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Flood Observations in Indonesian Regions to Support the Development of Synthetic Unit Hydrograph Based on Watershed Characteristics

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Abstract: This study intends to analyze the observed floods in some Indonesian areas to support the model development of synthetic unit hydrographs based on watershed characteristics. By using observed rainfall data, river discharge, and watershed morphology characteristics, this study also intends to understand the pattern and frequency of flood events in some Indonesian areas. The methodology consists of obtaining the parameter value of the watershed characteristic from the topography map and Digital Elevation Model (DEM) map, rather than using the Collins method to analyze the observed unit hydrograph due to the discharge hydrograph. Floods are natural disasters that often occur in Indonesia and have a significant impact on human life, the economy, and the environment. The geographical conditions and tropical climate in Indonesia make this country vulnerable to high rainfall and other natural phenomena that cause floods. The research results are expected to contribute more accurately to the development of the synthetic unit hydrograph model in accordance with the geographic conditions of Indonesia. Therefore, it can be used as an assistant tool in design and flood disaster mitigation in the future, the results show that the influenced area of rainfall (Automatic Water Rainfall Recorder) in Jawa Timur Province and Nusa Tenggara Barat province indicate the significant effect, however there is relatively small influence in Yogyakarta. In addition, the results show that the watershed shape significantly influences the duration of the time to peak and flood peak discharge.

Keywords: observed flood, observed unit hydrograph, Collins method

印度尼西亚区域洪水观测支持基于流域特征的合成单位线的开发

摘要：本研究旨在分析印度尼西亚部分地区观测到的洪水，以支持基于流域特征的合成单位水文线模型的开发。通过利用观测到的降雨数据、河流流量和流域形态特征，本研究还旨在了解印度尼西亚部分地区洪水事件的模式和频率。该方法包括从地形图和数字高程模型（DEM）图获取流域特征的参数值，而不是使用柯林斯法分析由于流量水文线而观测到的单位水文线。洪水是印度尼西亚经常发生的自然灾害，对人类生活、经济和环境产生重大影响。印度尼西亚的地理条件和热带气候使该国容易受到高降雨和其他导致洪水的自然现象的影响。研究结果有望为根据印度尼西亚地理条件更准确地开发合成单位水文线模型做出贡献。因此，可以作为今后设计和防洪减灾的辅助工具，结果显示，降雨影响区（自动降雨量记录仪）在东爪哇省和西努沙登加拉省的影响显著，而在日惹的影响相对较小。此外，结果还显示，流域形状对洪峰持续时间和洪峰流量有显著影响。

关键词： 观测洪水、观测单位过程线、柯林斯方法

1. Introduction

Floods are natural disasters that occur most frequently in Indonesia [1] and often cause significant economic and social losses. Data from the Indonesian National Institution of Disaster Countermeasures (BNPB) show that there are more than 300 flood events in 2021 that are reported in some areas, mainly in Java and the Sumatra Islands [2]. The increase in flood intensity and frequency is influenced by various factors, including climate change, rapid urbanization, and ineffective water resource management [3].

Accurate development of synthetic unit hydrograph models has become very important in the design of flood management [4-5]. This model can provide better information about the response of watersheds to rainfall and help formulate an accurate mitigation policy [6-7]. According to [8], modelling based on watershed characteristics can increase the flow and stimulate the implementation of more effective mitigation strategies.

The unit hydrograph is an important tool in the design and management of water resources, particularly in understanding the response of the watershed to rainfall. In the context of flood management, unit hydrographs work for predicting river discharge based on the rainfall that happened [9-10], so they can be used in the design of mitigation and flood control [11]. The Collins method is an effective approach for analyzing unit hydrographs. To build a flood hydrograph in a river, there is little or no observed flood hydrograph; therefore, so it is needed the characteristics or parameters of the watershed must be formerly [12].

This research intends to analyze unit hydrographs using the Collins method in some areas of Indonesia. Using this approach, accurate information about the dynamics of river flow influenced by rainfall can be obtained, and watershed characteristics contribute to this process. This research can contribute to the development of a more effective hydrological model for managing water resources and flood mitigation.

2. Materials and Method

This research was conducted in 16 watersheds spread across Java and Nusa Tenggara Barat (Figure 1). The 16 watersheds include DAS Lesti, DAS Brantas Hulu, DAS Welang, DAS Samiran, DAS Brang Biji, DAS Dodokan, DAS Meninting-Balencong, DAS Meninting-Orong Atas, DAS Jangkok-Jurang Malang, DAS Jangkok-Bug Bug, DAS Oyo Bendungan, DAS Oyo- Kedung Miri, DAS Serang, DAS Opak-Wonokromo, DAS Opak-Pulo Candi, dan DAS Opak-Kali Bawang.

The data used in this research were rainfall (Automatic Rainfall Recorder-ARR) and discharge (Automatic Water Level Recorder-AWLR). To determine the average rainfall, the Thiessen Polygon was used; therefore, a watershed map was needed to create a polygon in each watershed.

