Detection of Flood Inundation in the Progo Watershed using the SHETRAN Model

by Suroso Suroso

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Abstract. Floods are the most frequent disasters in Indonesia in the past 20 years. Based on the Indonesian Disaster Information Data (DIBI) compiled by BNPB, there are considered to be 9053 events (37.5%) of the total natural disaster events in Indonesia. The flood disaster has threatened and disrupted people's lives and even resulted in fatalities, environmental damage, property losses, and psychological impacts. Therefore several efforts of flood risk reduction are required. One of them is to develop a model to detect the depth of flood inundation. The purpose of this study is to apply the SHETRAN Model for flood inundation detection in the Progo Watershed. The SHETRAN model is a distributed hydrological model. The data required in this model are hydro-climatological data, including rainfall and evaporation, land use land cover, soil type, and topography data obtained from remote sensing. The results of this study indicate that in the range from 2001 to 2017, the maximum height of flood inundation between the data on flood events in the field and the phreatic depth of the results from the SHETRAN Model were 0.606 m which occurred on January 17, 2013 in Tirta Rahayu Village, Sub-district Galur, Kulon Progo Regency. While the maximum height of flood inundation results from the RStudio analysis on the Progo Watershed range from 2001 to 2017 were 3,856 m which occurred in 2010.

1. Introduction

Floods are the most frequent disasters in Indonesia in the past 20 years. Based on the Indonesian Disaster Information Data (DIBI) compiled by BNPB, there were 9053 events (37.5%) of the total natural disasters in Indonesia. Whereas in Central Java Province and Yogyakarta Special Region Province (DIY) flooding ranks third after landslides and tornadoes with 1449 events or around 23 percent of the total natural disaster events from early 2001 to the end of 2019 as shown in Figure 1. The frequency of floods in Central Java and DIY Provinces always changes every year. For that reason, flood disaster must always be a problem that needs attention at all times.
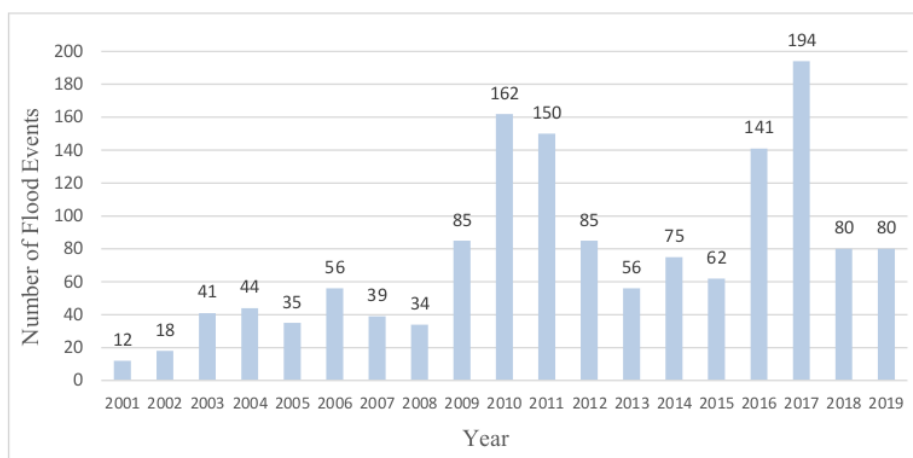
Figure 1. Frequency of Flood Events in Central Java and Yogyakarta in 2001-2019

Inundation is an event where water does not flow or water stops somewhere ([1];[12]). Thus, it is possible to have an inundation of water even though the water level in the river is still normal. Inundation is not a problem if it does not cause a problem, such as not causing casualties, losses, and not submerging community facilities that live in an inundation area [12]. Inundation becomes a problem and develops into a disaster or commonly called a flood if it interferes with human activities and even causes casualties and property.

In this research, flood modeling is developed using the SHETRAN Model. The SHETRAN Model is a spatial distributed hydrological model developed by Newcastle University ([2];[10];[14]). The SHETRAN physically-based distributed rainfall-runoff modelling system gives detailed simulations in time and space of water flow and sediment and solute transport in river catchments [2]. One of the advantages of this model is that only using input data from satellite data can produce multiple outputs in the hydrological cycle ([2];[3];[10]). The outputs of the SHETRAN Model include phreatic depth (m), overland flow (m^3/s), surface depth (m), soil moisture (m^3/m^3), and water table elevation (m). To detect flood inundation, the output of the SHETRAN Model used is phreatic depth (m) [3].

