Characteristic of rainfall in the flood period in DKI Jakarta in 1996, 2002, and 2007

Mangapul Parlindungan Tambunan^{1,*}

¹Department of Geography, University of Indonesia, Depok, 16424, Indonesia

Abstract. Spatial and temporal studies of rain characteristics were carried out in DKI Jakarta. This study aims to: assess the rain characteristic as the cause of flood in DKI Jakarta. Flood is studied from geography using a spatial approach. The data collection of the physical condition of the landform is obtained through interpretation of Topographic Map, Geological Map, and RBI Map. Data on flood areas (area, depth, and length) were obtained from survey and flood incident data obtained from Kimpraswil (PU) of DKI Jakarta, and West Java, rain data obtained from BMKG. The analysis of spreading and spatial distribution is done spatially and temporally using Geographic Information System (GIS) tools, while rain analysis is done descriptively on a scale of 1: 50,000. The results of the research suggest that there are differences and similarities of rainy anomalies in the prone areas of flooding in DKI Jakarta.

1 Introduction

Natural factors of flooding are high-intensity rainfall and not balanced with good water absorption. Naturally, the rain will absorb into the soil and then tied up by the roots of the trees and flowed again through the flow of water like a river that ultimately empties into the ocean. Rainfall has an influence on the morphology of the amount of water entering the watershed as a medium for fluvial processes, including erosion, transportation, and sedimentation. Intensive erosion process with increasing rainfall within the watershed.

Floods in DKI Jakarta in 1996, 2002, and 2007 can be categorized as a national and even regional flood disaster as the floods are the widest spread, and the number of deaths is more than in the previous year. The main flood period occurs in February except in 2013 (January 17-20) because in February it is located the equatorial thermal line or the inter-tropical convergence area just above the surface of the mainland and the waters of Jakarta which has the highest temperature with large water evaporation. This condition triggers the rain with high intensity and long rain time is suspected as the cause of heavy rain in the lowlands of DKI Jakarta.

Although there are many studies on the causes of flooding in Jakarta and has done a lot of control efforts floods are still happening and even tend to increase. The study of floods and controls can be done or can be viewed from various disciplinary viewpoints such as climatology, geography, and geomorphology. The study of the flood targets to be conducted is viewed from a geographical point of view [1]. and more specifically geomorphology and climatology.

From the perspective of fluvial geomorphology in the mainland of DKI Jakarta, interesting to be studied is spatial and temporal distributed flood areas. Distribution of areas targeted by floods can be approached with units of landform. The spatial approach of the flooded area in the form of land can be used to understand the flood characteristics caused by fluvial and fluvio-marine fluvial activities and can provide answers to the problem of the location of the original land as a prone area of a flood.

Based on the background and problems of flood areas in DKI Jakarta, the formulation of this research problem is as follows: what is the rainfall characteristic pattern on the spatial and temporal changes of the actual flood prone area?

This study aims to examine the rainfall characteristic pattern on the spatial and temporal-spatial distribution of the actual flood areas.

The framework developed in research in DKI Jakarta on the basis of climate concept i.e. rainfall (thickness, intensity, and distribution), the concept of landform, the concept of flood areas, and the concept of land use. The climate is represented in the rainfall in Jakarta and surrounding areas in January and February on 1996, 2002, and 2007. There are rainfall variations in both rainfall and daily, monthly, and yearly rainfall. Landform. the genetic origin process is fluvial, fluvial-marine, and marine. Based on the rain, the classification of landform, and land use, and supported by actual flood data of time series can determine the spatial and temporal pattern of flood-prone areas in DKI Jakarta.

*Corresponding author: mptgeoui@gmail.com

2 Methodology

The study approach in this research is a spatial approach. According to Verstappen [2] and Oya [3], the form of land that becomes a potential flood-prone area is a form of fluvial origin land. Areas with potential flood prone may not necessarily be flooded, depending on other factors, which in this study are limited to land use. Changes in wetland use and agriculture to residential areas could affect the actual flood. The three research variables used in this research are climate variables (daily rainfall and distribution), the form of material (relief, material, and geomorphic process), and flood area (spatial and temporal) Conceptual design of the research flow is as follows (Fig. 1.).