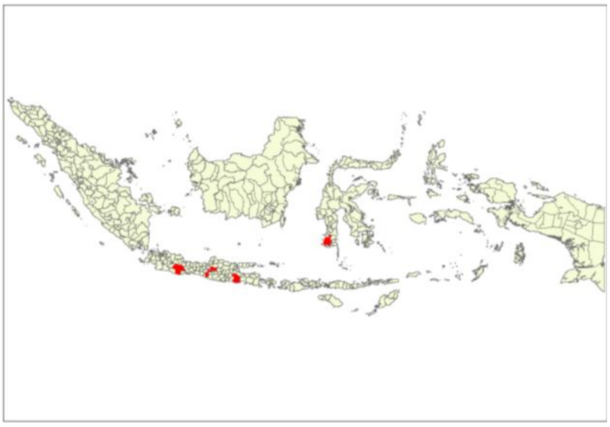


Figure 1. Research area
Source: own study

2.1. Average Rainfall Analysis

Rainfall is the most important factor influencing river discharge. Rainfall measurement tools are usually installed in watersheds. To determine the average rainfall, this study used a Thiessen Polygon. This Method allows the analysis of average rainfall by considering the geographical proximity of the observed stations.

The process starts by collecting rainfall data from several meteorology stations in the area to be analyzed. After the data are available, the next step is to map the station locations. By the position on the stations that have been mapped, we can create a polygon that represents the influenced area of every station. This step is performed by connecting the line between every pair of stations and then drawing a perpendicular line in the middle of every connecting line. The cutting point of these lines forms the Thiessen polygon, which illustrates the area where a rainfall station is the nearest. The polygon area can be used to analyze the area of average rainfall using the following equation:

$$P_{avg} = \frac{\sum (P_i \times A_i)}{\sum A_i} \quad (1)$$

where:
P_{avg} - average rainfall
P_i - rainfall from station-i
A_i - polygon area that is related with station-i

2.2. Observed Unit Hydrograph

The observed unit hydrograph in each watershed was calculated using the Collins method with the following analysis steps:

1. The stage hydrograph is transformed into discharge hydrograph by calibration.
2. The base flow is separated from the hydrograph using an empirical method such as Straight-Line Method [12].
3. The effective rainfall that causes flood is analysed by using Phi Index.
4. A trial unit hydrograph is determined by determining the ordinates with certain dimensions.
5. The initial unit hydrograph (trial) is multiplied by all effective rainfall, except for the largest effective rainfall.
6. The direct runoff hydrograph above is reduced by the measured direct run-off hydrograph, a direct run-off hydrograph that is caused by the maximum rainfall is obtained, and the second unit hydrograph (trial) is obtained.
7. The second unit hydrograph was compared to the initial unit hydrograph. If there is still a large difference (in accordance with the standard error that is determined), then it is returned in the fifth and sixth stages based on the last unit hydrograph.
8. Thus, until, the smallest possible difference between the last unit hydrograph and the previous one was obtained.

The result of the analysis is average time to peak and average peak discharge.

3. Results and Discussion

3.1. Average Rainfall Analysis

Analysis of average rainfall was carried out using Thiessen Polygon. Figures 2, 3, and 4 present the Thiessen polygons on watersheds in Jawa Timur, Yogyakarta, and Nusa Tenggara Barat, respectively.

Watersheds in Jawa Timur have four automatic rainfall recorders (ARRs): Lawang, Malang, Poncokusumo, and Dampit. All ARR in Jawa Timur are sufficiently significant for the contribution of the influenced area. Watersheds in Yogyakarta had six ARR: Terong, Kedung Keris, and Beji/Ngawen. Prumpang, Gemawang, and Bronggang. ARR in Yogyakarta, several of which contribute sufficiently to the influenced area; however, the others only give relatively small values in the influenced area. The watersheds in Nusa Tenggara Barat have five ARR: Samongkat, Jurang Malang, Batujai, Sesaot, and Gunungsari. All ARR in Nusa Tenggara Barat are sufficiently significant to contribute to the influenced area.

