stations on December 1999. Possible cause of the missing data is due to out of order instruments. During that year, from July to December, missing data are reported at 25 stations where only 9 station reported complete data. Thus, we miss the real picture of the peak of rainy season information during that year that cause shift of the peak of one-year period to the longer period (1.25 period). This data deficiency still does not prevent our conclusive statement above that there is a negative trend of intensities of one-year period. From Fig. 6, the monsoonal strength of each decade is decreasing, except in 1965-1974. Hence, the strength of the monsoonal pattern over the Brantas catchment is significantly reduced during

the last five decades. This conclusion is not clearly seen from the information of eigen map variances alone but from the FFT analyses of their PCs.

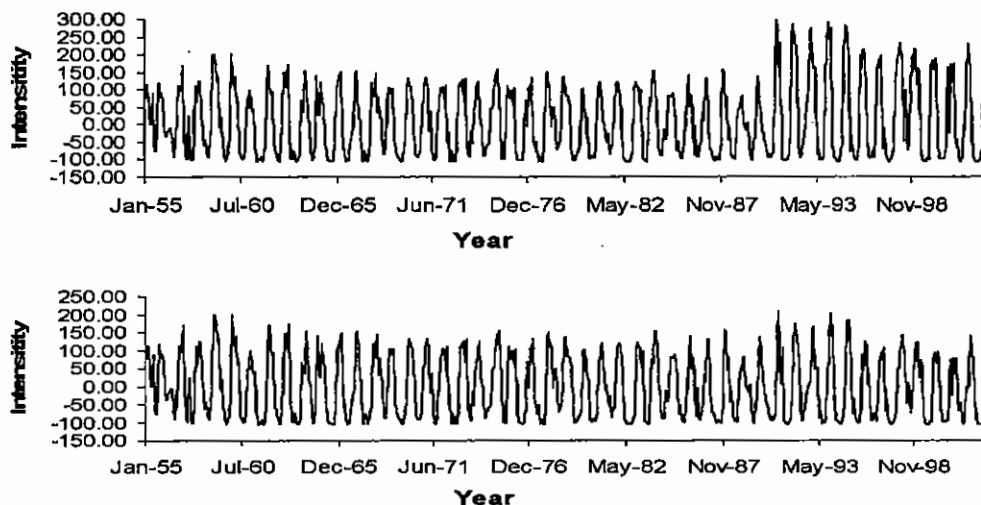


Figure 5. The first Principal Component (PC1) of the interannual data, before (above) and after (below) the evapotranspiration adjustment.

The spatial rainfall pattern of the Brantas catchments area for the monthly average data clearly indicates one year of periodicity or the monsoonal pattern, as the maximum value occurs in December, January, and February or the peak of the wet season. The amount of rainfall decreases to minimum on June, July and August or the peak of the dry season. This pattern follows the South East Asia monsoonal wind pattern that also passes over catchments. This monsoon brings moist air with high humidity from the South China Sea at the same time as the wet season, which is known locally as the West Monsoon, and on the other hand, in dry season the wind brings dry air from the Australian continent in a period known locally as the East Monsoon.

The first principal component from the EOF method also indicates yearly variability or the monsoonal pattern that explains about 72% of all variances. The analyses of the power density spectrum also confirms the latter result, where it turns out that one-year to be the most dominant period that exceeds ten times of other variabilities. Furthermore, the positive values from eigen map of PC1 over the whole area generally explain that the whole Brantas basin has synchronized patterns to the monsoonal variability with some locality differences between mountainous and lowland areas.

Over mountainous area such as Mount Wilis and Mount Kelud in dry season (June, July, and August) has more rainfall amount in comparison to other area. These spatial patterns clearly explain the orographic effect that take place on mountainous areas causing more rainfall amount above certain height. Such an

orographic effect usually occurs in the afternoon. There is no possible analysis to identify such effect, which needs hourly rain data.