Sources of research data obtained through documented searches and scholarships, regulations, and maps, and published by government agencies such as the National Land Agency (BPN) in the form of data, and land use maps; Regional Development Planning Board (Bappeda) i.e land use allotment; Rainfall data from Meteorology Climatology and Geophysics Agency (BMKG); The flood data from the DKI Jakarta Government through the Irrigation Service Office in five administrative cities are: 1) North Jakarta, 2) East Jakarta, 3) South Jakarta, 4) Central Jakarta, 5) West Jakarta and Water Resources Ministry of Public Works and Agency Disaster Management Area (BPBD) as shown in Fig. 1.

Fig. 1. Flow Chart of Theoretical Framework

3 Result and discussion

The Climate is one of the critical parameters to trigger flood events, especially rainfall. Analysis of rainfall ratio, number of rainy days, maximum rainfall and maximum rainfall date in each of its permanent stations as follows:

In February 1996, the most significant monthly rainfall was in the South of Jakarta, at Pasar Minggu Station 934 mm for 15 days of rain or average daily rainfall of 62.3 mm and maximum rainfall of 300 mm on the 10th. The smallest monthly rainfall is in the West Jakarta at Curug Tangerang Station 310 mm (21 rainy days) with the mean of 14.8 mm. Actual flood on the 9th

to the 14th with the peak of the flood on the 10th and the number of rainy days 21 to 24 rain days in the lower land of Jakarta.

In February 2002, the monthly rainfall was relatively large compared to February 1996. The largest monthly rainfall in eastern Jakarta was at Tambun Station (Bekasi) 773.3 mm for 27 days of rain or average daily rainfall of 28.6 mm while maximum rainfall of 168.1 mm located in the middle of Jakarta at BMKG Kemayoran Station on the 2nd. The smallest monthly rainfall in southwestern Jakarta is at Pakubuwono Station 310 mm (22 days of rain). Actual flood from 1 to 2 with daily rainfall of more than 500 mm.

In February 2007 that monthly rainfall was more than 500 mm except in Dramaga Bogor Station 438 mm or south of Jakarta. Monthly rainfall is relatively large compared to February 1996 and 2002. The largest monthly rainfall in Southeast of Jakarta is at Station Halim Perdana Kusuma 997.3 mm for 20 days of rain or average daily rainfall of 49.9 mm while maximum rainfall of 339.8 mm Located in South-west of Jakarta at Pondok Betung Station (South Tangerang City) on the 2nd. The smallest monthly rain is in the south of Jakarta, at Dramaga Bogor Station 83 mm (25 rainy days). The actual temporal pattern of the flood in lowland Jakarta is similar to 2002 on the 2nd day with daily rainfall of more than 500 mm and maximum rain reaches 100 mm per day.

There is an increase in rainfall both west of Jakarta; it is represented by Curug Tangerang Station (253.8 mm) followed by Cileduk (96.4 mm), Depok (78.4 mm) Halim Perdana Kusuma (68.1 mm), Cengkareng Except in Dramaga Bogor Station. In February 1996 rainfall of more than 500 mm in 1996 was at Cengkareng, Tanjungpriok, BMG Kemayoran, Pasar Minggu, and Dramaga Bogor Station. In February 2002 there were at Curug Tangerang, Cengkareng, and Kedoya Station located west of Jakarta, and Tanjungpriok, BMG Kemayoran in the north of Jakarta, and Halim Perdana Kusuma in eastern Jakarta. In February 2007 more than 500 mm of rain was present in 13 rain-stopping stations except for Dramaga Station in southern Jakarta.

There were changes and shifts in the number (max) and rainy days in both February 1996, 2002 and 2007 in mainland Jakarta described as follows:

February 1996 has an average of 21 rain days, and a maximum of 24 days of rain except in Rawamangun, Pasar Minggu and Depok Station which is less than 20 rainy days with maximum rain every 10th as the peak of the flood in lowland Jakarta.

February 2002 experienced maximum rain acceleration at the beginning of every month (1st to 4th) with the rainy day more than 21 days. There was even rain (27 days) in East Jakarta precisely at Tambun Bekasi Station (844 mm, maximum 97 mm on February 1st.