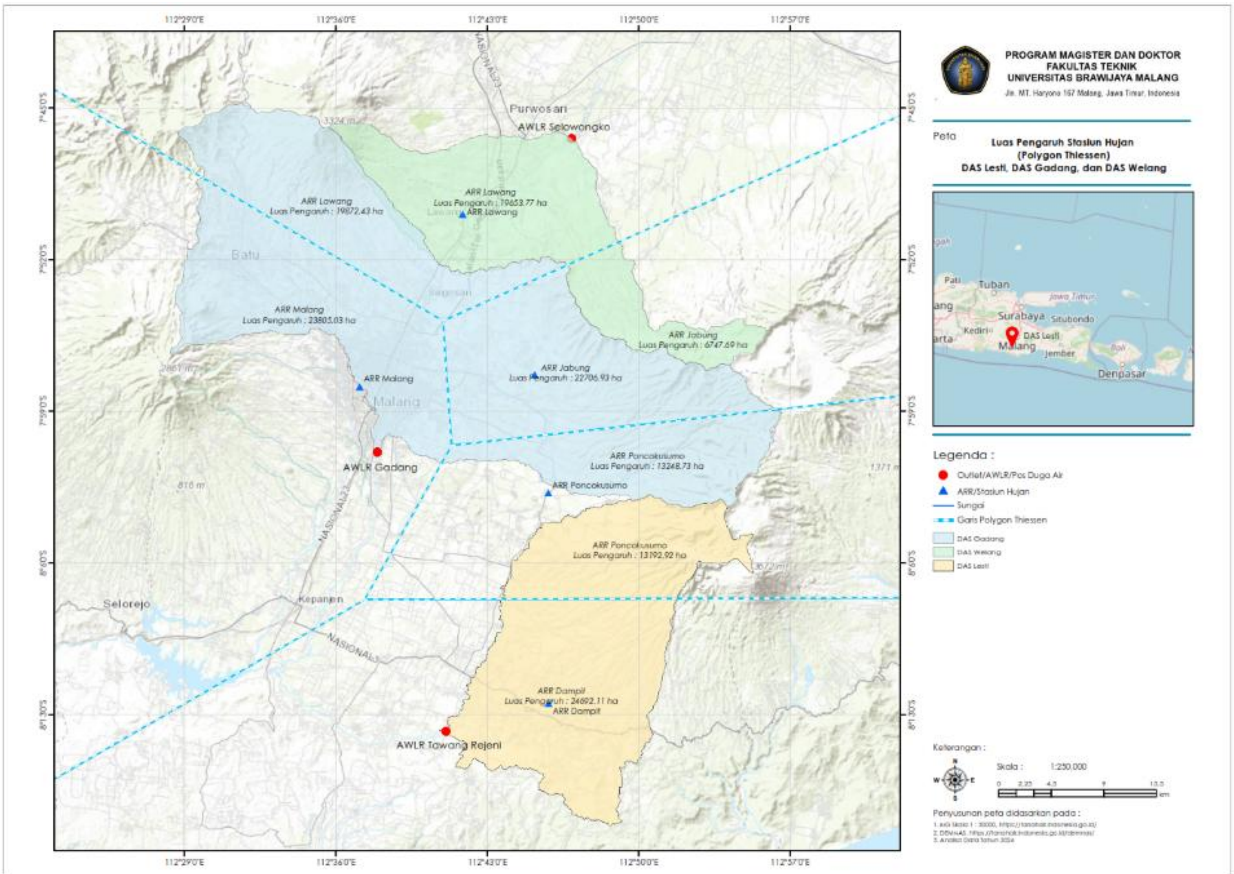


Figure 2. Polygon of Watershed in East Java
Source: own study

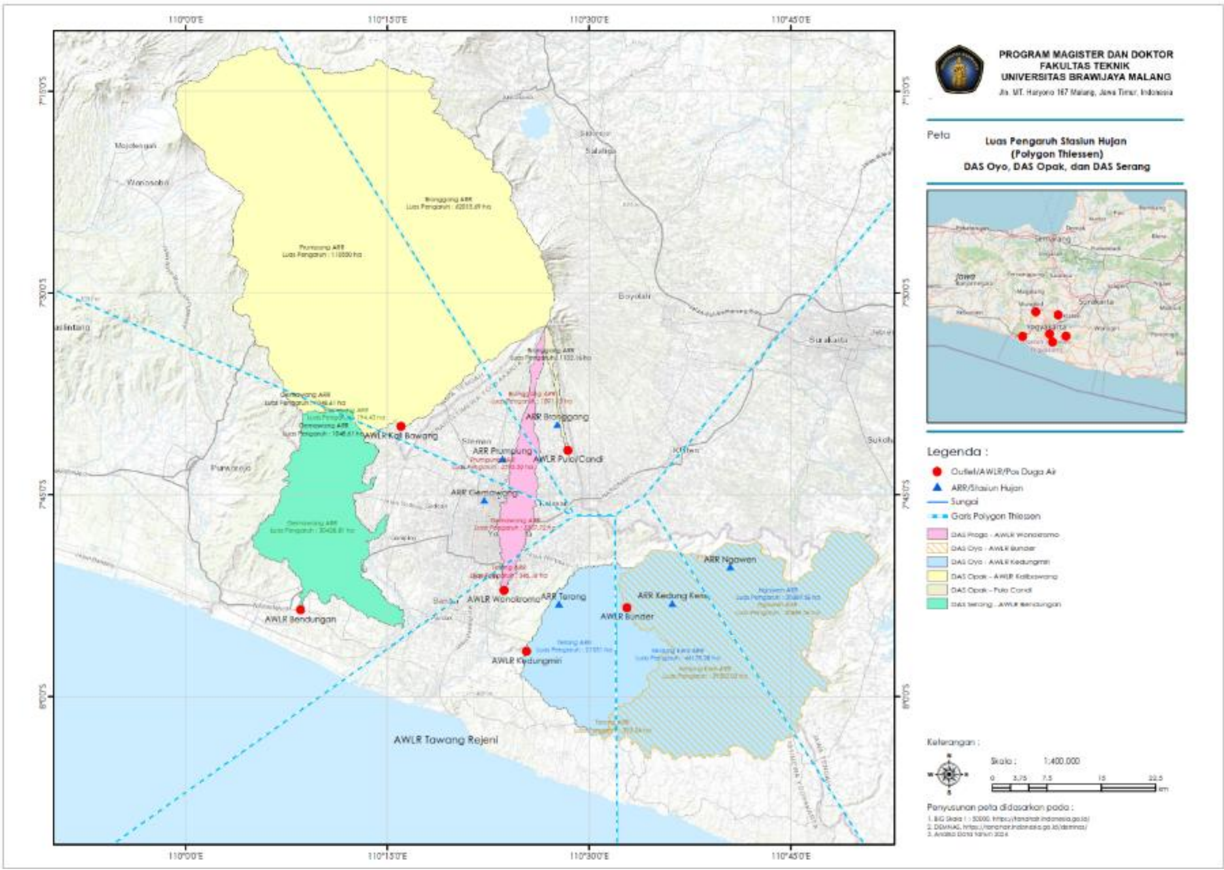