The data needed to use this model is hydroclimatological data. In this study, hydroclimatological data were obtained from satellite data obtained from related agencies such as the Meteorology, Climatology and Geophysics Agency (BMKG). Hydro-climatological data used include (1) topographic data obtained from Digital Elevation Model (DEM) data; (2) rainfall data and evaporation data obtained from Tropical Rainfall Measuring Mission (TRMM) data; (3) soil type data obtained from Hermonized World Soil Database (HWSD) data; and (4) land use data obtained from Land Use Land Cover (LULC) data.

River floods are common natural disasters that cause serious economic damage worldwide. In addition to direct economic damage, such as the destruction of physical assets, floods with long-lasting inundation cause direct and indirect economic losses within and outside the affected area. Direct economic losses include loss of opportunity, due to interruption of business activities, and the costs associated with emergency measures such as cleaning, while indirect economic losses affect sectors within the trade and supply network [12]. There are many factors that can cause flooding, but the causes of flooding cannot be completely eliminated. Therefore, efforts are needed to reduce the impact caused by flooding. One way to overcome the problem of flooding is to make flood modeling that can detect inundation. This study aims to apply the SHETRAN Model to detect flood inundation in the Progo Watershed.

2. Data and Study Location

2.1. Study Location

The research location was carried out in the Progo Watershed, located in Central Java Province and Yogyakarta Special Region. The Progo Watershed area covers 11 districts/cities, there are Bantul Regency, Yogyakarta City, Kulon Progo Regency, Sleman Regency, Purworejo Regency, Boyolali Regency, Magelang Regency, Magelang City, Semarang Regency, Temanggung Regency, and Wonosobo Regency as shown in Figure 2. The area of Progo Watershed is ± 2659 km^2 with the Progo River as the main river which has a length of ±138 km.

Geographically, the Progo Watershed is located at 09^0 59 'BT - 110^0 291' BT and 07^0 12' LS - 08^0 04' LS. The Progo Watershed has a tropical climate, with a rainy season between October and March, and a dry season between April and September. The amount of rain per year in the Progo Watershed varies from 1700 mm to 4000 mm per year, with monthly variations between 33 to 385 mm. Flooding is a routine problem that occurs in several areas within the Progo Watershed. This can happen because in the upstream part of the Progo Watershed is an agricultural area and many of them are turning into non-agricultural functions. Whereas in the downstream areas there was a reduction in irrigation areas due to the conversion of irrigated land into settlements due to population pressure.
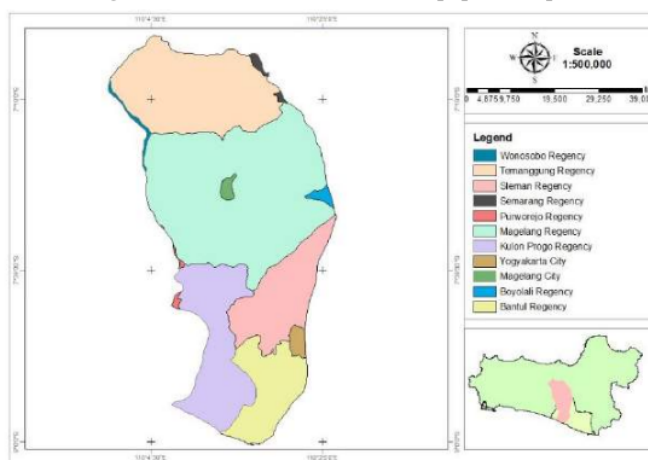

Figure 2. Progo Watershed Map

2.2. Data Collection

The data needed in this study can be explained as follows:

2.2.1. Topographic Data.

Topographic data is obtained from Digital Elevation Model (DEM) data, which is digital data that is able to describe the shape and condition of the earth's surface needed in flood modeling using the SHETRAN Model ([9];[11]). Therefore, the DEM data in this study was processed using ArcGIS software to describe the Progo Watershed so that it can be run on the SHETRAN model. The following is DEM map of Java Island can be seen in Figure 3.
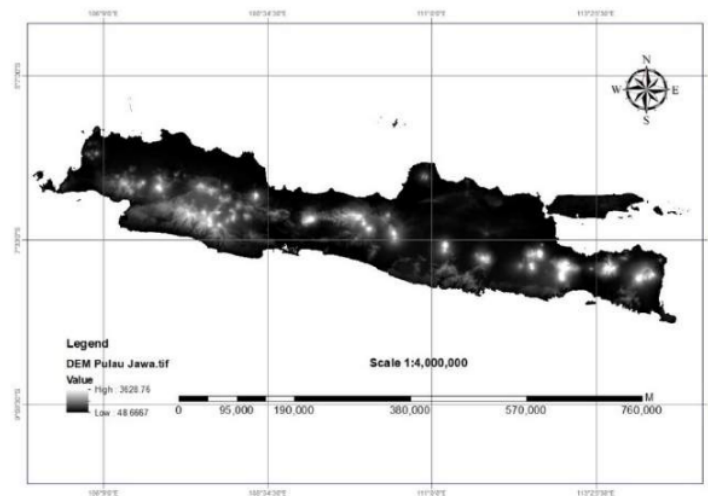
Figure 3. DEM Map of Java Island

2.2.2. Rainfall Data and Evaporation Data.
Rainfall data and evaporation data are obtained from Tropical Rainfall Measuring Mission (TRRM) data obtained using remote sensing technology ([7];[11]). In this study, the satellite data is processed using ArcGIS and Microsoft Excel to produce rainfall data and evaporation data on a daily scale in the Progo Watershed area so that it can be run on the SHETRAN Model. The following is TRMM map of Central Java Province and Yogyakarta Special Region can be seen in Figure 4.
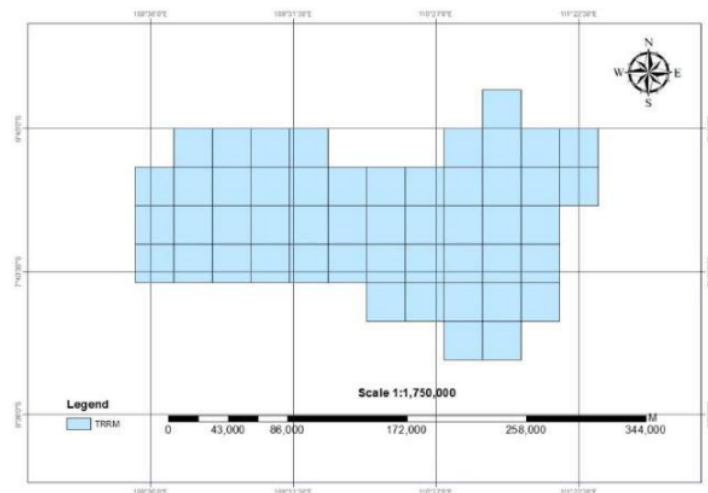

Figure 4. TRRM Map of Central Java Province and Special Region of Yogyakarta

2.2.3. Soil Type Data.

Soil type data is obtained from Hermonized World Soil Database (HWSD) data derived from satellite data ([6];[8];[14]). In this study, HWSD data was processed using ArcGIS and Microsoft Excel to determine raster data of soil types in the Progo Watershed area so that it can be run on the SHETRAN Model. The following is HWSD map of Java Island can be seen in Figure 5.
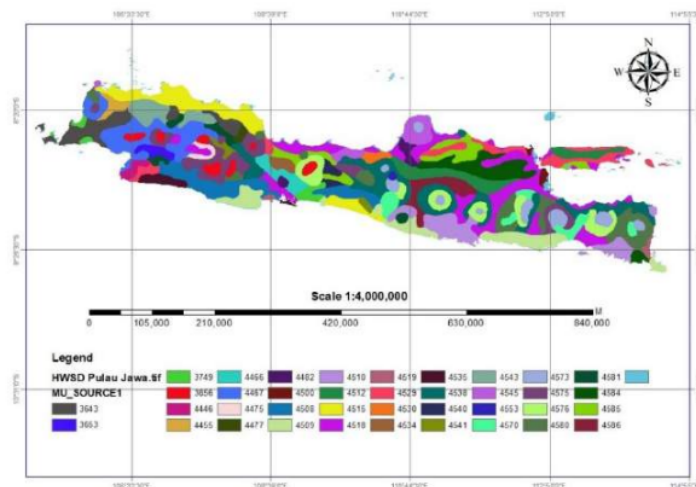