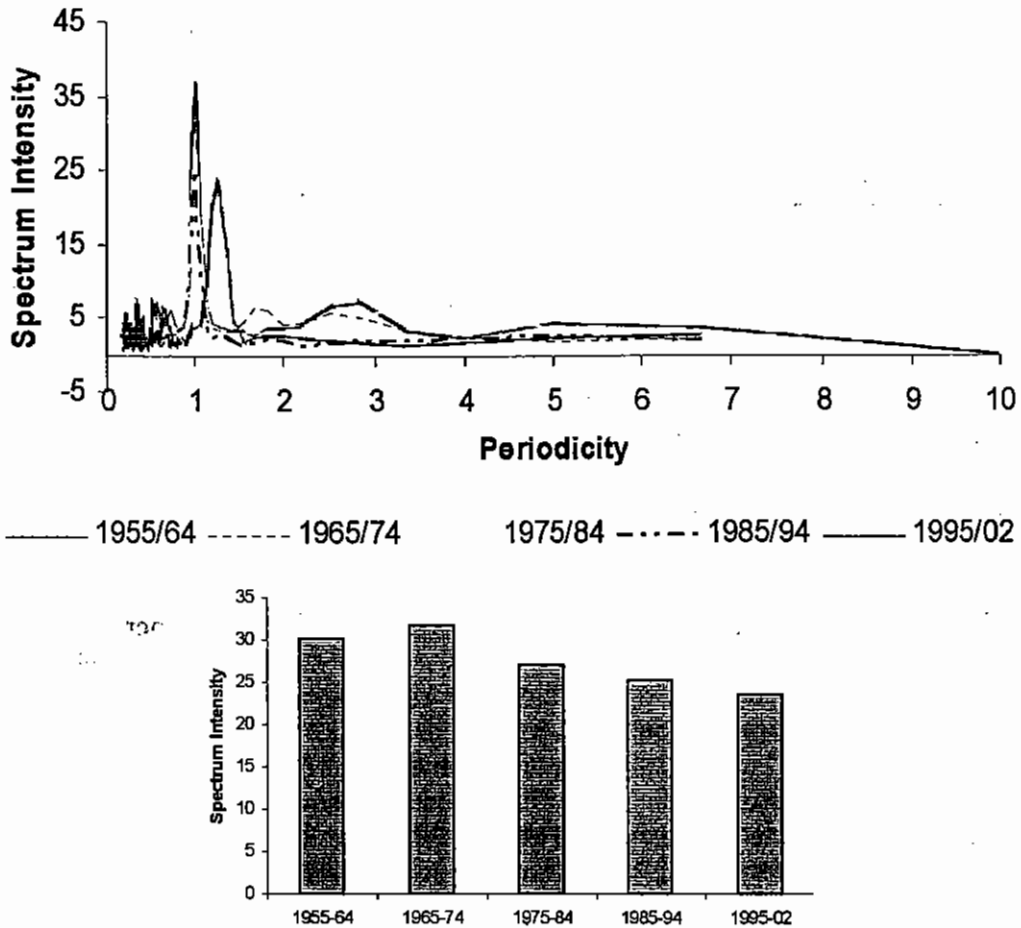


Figure 6. Power density spectrum of PC1 for each decade from 1955 to 2002 (above) and the spectrum intensity of the annual period (below) that represent the decadal monsoonal strength.

Differences between mountain and coastal area also appear in the eigen map for PC1 with more variability contrast in high land areas. The spatial pattern of that eigen map also shows similar spatial distribution as the isohyet pattern that visualizes the earth surface contour. From that eigen map, the significant value in mountain area is more positive than coastal area. This condition explains the previous explanation about orographic rain in mountain area and about the coastal area is more susceptible to the annual pattern change.

The principal component of PC1 for the interannual data shows a negative trend on the yearly maximum intensity for the last five decades on the Brantas catchments area. This condition also supports the expansion of dry land area in

certain months from isohyet profile on each decade. The most obvious of dry area expansions occur in March, January and December. In other word, dry season comes earlier for latter decades and make the dry season longer than the wet season. This fact also explains the decrease of the maximum rainfall value from monthly data. This is also supported by the result of the FFT method for the first principal component on each decade that shows in Fig. 6, the intensity of the *Power Density Spectrum* for one year of period appear to decrease simultaneously along the decades. This condition explains that in the Brantas catchments the monsoonal pattern is weakening for the last five decades.

From all the previous explanations, we decide to investigate more on the dryness period and compare the condition of rainfall data from two different locations, the mountain area and the coastal areas. The mountain area represent by Pujon (>1000 m), and for the lowland area is Mojokerto city (<100 m). Both stations are located on the similar phase of the eigen map (positive side) and at the northern part of the Kelud Mountain. Thus, they receive similar monsoonal exposure. We used a threshold value for extreme dry months of 5 mm/month rainfall in the two areas, where the result can be seen in Fig 7. The 5 mm/month standard refers to the dry month criteria of the Indonesian Bureau of Meteorology of 150 mm/month or 5 mm/day. Thus rainfall amount less than 5 mm/day is assumed as no rainy day at all (extreme dry month).

Mojokerto has more numbers of extreme dry months that was increasing for the last five decades in compare to Pujon that has lower numbers and more stable. Mojokerto in early years of investigation had similar number of dry months to Pujon, which is about 2 months. However, in the last ten years the number increases to 4 months and in 2002 it reaches 8 months of dry season that appear to be the longest dry season for the whole five decades. Meanwhile, the Pujon area has a more stable amount of dry months in about 1-2 months for the last ten years with maximum number of 4 months. This result support the previous explanation about the orographic rain that occur in mountain area, and reveal that the monsoon negative trend had more effect in lowland area than in mountain area. As a result, the expansion of the dry area has shifted the balances between the wet season and dry season. Moreover, Fig. 7 also indicates that the lowland areas are more susceptible to the climate change.

