Relationship between extreme rainfall and design flood-discharge of the Ciliwung river

M Farid1,4, D Saputra2, T R Maitsa2, T N A Kesuma3, A A Kuntoro1,5 and A Chrysanti1

1Water Resources Engineering Research Group, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Bandung 40135, Indonesia
2Civil Engineering Master Program, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Bandung 40135, Indonesia
3Civil Engineering Doctoral Program, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Bandung 40135, Indonesia
4Center for Coastal and Marine Development, Institut Teknologi Bandung, Bandung 40135, Indonesia
5Center for Water Resources Development, Institut Teknologi Bandung, Bandung 40135, Indonesia

Corresponding author: dery.saputra16@yahoo.com

Abstract. Flood in Jakarta is occurred almost every year due to inadequate flood control systems to the flood prediction, inadequate drainage system, and trash that clog the drainage. The increase of rainfall is also one of the causes of flooding. That changing rainfall characteristics can affect river flow. This study aims to analyze the trend of rainfall in different time frames and its effect to flood discharge. The extreme rainfall trend is analyzed for every 15 years period from rainfall data of 1985 to 2019 for several return periods. Three period is selected for trend analysis and compared to the baseline data (1985-2019). Based on the analysis, the extreme rainfall for 1995-2009 and 2005-2019 period compared to the baseline is increased for all return periods. The increasing percentage is approximately 3-10% and 5-16% respectively. Since the extreme rainfall is increased, the design discharge is also increased for all return periods. The increasing percentage for 1995-2009 and 2005-2019 period compared to the baseline is 4-12% and 7-19% respectively. However, the design rainfall and discharge for the period 1985-1999 is lower than the baseline.

1. Introduction
Jakarta is well known not only as of the capital of Indonesia with very high population growth but also as the flood prone area in the northern part of Java Island. The projection of DKI Jakarta population in 2019 reached 10.5 million people, with a population growth rate of 1.19 percent per year [1]. Most of the Jakarta area located in the flat riverine area. Jakarta also located very close to the coastal area and traversed by many rivers from the upstream area. The combination of those geographical condition with the increasing environmental damage due to population growth make Jakarta becomes more vulnerable to flood disasters. Floods are considered as a major natural disaster in Indonesia. Annual flood may occur in most parts of Jakarta [2]. Flood becomes a serious problem since it has big impacts on environmental, social, and economic damages [3].
The increase of rainfall also recorded as one of the causes of flooding [4]. The rainfall is increased due to climate and land-use changes [5]. High rainfall frequency that occurred in a short duration and land cover change becomes the impermeable area that can cause higher runoff discharge [6]. The problem of flooding arose from the inaccurate prediction of flood loads on the flood control infrastructure [7] and the decrease of drainage capacity due to trash clogging [8].

In the last decade, flood frequency has been increasing [9]. A study had been conducted by [10] to detect trends in tropics rainfall changes using tropical rainfall data sets for the period 1979-2003 from the Global Precipitation Climatology Project (GPCP), and the Climate Prediction Center Merged Analysis Product (CMAP). The results showed that the trend of heavy and light rain frequency is increasing. Yet the moderate rain events showed a negative trend during that period. Another study also had done by [11] for the study case in Java Island using CMAP rainfall data for the period 1981-2016. The results obtained for the annual rainfall pattern is still similar but has significant changes in rainfall intensity.

There are so many recorded data and previous studies that can be used to conclude that most of the flood-prone areas in Jakarta are a natural floodplain area [4]-[7]-[12]-[13]-[14]. Several previous studies (such as [7]-[9]-[12]-[14]-[15]) also discussed several well-known large floods of Jakarta in 1619, 1872, 1996, 2002, 2007, and 2013. Based on the secondary data and the results of those previous studies, it could be concluded that the implemented several structural flood mitigations could not significantly decrease the flood risk in the last two decades. This paper discussed the important relationship of the increasing flood hazard to the increasing flood risk level of the flooded area [16]. All the above previous studies [7,9,12]-[13] concluded that most structural flood mitigation efforts that may cause high-cost construction, and social problems are not significantly reduced the risk of Jakarta flood. Concluded that an improvement of flood early warning systems could significantly contribute to the flood disaster risk reduction effort wherever the flood hazard models could predict a reliable flood propagation [14]. One of the most difficult efforts of flood propagation model prediction improvement is to determine the reliable flood hydrograph [4,9,12]. Nowadays, the flood hydrograph is influenced not only by land-use change but also by climate change where the flash flood is more frequently recorded than previous time [4,12,15,17,18]. Suggested to encounter the correlation of the trend of extreme rainfall and runoff discharge in addressing the influence of land-use change and climate change [4,15,17]. This paper discusses the trend of the rainfall-runoff frequency distribution of the Ciliwung River.