Figure 3. Polygon of Watershed in Yogyakarta
Source: own study

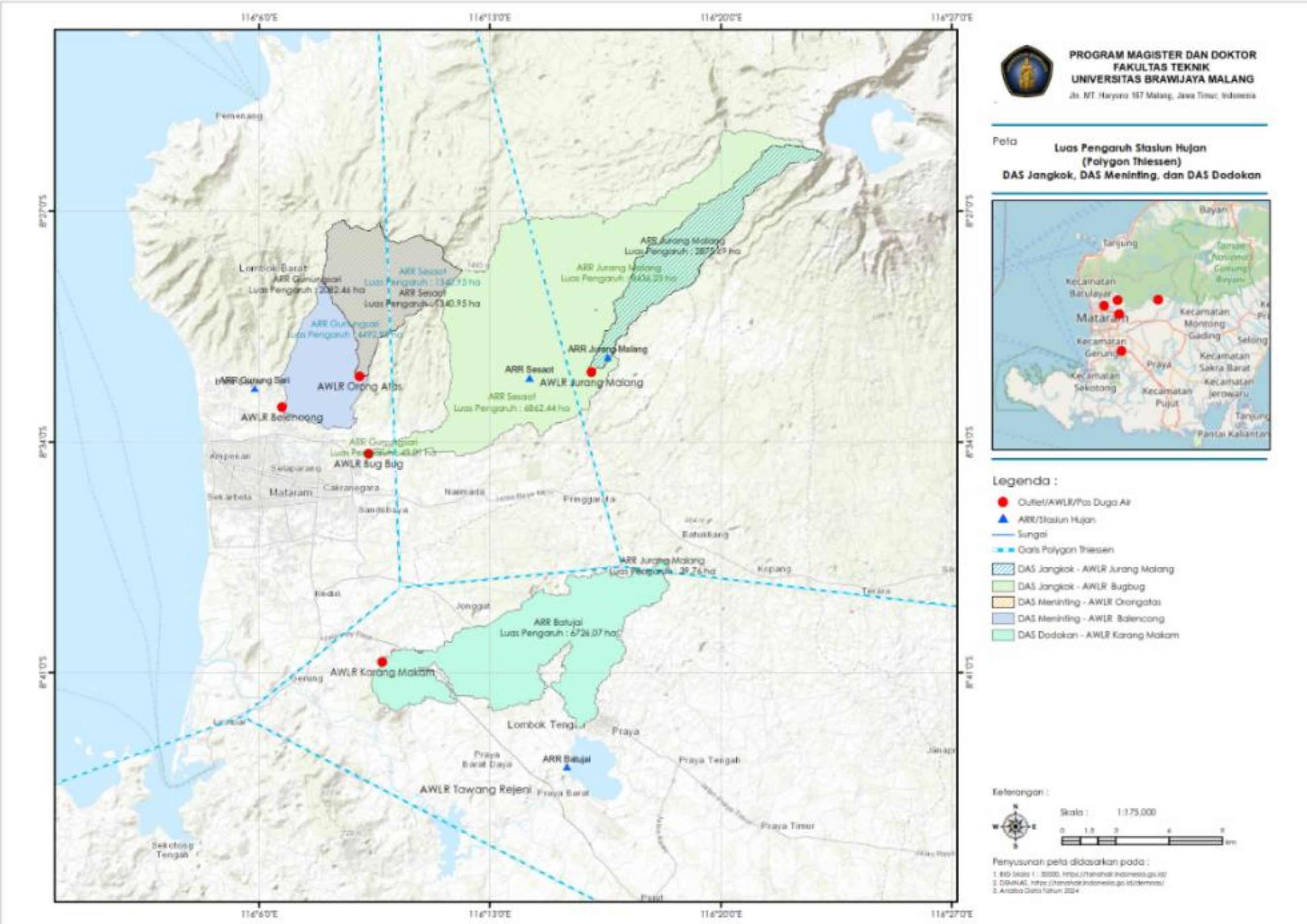
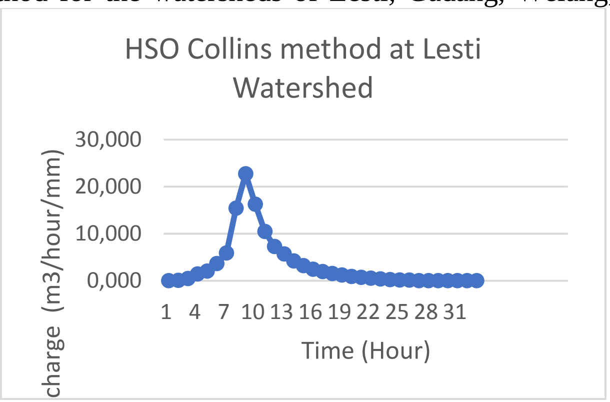