February 2007 in all rainfall gauge station has rainfall > 500 mm/month; rain day number reaches 17 to 25 days rain Maximum rain 339,8 mm on February 2 at Station Pondok Betung whereas the smallest maximal rain at Station Dramaga 83 mm on date February 4th.

Table 1. Rainfall Characteristics on February 1996, 2002, and 2007.

No	Name of Climatology Station	Rainfall (mm)			Total Days of Rainfall			Maximum Rainfall (mm)			Date of Maximum Rainfall		
		1996	2002	2007	1996	2002	2007	1996	2002	2007	1996	2002	2007
1	Curug Tangerang	310.2	564	528	21	26	20	64.5	123	98	20	20	8
2	Cengkareng	546	560.7	543	24	24	19	107	52.7	122	9	20	2
3	Cileduk	329	425.4	846	21	24	21	80	49.3	340	11	1	2
4	Pondok Betung	482.4	425.4	831.4	21	24	22	129.5	49.3	339.8	10	1	2
5	Kedoya	---	638.4	785.6	---	25	17	---	92.7	185.1	---	9	2
6	Tanjung Priok	858	616	664.7	22	24	18	231	138	168	10	2	2
7	BMG Kemayoran	689	658.7	729.9	23	25	19	261	168.1	234.7	10	2	2
8	Rawamangun	500	----	----	18	----	----	120	----	----	5	----	----
9	Pakubowono	328	393	752	21	22	20	85	67	178	10	1	2
10	Halim PK	480	548.1	997.3	23	24	20	100	108	259.1	10	2	3
11	Pasar Minggu	934	----	----	15	----	----	300	----	----	10	----	----
12	Depok	389	467.4	793	19	24	18	74	73	132	29	15	3
13	Dramaga (Bogor)	537.4	475.3	438	24	23	25	102.8	126	83	11	1	4
14	Tambun (Bekasi)	----	773.3	844	---	27	20	---	97	201	---	1	2

Source: Data processing, 2011

--- no data

Based on the daily rain analysis in February 1996, 2002 and 2007 then the number of rainy days then the rain of February 2007 has in common with February 1996 that is 21 days rainfall. Differences in the flood pattern due to differences in the temporal pattern of maximum rain and rainy date. In February 1996 floods occurred on the mainland of Jakarta on the 10th. In February 2002 and 2007 there were floods in mainland Jakarta in early February on every 1 to 4th day.

Flood due to the amount of rainfall (mm) showered on lowland of Jakarta and surrounding areas were on February 1996, 2002, and 2007. The comparative characteristics of rainfall in each climatology station (see Table 2) are described in the following Table 1.

On February 1996, the maximum monthly rainfall existed in southern part of Jakarta, i.e., the station of Pasar Minggu (934 mm) for 15 days of rainfall or an average of its daily rainfall reached 62.3 mm, and maximum rainfall (300 mm) was on the date of 10th. The minimum monthly rainfall existed in western part of Jakarta, i.e., Curug Tangerang Station (310 mm) for 21 days of rainfall or in average 14.8 mm. Actual flood was on the date of 9th until 14th with the maximum flood was on the date of 10th with 21 – 24 total of rainfall days.

The monthly rainfall in February 2002 was relatively more abundant rather than rainfall in February 1996. The maximum monthly rainfall existed in the eastern part of Jakarta, i.e., Tambun (Bekasi) Station with 773.3 mm for 27 days of rainfall, or an average of its daily rainfall reached 28.6 mm whereas the maximum daily rainfall reached 168.1 mm existed in central part of Jakarta, i.e., BMG Kemayoran Station on the date of 2nd. The minimum monthly rainfall existed in the southwestern part of Jakarta, i.e., Pakubowono Station with 310 mm rainfall for 22 days of rainfall. Actual flood was on the date of 1st until 2nd with the daily rainfall reached more than 500 mm.