2. Study case location

Jakarta Province is located at 5°19'12" – 6°23'54" S and 106°22'42" – 106°58'18" E. The elevation is around 8 meters above the sea level. Jakarta region consists of 662.33 km² land and 6,977.5 km² sea. According to its geographical location, the boundaries of Jakarta Province are:

- **Northern Part**: ± 35 km coastline from west to east
- **Eastern Part**: Bekasi
- **Western Part**: Banten Province
- **Southern Part**: West Java Province

Ciliwung River is the main and longest river in Jakarta [19]. The upstream is in Pangrango, and the river flows northwards through Jakarta into the Java Sea. Ciliwung river basin is approximately 117 m long and has 382.6 km² of the catchment area [2]. The river flow primarily depends on seasonal characteristics. Naturally, the basin consists of steep terrains in the upper basins and flat in the lower basins. In this kind of situation, Jakarta becomes more vulnerable to be flooded in the wet season.

Jakarta has an important role in commercial activities. It also has the most densely populated area and located in the downstream part of the Ciliwung River Basin [20]. Since Jakarta is in the downstream area, the occurrence of a flood is related, especially to its upstream area. Due to many kinds of important activities in Jakarta, flood occurrence will have very serious impacts on several aspects.
3. Material and method

The data we used in this study are secondary data from Balai Besar Wilayah Sungai Ciliwung-Cisadane and BMKG. Those are maximum daily rainfall data (1985 - 2019) from rainfall stations around Ciliwung River Basin and hourly discharge data. Table 1 shows the rainfall station and its area of influence in the Ciliwung River Basin.

The rainfall design trend is analyzed by using regional rainfall in Ciliwung River Basin. Each maximum daily rainfall data from 9 rainfall stations around Ciliwung River Basin is calculated by Polygon Thiessen Method to obtain the regional rainfall. To analyze the rainfall trend, firstly, the regional rainfall data is divided into three sequences, as in Table 1.

The baseline data are selected from whole data set from 1985-2019. The data then calculated to obtain the maximum daily rainfall return period of 2-100 years. In order to see the average increase of the design rainfall return period, a regional maximum rainfall statistical approach is taken with a span of 15 years period. Three sequence are selected there are 1985-1999 (sequence 1), 1995-2009 (sequence 2), and 2005-2019 (sequence 3). The three sequence rainfall data will be compared against the baseline. Then the rainfall design is used to calculate design discharge in Ciliwung River Basin.

Design discharge modeling is conducted in HEC-HMS by using Snyder and SCS-CN Synthetic Unit Hydrograph Method. The calibration is done using the measurement data. Based on several flood hydrograph event, parameters are obtained for each flood event. The input parameters are then

![Rainfall station area of influence in Ciliwung River Basin](image)

**Table 1 Data sequences**

| Data sequences | Year       |
|----------------|------------|
| 1              | 1985-1999  |
| 2              | 1995-2009  |
| 3              | 2005-2019  |
calibrated against the hydrograph measurement at the time of the event. The parameter of calibrated models will be used in the re-design discharge analysis.

4. Results and discussion

4.1. Rainfall design trend analysis
Regional rainfall obtained from the calculation using the Thiessen Polygon. Rainfall data of 1985-2019 is used to calculate the regional rainfall design. The lowest regional rainfall occurred in 1997. At that time, the el-Nino phenomenon occurred. Thus, there was a rainfall anomaly and caused drought in Indonesia. The highest regional rainfall occurred in 2007. The heavy rainfall is evenly distributed spatially in Ciliwung River Basin.