Figure 4. Polygon of Watershed in Nusa Tenggara Barat
Source: own study

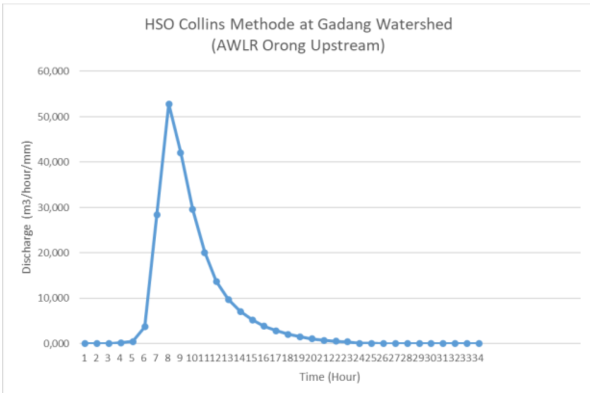
3.2. Observed Unit Hydrograph Analysis

The observed unit hydrograph in each watershed was analyzed using the Collins method, with the analysis steps described above. The analysis result is the average time to peak and peak discharge. Figure 5 shows the observed unit hydrographs due to Collins method for the watersheds of Lesti, Gadang, Welang, Samiran, Brang Biji, Dodokan, Meninting Blencong, Meninting Orong, Jungkok Jurang, Jungkok Buk Buk, Bunder, Kedungmiri, Serang, Opak Wonokromo, Opak Pulo, and Opak Kalibawang.

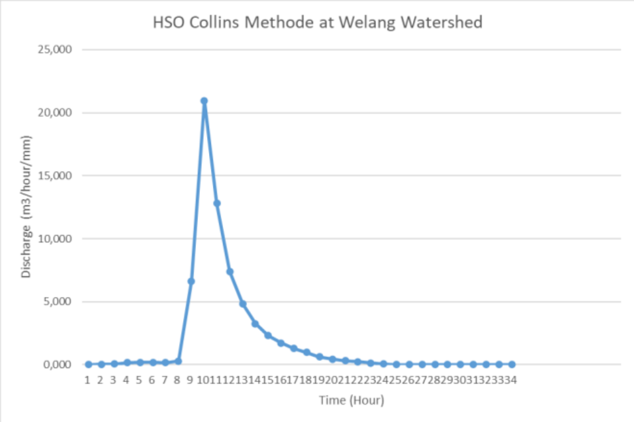
The analysis results for the time to peak and peak discharge for each watershed are presented in Table 2.



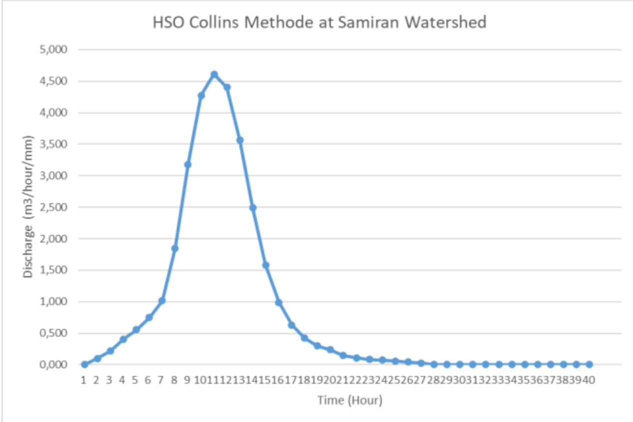
HSO Lesti Watershed Collins method



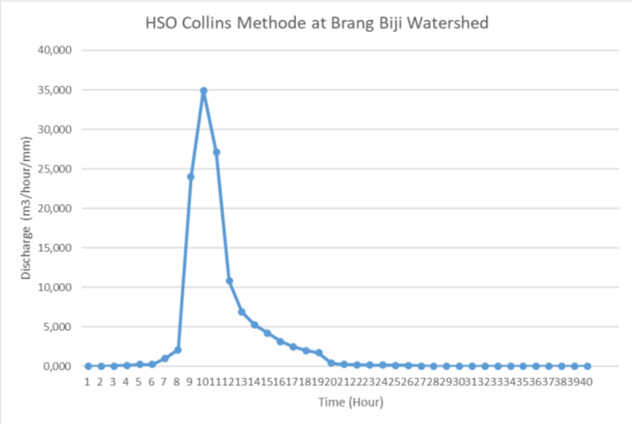
HSO Brantas Upstream Watershed Collins method