Figure 5. HWSD Map of Java Island

2.2.4. Land Use Data.

Land use data is obtained from TERRA MODIS satellite data in the form of Land Use Land Cover (LULC) data ([4];[5];[13]). In this study, the data used is LULC data on Java Island in the range of 2001 to 2017 that is processed using ArcGIS software to produce 7 classes of land use according to the SHETRAN Model requirements. The following is LULC Map of Java Island can be seen in Figure 6.
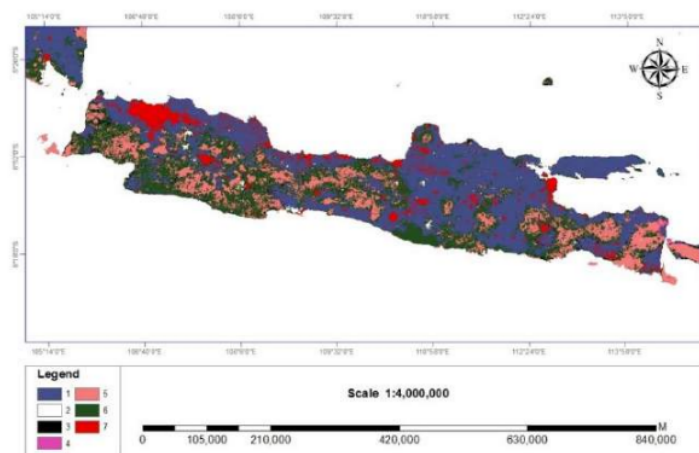

Figure 6. LULC Map of Java Island

2.2.5. Flood Event Data.
Flood event data is historical flood data that contains the time when a flood event occurred in an area at a certain time. Data on flood events was obtained from the National Disaster Management Agency (BNPB) and several well-known news portals such as Detik.com, Kompas.com, and others. In this study, the data used are data of flood events in the range of 2001 to 2017 in several cities/districts in the Progo Watershed area, which consists of data on flood events in Bantul Regency, Yogyakarta City, Kulon Progo Regency, Sleman Regency, Purworejo Regency, Boyolali Regency, Magelang Regency, Magelang City, Semarang Regency, Temanggung Regency, and Wonosobo Regency.

Method

As mentioned above, the purpose of this study is to detect flood inundation in the Progo Watershed using the SHETRAN Model. The method used is as follows:

3.1. Analysis of HWSD Data
HWSD data analysis was performed to determine the type of soil in the Progo Watershed area. Determination of soil type in this study uses the British Standards System. The stages of this analysis are HWSD data processed into raster data using ArcGIS software, then HWSD raster data is processed using Microsoft Excel to obtain the percentage of sand, clay, and silt used as a reference in using the soil texture triangle to determine soil types in the Progo Watershed.

3.2. Analysis of TRRM Data
TRRM data analysis was performed to determine rainfall and evaporation in the Progo Watershed. The stages of this analysis are that TRRM data is processed into raster data using ArcGIS software. Then the grid code from the TRRM raster data is used to determine daily rainfall and daily evaporation data located in the Progo Watershed area from 2001 to 2017 using Microsoft Excel.

3.3. Analysis of LULC Data
LULC data analysis was carried out to determine land use in the Progo Watershed. LULC data obtained from TERRA MODIS satellites are processed using ArcGIS software to obtain the type of land use according to the SHETRAN Model requirements.

3.4. Analysis of Flood Inundation
Flood inundation analysis is carried out to detect flood inundation in the Progo Watershed from 2001 to 2017. There are several steps that need to be done, the first stage is processing DEM, TRRM, HWSD, LULC data using ArcGIS software to produce output in ASCII format. The second stage is processing daily rainfall data and daily evaporation data of the Progo Watershed from 2001 to 2017 into output in CSV format. The third stage is creating an XML markup language, and the last stage is running the SHETRAN Model.