The monthly rainfall on February 2007 generally in 14 stations of rainfall reached more than 500 mm, except Dramaga Bogor Station (438 mm) or southern part of Jakarta. The monthly rainfall in February 2007 was relatively larger rather than in February 1996 and 2002. As for details, maximum monthly rainfall existed in southeastern part of Jakarta i.e in Halim Perdana Kusuma Station that reached 997.3 mm for 20 days of rainfall or an average of daily rainfall reached 49.9 mm with maximum daily rainfall was 339.8 mm that existed in southwestern part of Jakarta i.e in Pondok Betung (South Tangerang city) Station on the date of 2nd. Meanwhile, the minimum monthly rainfall existed in southern part of Jakarta, i.e., Dramaga Bogor Station with 83 mm for 25 days of rainfall. The temporal pattern of the actual flood was similar to the pattern in 2002; i.e., on the date of 2nd with the daily rainfall reached more than 500 mm and maximum rainfall reached 100 mm per a day.

There was an increasing number of rainfalls, in the western part of Jakarta which was represented by Curug Tangerang Station (253.8 mm) then followed by Cileduk Station (96.4 mm), Depok Station (78.4 mm), Halim Perdana Kusuma Station (68.1 mm), and in each station in Cengkareng, except Dramaga Bogor Station. On February 1996, the rainfall classification which was more than 500 mm existed in Cengkareng Station, Tanjungpriok Station, BMG Kemayoran Station, Pasar Minggu Station, and Dramaga Bogor Station, whereas, in 2002 existed in Curug Tangerang Station, Cengkareng Station, and Kedoya Station which all were located in the western part of Jakarta; Tanjungpriok Station and BMG Kemayoran Station in northern part of Jakarta, and Halim Perdana Kusuma Station in eastern part of Jakarta. In February 2007, more than 500 mm of rainfalls happened in 13 rainfall gauge stations, except Dramaga Bogor Station that was laid in the southern part of DKI Jakarta Province (Fig. 2.).

Fig. 2. Graph of Rainfall on February 1996, 2002, and 2007 (Data processing, 2011)

Total of rainfall days also experienced significant changes on February 1996, i.e. 21 days of rainfall in average and maximum 24 days of rainfall, except in Rawamangun Station, Pasar Minggu Station and Depok Station which had less than 20 days of rainfall with maximum rainfall was every date of 10th that formed as maximum flood in lowland of Jakarta. Meanwhile on February 2002, there was an acceleration of maximum rainfall on every beginning of months (date of 1st until 4th) with the total days of rainfall was more than 21 days, even, there was region where was always showered by rain for 27 days, i.e. in eastern part of Jakarta or exactly existed in Tambun Bekasi Station (844 mm, maximum rainfall was 97 mm on February 1st). According to the total days of rainfall, the rainfall pattern on February 2007 has similarity with the rainfall pattern on February 1996 that both, on average, had 21 days of rainfall. There was different flood pattern because of the differences in temporal pattern of maximum rainfall and existence date of rainfall that on February 1996, flood existed on middle of the month (the date of 10th) while flood on February 2002 and 2007 existed at the beginning of the month (the date of 1st – 4th).

There were differences in flood incidence in Jakarta in January and February 1996 due to heavy rain. In January it falls along the Manggarai corridor to Depok and the area/corridor of Depok to Katulampa (downstream of DA Ci Liwung). At that time, the tidal conditions in January did not affect the flood event in DKI Jakarta Province. The flood incidence of Jakarta in February of 1996 was caused by the rain falling in the catchment area of Katulampa and along the Depok to Katulampa corridors covering the upstream and middle watershed of Ciliwung watershed as well as the downstream area affected by the tides (rob) in Jakarta Bay. This condition resulted in widespread flooding in the land [4], [5].

Reference [4] concludes that floods in early 2002 occurred due to a high volume of water flow from Bogor and high rainfall in Jakarta which lasted at the same time in a few days. Floods in Jakarta peaked on February 4, 2002. The flood peak of the Ciliwung River on 4 February was caused by heavy rains in the middle of the watershed along the Depok-Manggarai plot. Significant floods from February 1 to 4, 2002 with floods reaching 1/6 of its land area were soaked by floods. Then Asriningrum [6] notes that the great floods in early February 2002 due to long periods of heavy downstream rainfall, plus the high intensity of rainfall in the center, and upstream of Ciliwung watershed.