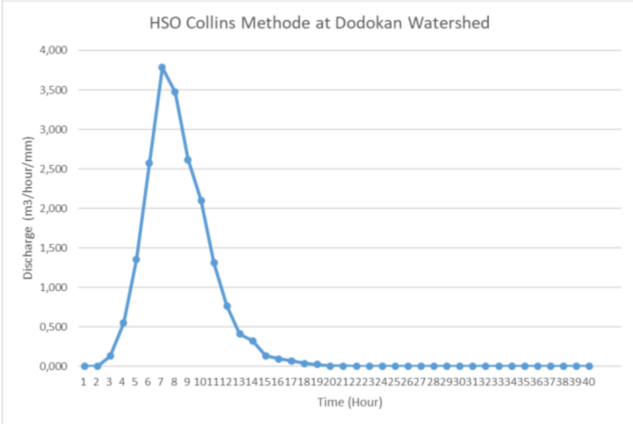
HSO Welang Watershed Collins method



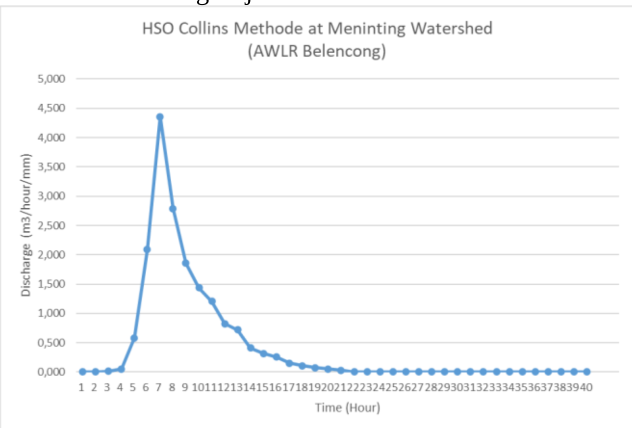
HSO Samiran Watershed Collins method



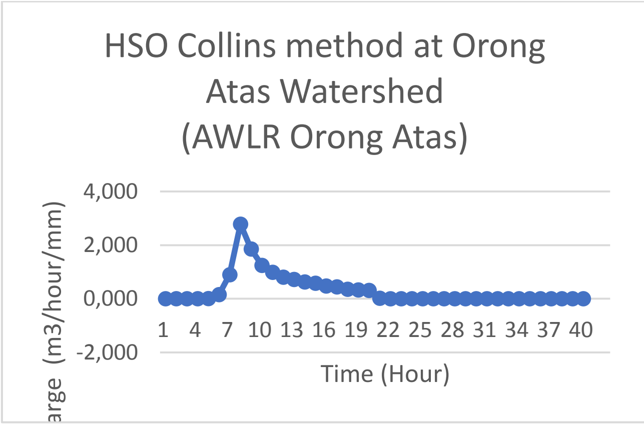
HSO Brang Beji Watershed Collins method



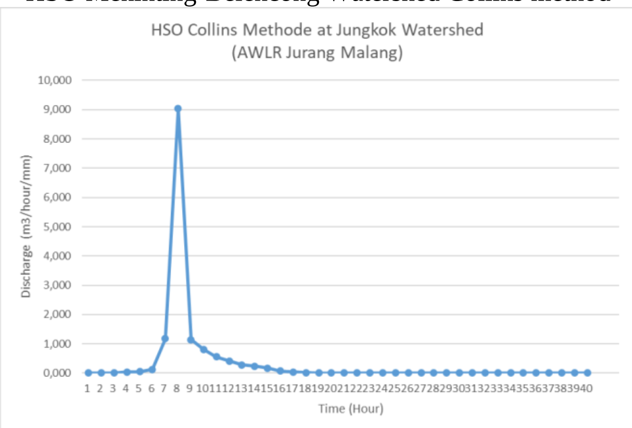
HSO Dodokan Watershed Collins method



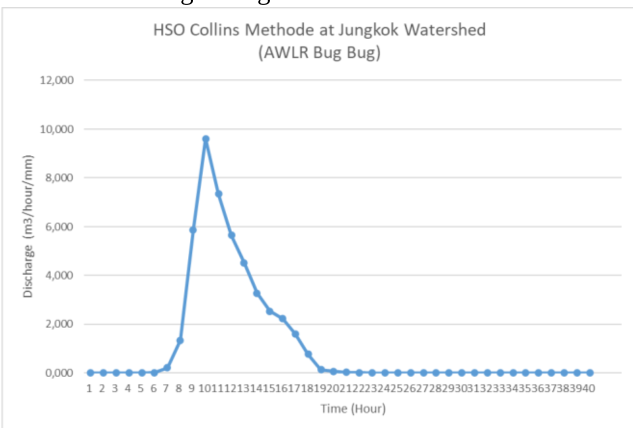
HSO Meninting-Belencong Watershed Collins method