4. Results and Discussion

4.1. Analysis of HWSD Data
HWSD data that has been processed into soil raster data using ArcGIS software has a soil code (value) and output file in ASCII format. The Progo Watershed consists of nine soil codes that can be seen from the different colors on the soil raster map. Then, the Progo Watershed soil code is processed using Microsoft Excel to get the percentage of sand, clay, and silt in the top soil and sub soil parts used as a reference in using the soil texture triangle to determine the soil type in the Progo Watershed. The following is soil code map of the Progo Watershed can be seen in Figure 7.
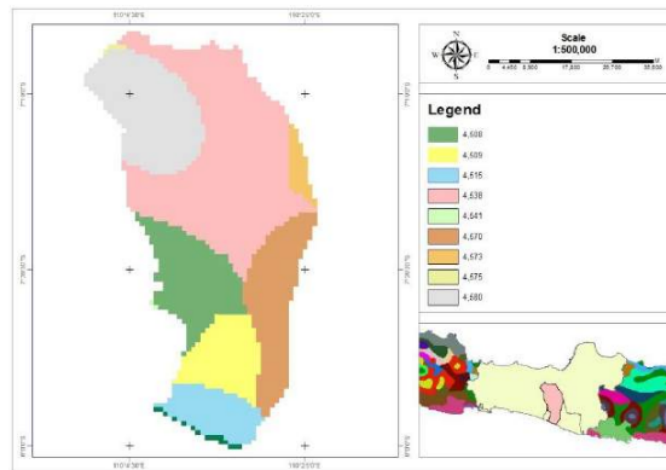
Figure 7. Soil Code Map of Progo Watershed

The Progo Watershed consists of 9 soil code which can be seen from the difference in color on the soil code map. The soil code is processed using Microsoft Excel so that it is known that the Progo Watershed consists of 5 types of soil, namely clay loam, clay, loamy sand, silt loam, and sandy clay loam.

4.2. Analysis of TRRM Data

TRRM data which is processed using ArcGIS software into rain raster data and evaporation raster data has grid code and output file in ASCII format. This grid code is used as a reference in determining daily rainfall and daily evaporation in the Progo Watershed using Microsoft Excel to be a file in CSV format. The following is map of TRRM grid code of the Progo Watershed can be seen in Figure 8.

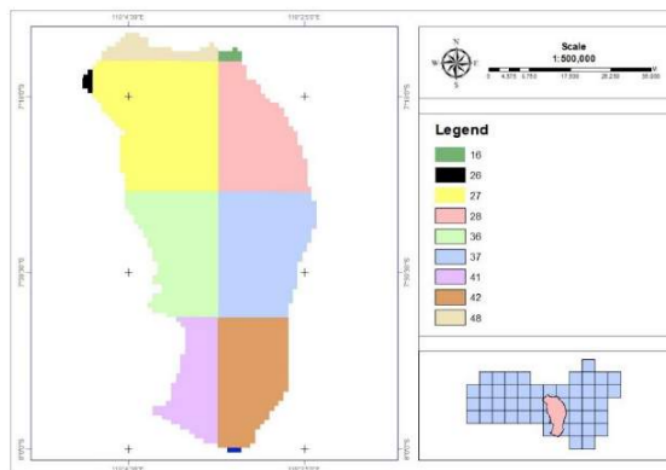**Figure 8.** TRRM Grid Code Map of Progo Watershed

4.3. Analysis of LULC Data

LULC data that is processed using ArcGIS software will obtain area of the Progo Watershed data, land use maps, and output files in ASCII format from 2001 to 2017. The following is land use map of the Progo watershed in 2017 can be seen in Figure 9.
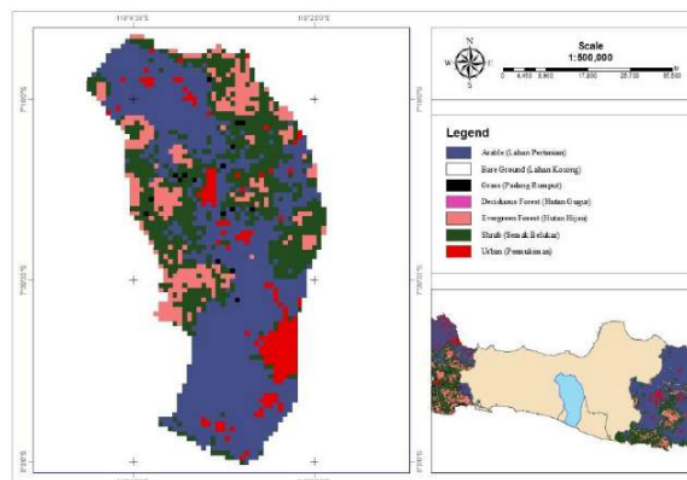

Figure 9. Progo Watershed Land Use Map in 2017

4.4. Analysis of Flood Inundation

Flood inundation in the Progo watershed is detected by the SHETRAN Model using a file in ASCII format containing hydroclimatological data (minimum DEM, average DEM, watershed map, soil, rainfall, evaporation, land use) and files in CSV format containing daily rainfall data and daily evaporation data to create files with the extension XML. Then, this XML file is run using the SHETRAN Model (SHETRAN Result Viewer 1.6.6) which can produce graphical outputs and phreatic depth grid maps so that it can be known the height of flood in a region. The height of flood inundation can be known at each point of the elements on the map displayed on the SHETRAN Model on a daily scale, so it is quite specific in detecting the height of flood inundation in an area.