The decrease of the monsoonal strength detected by the EOF and FFT methods are caused by the imbalances between the wet and dry season that usually took about 6 months of period in early decade. The annual pattern turns out to be a different state based on longer dry season in one-year period of monsoon. Longer dry period with lower rainfall amount may also indicate global change in the evaporation supply, which has been, reduced persistently during the last five decades. Persistent reduction of evaporation maybe associated to the global dimming phenomena [Ohmura, 2002; Liepert, 2002; Stanhill and Cohen, 2001; Roderick and Farquhar, 2002]. Long term and persistent air pollution in the lower and middle atmosphere due to traffics over land, sea and air has reduced the

radiation amount received by the surface of the earth. The air pollutant has hindered the solar radiation to reach the ground. As a result, local evaporation especially over large water body will be reduced.

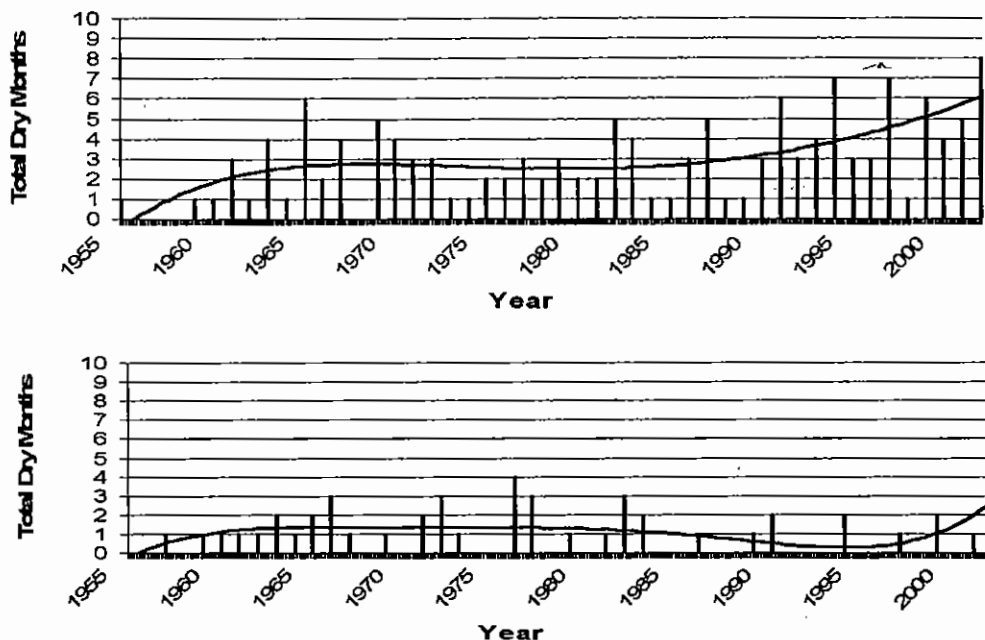


Figure 7. Number of extreme dry month (<5 mm) period for Mojokerto (top) and Pujon (bottom) from 1955 to 2002. Curve on each graph is polynomial regression on the fifth power.

The global dimming phenomena may not be the only one responsible for the less evaporation. The critical SST over the Indonesia maritime continent may also be responsible. The higher above that critical SST value does not bring more evaporation, instead, it will reduce it. According to Aldrian and Susanto [2003] the critical SST during the peak of the wet season or December/January is around 29.6°C. If SST rises above that critical value, then the rainfall as well as evaporation will be reduced since more evaporation will take more latent heat away from the surface of the sea and eventually cool the sea surface. The cause of the SST rise comes from the global surface temperature increase or the global warming. Both global dimming and warming have opposite effects that may lead to the same consequence, i.e. the reduction of local surface evaporation. Other local possible causes of the evaporation reduction may come from local land use change such as deforestation. Deforestation will cause the reduction of the evapotranspiration from leaves of the forest. Thorough explanation and investigation of the probable cause of the evaporation reduction is beyond the scope of this study. As a matter of fact, the global climate change apparently has changed the local climate in this catchment.

The result of this study has not only implication for the climate assessment, but also for the agricultural needs. Change in the climate pattern may lead to the change of plantation period as well as the distribution of the plantation area. Farmers and researchers should consider new type of species resistant to longer dry period or warmer climate. Less evaporation and rainfall should yield higher land surface temperature that leads to hotter day. Thus, the optimized staple food production may be in danger to the new local climate condition.