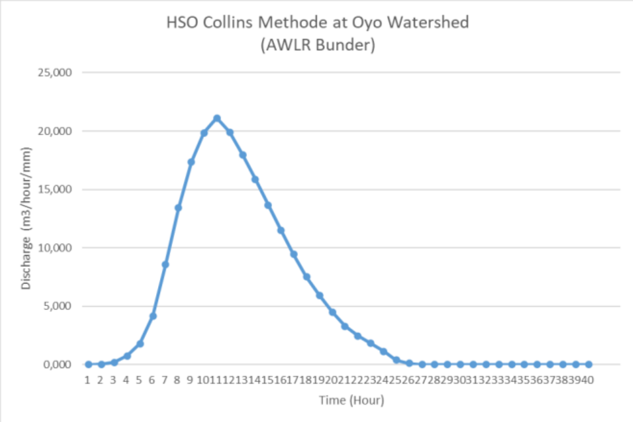
HSO Meninting-Orong Atas Watershed Collins method



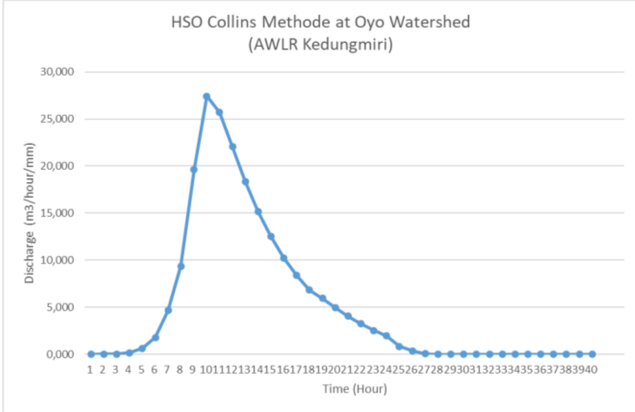
HSO Jungkok-Jurang Malang Watershed Collins method



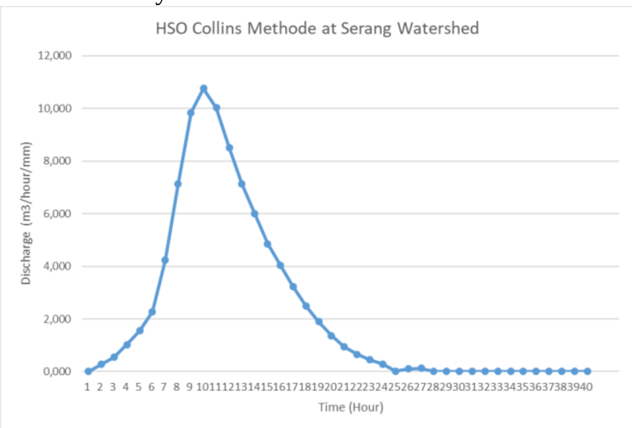
HSO Jungkok-Bug Bug Watershed Collins method



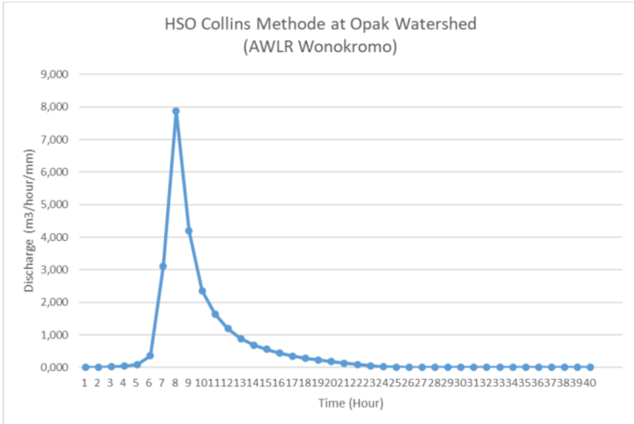
HSO Oyo-Bunder Watershed Collins method



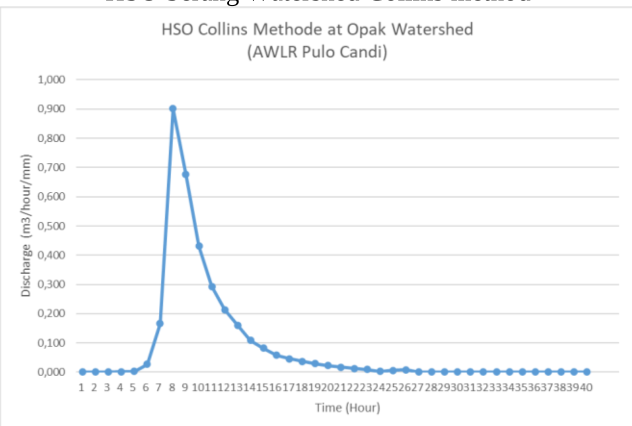
HSO Oyo-Kedungmiri Watershed Collins method