The results of rainfall analysis in 12 months (January to December) in 1996, 2002 and 2007 in DKI Jakarta have varying thickness and rainfall which time-varying in each rain gauge station owned by BMKG and Jakarta Agriculture Agency. There are 8 months of rainfall of more than 100 mm, during 4 months rainfall <100 mm/month. Based on these rain phenomenon, as the beginning of the rainy season, namely September, October, December, January, February, March, April, and ends in May in Jakarta. The highest monthly rainfall in January and February is over 300 mm each, while the other six months average 150 mm / month.

Based on the height and location of the rainfall observation station in DKI Jakarta, the dispersal of the coastal region consists of rainfall patterns in the north, central and south of DKI Jakarta described below. The pattern of the rainfall area in the northern part of DKI Jakarta is as follows:

1. There is a tendency of heavy rainfall to increase significantly from October to February. In February the maximum rainfall occurred at each rainfall meter station;
2. In September is the beginning of the rain, as well as for October with the pattern of rainfall is relatively

Fig. 3. Bar Chart Rainfall in North DKI Jakarta (West to East) on February (Data processing from BMKG Agency in DKI Jakarta, 2011)

The same as in september. In the second of this month what differentiates rain earlier and dramatically rains in the west is at Station Tangerang while to the east like Station Tanjungperiuk has a small rain compared to other rainfall gauge stations, such as Tambun and Bekasi which are located inland in the north coast of Jakarta;

3. In November, the thickness of rainfall can reach 200 mm, except Teluk Naga Station is located in the same direction or parallel to the coastline;
4. Rainfall in December can reach 200 mm almost evenly in every rainfall gauge station, except Tambun Station;
5. The increase in rainfall occurred in January, where all the rainfall staging stations accommodate 200 - 300 mm, except Teluknaga, Tanjungperiuk, Tambun, and Bekasi Stations where the rain reaches 300 to 350 mm;
6. There was a maximum increase or climax of heavy rainfall occurred in February, where rainfall can reach 500 mm, as happened at Station Tambun in east Jakarta while the other station of heavy rainfall ranges from 200 to 300 mm except in Station Bekasi; and
7. massive rainfall decline in March, April, and May which be the beginning of the season transition to the summer. The thickness of the rain falling on the surface of the soil this season is uncertain due to the transition period. Rainfall is equal to October 100-200 mm except in Tambun and Bekasi Stations

Rainfall in the north of Jakarta in February is higher than March to January. In February, there are 6 stations where the rain is more than 200 mm/month except in Station Bekasi. This heavy rain condition contributes significantly to the flood incident in the low and lowland plains of Jakarta. The spread of dominant flood targets includes areas on the coastal alluvial plains and beach rides rides. The monthly rainfall graph in north Jakarta is presented in Fig. 3.

The pattern of the rainfall region in the center of Jakarta, is as follows: 1. there is an early delay in the rainy season in this region, because the rainfall is less than 100 mm in September; 2. classification of moderate rain (100-200 mm) and evenly occurred in every BMKG rainfall measurement station, as in October, November, and December; 3. an increase in the thickness of rainfall that occurred in January, where the rainfall thickness reaches 201-300 mm, except in Station Ulujami; 4. the thickness of the rain is considerable and evenly distributed, occurring in February. Where Kemayoran and Manggarai Stations have the highest rain thickness that is more than 400 mm; 5. gradually there is a decrease in rainfall, i.e., in March, April and May; and 6. in June, July, August, and September is rides. summertime indicated by rainfall <200 mm / month.

The rainfall in central Jakarta in February was thicker compared to other months. There are 6 Stations where the rain is more than 200 mm/month even in Kemayoran Station 500 mm/month. In February, the thickness of this rain contributed significantly to the flood incident in the flat and lowlands of Jakarta. The dominant spread of flood targets is found in areas in alluvial plains. The monthly rainfall graphic in DKI Jakarta in the center is presented in Fig. 4.