CONCLUSION

We have analyzed and investigated the long term spatial, temporal and trend of climate over the Brantas Catchment Area, East Java. The analyses is performed for 48 year period (1955 – 2002) from monthly rainfall data with two main methods: the Empirical Orthogonal Function and Fast Fourier Analyses methods. The results show that there is significant climate pattern change temporally and spatially.

The spatial and temporal of climate pattern in Brantas Catchments Area is dominated by the monsoonal pattern with a one-year of period. This pattern consequently brings high amount of rainfall in December, January and February, and the lowest happen in June, July and August. The local orographic effect regularly happens in the mountains of Brantas Catchments Area (Mount Kelud and Mount Wilis) during the dry season that preserving high rainfall area. Hence, the mountainous area is less susceptible to the climate pattern change.

Lowland area had more influences of the decrease of monsoonal strength than mountain area, which can be seen in the higher amount of dry months that increase along the year in lowland area in comparison to the low and more stable dry period over the mountain area. In fact more extension of the dry areas are detected over the lowland area.

The climate trend detected by the EOF method shows the decrease of the monsoonal strength in catchments area for the last five decades. This trend is due to the imbalances of the wet and dry seasons, which the dry season gets longer than wet season during the recent decades causing the decrease of total yearly amount of rainfall.

ACKNOWLEDGEMENTS

We are thankful to Sutopo Purwo Nugroho and Irman who share, collect and tabulate the Brantas rainfall data. The authors are indebted to Perum Otorita Jasa Tirta I as the Brantas Catchment Area authority, who has managed and collected long term daily rainfall data. lastly, our thanks goes to Sri Hartati Soenarmo for the fruitful discussion of the whole study.

REFERENCES

- Aldrian, E., L.D. Gates, D. Jacob, R. Podzun, and D. Gunawan (2004), Long term simulation of the Indonesian rainfall with the MPI Regional Model, *Climate Dynamics*, 8, 794-814.
- Aldrian, E., and R.D. Susanto (2003), Identification of three dominant rainfall regions within Indonesia and their relationship to sea surface temperature, *International Journal of Climatology*, 23, 1435-1452.
- Anzhar K. (1996), Tinjauan Klimatologi Curah Hujan di Pulau Jawa Berdasarkan Analisa Kluster, Tugas Akhir (Final Assignment), GM ITB, Bandung.
- Cressman, G.P. (1959), An operational objective analysis scheme, *Monthly Weather Review*, 117, 765-783.
- Dommenget D., M. Latif (2001), A cautionary note on the interpretation of EOFs, *International Journal of Climatology*, 15, 216-225.
- IPCC (2001), Climate Change 2001: The Scientific Basis, IPCC Report, Inter Governmental Panel on Climate Change.
- Jamaluddin, Z.A. (1991), Identifikasi Pola-Pola Cuaca Ortogonal Melalui Analisa Komponen Utama dan Spektral, Tugas Akhir (Final Assignment), GM ITB, Bandung.
- Johnson, R., D. Wichern (1998), *Applied Multivariate Statistical Analysis*, 4th ed., Prentice Hall, New York.
- Liepert, B. (2002), Observed reductions of surface solar radiation at sites in the US and worldwide, *Geophysical Research Letters*, 29, 1421-1433.
- Lorenz, E.N. (1956), Empirical Orthogonal Functions and Statistical Weather Prediction, Sci.Rep. 1. Statistical Forecasting Project, Departement of Meteorology, MIT.
- Ohmura, A. and M. Wild (2002), Climate change: Is the hydrological cycle accelerating?, *Science*, 298, 1345-1346.
- Ratnawati H. (2003), Penerapan Analisis Multivariat dan Spektral dalam Pengelompokan (Clustering) Curah Hujan Homogen di Wilayah Tanjung Muria, Tugas Akhir (Final Assignment), GM ITB, Bandung.

- Roderick M. and G. Farquhar (2002), The cause of decreased pan evaporation over the past 50 years, *Science*, 298, 1410-1411.
- Stanhill G. and S. Cohen (2001), Global dimming: A review of the evidence, *Agricultural and Forest Meteorology*, 107, 255-278.
- Sumantri Y. (1996), Model Empiris Aplikasi Vektor Eigen untuk Prediksi Temperatur Sebagai Fungsi Variabel Spasial dan Meteorologi, Tugas Akhir (Final Assignment), GM ITB, Bandung.
- Suwarman, R. and E. Aldrian (2004), Sensitivitas variabilitas hujan di Pulau Jawa terhadap suhu muka laut dan evaporasi di sekitarnya: Studi model iklim kasus tahun 1979 – 1983, *Jurnal Meteorologi dan Geofisika*, 5(3), 1-15.
- Tugiono (2003), Penerapan Teknik Rotasi Faktor Utama dan Spektral pada Studi Identifikasi Pola Curah Hujan di Wilayah Tanjung Muria, Tugas Akhir (Final Assignment), GM ITB, Bandung.