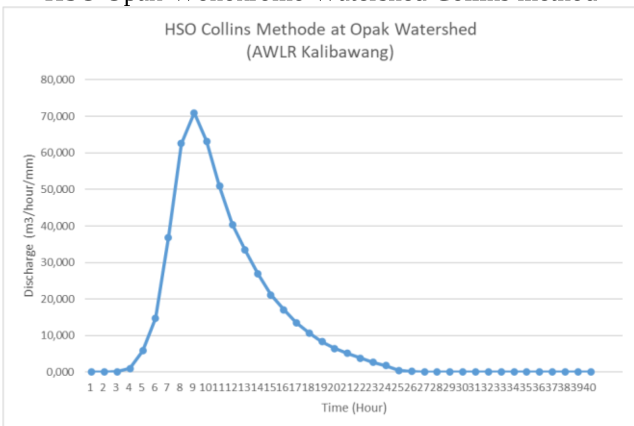
HSO Serang Watershed Collins method



HSO Opak-Wonokromo Watershed Collins method



HSO Opak-Pulo Candi Watershed Collins method



HSO Opak-Kalibawang Watershed Collins method

Figure 5. Observed unit hydrograph due to Collins method

Source: own study

Table 2. Analysis Result of Collins (developed by the authors)

No	Name of Watershed	AWLR Station	Tp (hour)	Qp (m^3/s/mm)
1	Lesti	Tawangrejeni	10	21.954
2	Brantas Hulu	Gadang	8	52.728
3	Welang	Welang	11	25.072
4	Samiran	Samiran	10	4.657
5	Brang Biji	Brang Biji	11	17.907
6	Dodokan	Karang Makam	10	3.949
7	Meninting-Belencong	Belencong	12	4.550
8	Meninting-Orong Atas	Orong Atas	12	3.413
9	Jungkok-Jurang Malang	Jurang Malang	13	6.401
10	Jungkok-Bug Bug	Bug Bug	14	9.899
11	Oyo-Bunder	Bunder	10	21.012

No	Name of Watershed	AWLR Station	Tp (hour)	Qp (m^3/s/mm)
12	Oyo-Kedungmiri	Kedung Miri	9	26.821
13	Serang	Bendungan	9	10.680
14	Opak-Wonokromo	Wonokromo	7	7.936
15	Opak-Pulo Candi	Pulo/ Candi	7	0.919
16	Opak-Kalibawang	Kali Bawang	8	71.496

The highest time to peak was 12 h for the Meninting-Blencong and Meninting Orong Atas watersheds, respectively. However, the peak discharge in both watersheds is relatively low, that is 4.55 m^3/s/mm in Meninting Blencong watershed and 3.413 m^3/s/mm in Meninting Orong Atas watershed. This indicates that the two watersheds are relatively wide, so there is a need for sufficient time to reach peak flood discharge.

The lowest time to peak was 7 h for the Opak-Wonokromo and Opak Pulo Candi watersheds. However, the flood peak discharge in the Opak Wonokromo watershed is 7.736 m^3/s/mm and that in Opak Pulo Candi is 0.919 m^3/s/mm. This result indicates that the Wonokromo watershed is wider than the Pulo watershed. This result reflects that watershed shape affects the time to peak and flood peak discharge.

4. Conclusion

Floods are natural disasters that often occur in Indonesia and have a significant impact on human life, the economy, and the environment. The geographical conditions and tropical climate in Indonesia make this country vulnerable to high rainfall and other natural phenomena that cause floods.

The research results for 16 watersheds that are spreading in Jawa Timur, Yogyakarta, and Nusa Tenggara Barat produced a rainfall-influenced area from ARR (Figure 2), peak discharge, and time to peak (Table 2) in Jawa Timur, Yogyakarta, and Nusa Tenggara Barat. The rainfall influenced area (ARR) in Jawa Timur and Nusa Tenggara Barat show a significant influence; however, in Yogyakarta, several of them have significant influence and the others have relatively small influence.

The highest time to peak was 12 h for the Meninting-Blencong and Meninting Orong Atas watersheds, respectively. However, the peak discharge in both watersheds is relartively low, that is 4.55 m^3/s/mm in Meninting Blencong watershed and 3.413 m^3/s/mm in Meninting Orong Atas watershed. The lowest time to peak was 7 h for the Opak-Wonokromo and Opak Pulo Candi watersheds. However, the flood peak discharge in the Opak Wonokromo watershed is 7.736 m^3/s/mm and that in Opak Pulo Candi is 0.919 m^3/s/mm. This result reflects that watershed shape affects the time to peak and flood peak discharge.

The research results are expected to contribute more accurately to the development of the synthetic unit hydrograph model in accordance with the geographic conditions of Indonesia.

Declarations

Author Contributions

Conceptualization, A.G.M. and L.M.L.; methodology, A.G.M. and L.M.L.; formal analysis, A.G.M., S. and U.A.; writing—original draft preparation, all authors contributed equally; writing-review & editing, A.G.M.; visualization, U.A.; project administration, A.G.M. and L.M.L. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data presented in this study are available in this article.

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Funding information is not available.

Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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