The pattern of the rainfall region in the southern part of DKI Jakarta is as follows: 1. the trend of rainfall increases from December and ends in February. Maximum rainfall increase occurred in February; 2. on the contrary in May to August, there is a decrease in rainfall, where the transition season to summer occurs; 3. February rainfall that occurred at each Station the average of 300 above and the maximum 700 mm rainfall that occurred at Gunung Mas Station, while the lowest rainfall 250 mm in Kebayoran Station which is the cause of flooding in the Jakarta area; 4. in December, January and February at Kebon Raya Bogor, Dramaga, Ciawi and Gunung Mas Stations (south of Jakarta) 450 mm - 700 mm; and 5. in May, June, July, and August at Pasarminggu, Depok, Cimanggis and Sawangan Stations convective rain occurred with a thickness of 200-300 mm

Fig. 4. Bar Chart Rainfall in Central DKI Jakarta (West to East) on February (Data Processing From BMKG Agency in DKI Jakarta, 2011.)

The rainfall in southern Jakarta in February is more substantial than the other months. There are 10 stations where the rain is > 200 mm/month either at Kebayoran, Jati Padang, and Pasar Minggu Stations. In February, the thickness of this rain contributed significantly to the

incidence of floods in the flat and lowlands in Jakarta. The dominant spread of flood targets is found in alluvial plains and alluvial fans. The monthly rainfall charts in southern Jakarta (Fig. 5.).

Fig. 5. Bar chart rainfall in south DKI Jakarta (west to east) on February (Data processing from BMKG agency in DKI Jakarta, 2011)

Prone areas of flooding in beach ridge more breadth, depth, and length than the coastal alluvial plain, alluvial plain and alluvial fan. The spread of flood prone area flooding in the northwest, and northeast of Jakarta. Topography in the flood-prone area is located on the slope of the flood until basin flat with the surface altitude of fewer than 3 m above sea level. Beach ridge located in the northwest, and northeast of Jakarta, where the tendency is landform direction perpendicular to the coastline. Distribution of flooded areas in beach ridge increasingly widespread, high and long on the slopes of the flat to very flat compared to the rather steep slope. Prone areas of the alluvial floodplain are located on the north coast of Jakarta includes all the sub-districts in North Jakarta area and a small sub-district in the City of West Jakarta and East Jakarta bordering the sub-district administration in north Jakarta. Topography in the flood-prone area is located on the slope of the flooded flat with the surface altitude of fewer than 3 m above sea level.

The actual Prone area flooding in Jakarta in February 1996 occurred in 181 sub-districts (69.4%). The actual

flood-prone area on February 2002 has in common with the floods in February 1996. There is an excellent addition of flooded areas in Jakarta, West Jakarta, Central Jakarta, North Jakarta, and South Jakarta. The actual flood-prone area in DKI Jakarta province on February 2007 has in common with the floods in February 1996 and 2002. There are additional areas of flooding in East Jakarta, West Jakarta, North Jakarta and South Jakarta except Central Jakarta, and North Jakarta. In February 1996, widespread flooding reached 1809.5 hectares or 2.76 percent. Widest spread of flooding is located in the alluvial plain in beach ridge then 30 percent and 20 percent in the alluvial plain of the coast. In February 2002, widespread flooding in Jakarta 3850.84 hectares or 5.88 percent Contained the most massive flood in alluvial plain and coastal alluvial plain, and beach ridge. In February of 2007 floods in Jakarta, reaching 3775.5 hectares or 5.76 percent (Fig. 6.).

Fig. 6. Map Actual flood-prone area in DKI Jakarta province

4 Conclusion

Flooding in DKI Jakarta Province can occur in the months with rainfall > 200 mm/month in February. Heavy daily rainfall from 1 to 5 and the thickness of this rain contribute substantially to the flood incident in lowland Jakarta. Heavy rains that flooded the lowlands of Jakarta decreased to the south and west, namely in February 2002 and 2007. From the results of this study, it is evident that the rainfall in the lowlands of Jakarta contributed significantly to the incidence and spread of the flood. The incidence of floods in February 2007 was longer than in 2002 and 1996. There are differences and similarities of rainy anomalies in the prone areas of flooding in DKI Jakarta.

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