Then frequency analysis is conducted for each data sequence to obtain the rainfall design for any return periods. Based on the parametric analysis, chi-square, and Smirnov Kolmogorov test, the most suitable distribution than the other methods is Gumbel Distribution.

All sequences are compared to the baseline to obtain the trend of rainfall design in each return period. Based on the calculation, the rainfall design in sequence 1 is smaller than the baseline, yet sequences 2 and 3 are higher than the baseline. The increasing percentage is plotted to a logarithmic scale graph, as shown in Figure 2.

![Figure 2 Increasing percentage for several return periods rainfall design](image)

Extreme rainfall in 1985-1999 is about 4-5% lower than the baseline. Whereas for 1995-2009 and 2005-2019 period, the extreme rainfall is higher in the return period of 2-100 years, about 3-10% and 5-16% compared with the baseline, respectively. By this analysis, we obtain higher design rainfall when we used the latest data. The design rainfall is very important in designing hydraulic infrastructure. Thus, using the newest rainfall data are important for design rainfall. Therefore, the infrastructure has the appropriate capacity to overcome the load discharge in the future.

4.2. Flood hydrograph analysis
In this study, the calibration of the flood hydrograph was carried out with a trial and error approach manually, due to the limitations of hourly rainfall data. Modeling without calibration and verification
will only provide modeling results based on the assumptions of the researcher. The weakness of the calculation of flood discharge using rainfall data is that we must always assume that rain occurs in all watersheds. Even though it rarely happens uniform and simultaneous rain events in a watershed, especially in large watersheds.

Based on the analysis of synthetic unit hydrographs that have been carried out on several flooding events using the SCS-CN and Snyder methods, the best value that has been calibrated and validated is on 9 February 2015 with an NSE value of 0.959 and an RMSE of 0.2. This can be said to be a good category, so for subsequent re-discharge analysis will use Snyder with a standard lag parameter (hr) of 12.07 and a peaking coefficient of 0.61. The discharge in each sequence is also compared to the baseline to see the trend for design discharge. From the analysis of the design discharge on the data, the following values were obtained.

![Figure 3 Increasing percentage for several return periods rainfall design](image)

As the design rainfall for sequence 1 is lower than the baseline, thus the design discharge for this sequence is also lower than the baseline. Meanwhile, design discharge in sequence 2 is increased 4-12%, and in sequence 4 is increased by about 7-19%. Both increasing percentages are relative to the baseline design discharge. These two sequences show an increase in the amount of rain in each period, which causes the average amount of rain later periods to be higher than the former period. The slope of the graph for the formation of the magnitude of the return period also shows a higher increase in the later period, which indicates the variation of the occurrence of the maximum rainfall is getting bigger. The likelihood of higher extreme rainfall occurring in future rain periods also increases.

These indications lead to the need for a review of the rain plan used to design water structures. With the increase in the magnitude of the rain return period that occurred, it could be that the capacity needs of the water infrastructure plan that have been designed for more than 15 years need to be reviewed and revised.
5. Conclusions
The analyses of extreme rainfall trends from 1985 until 2019 rainfall data for several return periods have been conducted to assess the change of flood discharge in Ciliwung River. Three sequence of 15 years period are selected for analysis. There are 1985–1999 (sequence 1), 1995–2009 (sequence 2), and 2005–2019 (sequence 3). The three sequence rainfall data will be compared against the baseline (1985 – 2019). Based on the results, it can be concluded that design rainfall and discharge for the period 1985-1999 is lower than the baseline. Yet the design rainfall and discharge are higher for the period 1995-2009 and 2005-2019.

The increasing percentage of rainfall and discharge for the period 1995-2009 is about 3-10% and 4-12% respectively and for the period 2005-2019 the rainfall is increased 5-16% and for the discharge is 7-19%. As the design rainfall is getting higher, design discharge is also increased. By these results, the use of the latest data is highly suggested to obtain adequate flood control infrastructures. This study can be used to evaluate the forecast of flood inundation and to evaluate the performance of water structures in the Ciliwung River Basin.

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