To find out how accurate the SHETRAN Model is in detecting flood inundation, flood event data in the field is used as a reference in determining flood inundation using the SHETRAN Model. Flood event data taken is the flood event data for each region in the Progo Watershed in the range of 2001 to 2017, then adjusted to the element point above the map of an area in the SHETRAN Model. The following sample flood events with inundation heights above 0.1 m in the range from 2001 to 2017 have been correlated between flood event data in the field and the phreatic depth results from the SHETRAN Model can be seen in Table 4.

Table 1. Samples of Flood Event Data and Progo Watershed Inundation Height

No	Date	Village	Sub-district	Regency / City	Inundation Height (m)	Element
1	11/12/2005	Depok	Panjatan	Kulon Progo	0,105	578
2	11/12/2005	Tayuban	Panjatan	Kulon Progo	0.13	625
3	17/12/2005	Giri Peni	Wates	Kulon Progo	0.141	699
4	01/01/2011	Tirtonirmolo	Kasihan	Bantul	0.337	786

No	Date	Village	Sub-district	Regency / City	Inundation Height (m)	Element
5	25/02/2011	Panjatan	Panjatan	Kulon Progo	0.158	602
6	01/01/2012	Gadingsari	Sanden	Bantul	0.17	475
7	17/01/2013	Bumirejo	Lendah	Kulon Progo	0.141	606
8	17/01/2013	Banaran	Galur	Kulon Progo	0.314	468
9	17/01/2013	Wahyurejo	Lendah	Kulon Progo	0.589	533
10	17/01/2013	Panjatan	Panjatan	Kulon Progo	0.243	603
11	17/01/2013	Tirta Rahayu	Galur	Kulon Progo	0.606	507
12	20/01/2013	Bumirejo	Lendah	Kulon Progo	0.146	606
13	20/01/2013	Tirta Rahayu	Galur	Kulon Progo	0.32	468
14	20/01/2013	Ngentakrejo	Lendah	Kulon Progo	0.587	533
15	08/01/2014	Ngentakrejo	Lendah	Kulon Progo	0.237	533
16	25/04/2015	Banaran	Galur	Kulon Progo	0.341	452
17	25/04/2015	Panjatan	Panjatan	Kulon Progo	0.339	603
18	18/06/2016	Banaran	Galur	Kulon Progo	0.188	452
19	18/06/2016	Panjatan	Panjatan	Kulon Progo	0.157	603
20	02/12/2016	Wijirejo	Pandak	Bantul	0.143	616
21	28/11/2017	Bangunjiwo	Kasihan	Bantul	0.111	785
22	28/11/2017	Bumirejo	Lendah	Kulon Progo	0.208	606
23	28/11/2017	Banaran	Galur	Kulon Progo	0.331	452
24	28/11/2017	Panjatan	Panjatan	Kulon Progo	0.316	603
25	28/11/2017	Pendoworejo	Girimulyo	Kulon Progo	0.212	1108
26	28/11/2017	Wijirejo	Pandak	Bantul	0.119	616
27	09/12/2017	Bumirejo	Lendah	Kulon Progo	0.126	606

From 232 flood events in the Progo watershed recorded by online media, and after correlated with the SHETRAN Model it is known that 217 flood events in the field were detected there are inundation by the SHETRAN Model and the remaining 15 were not detected. The SHETRAN model detects flooding with phreatic depth. If the phreatic depth is positive (+), it means that the area does not have a flood, and the soil can still absorb water. Conversely, if the phreatic depth is negative (-) then there is a flood inundation.

In this study, a programming language was created and running using the RStudio program to determine the maximum height of flood inundation data in the Progo Watershed that occurred from 2001 to 2017. Data of the maximum height of flood inundation from the RStudio analysis results will be compared with the maximum height of flood inundation the result of correlation between flood event data in the field and the phreatic depth results from SHETRAN Model that can be seen in Table 4. To be able to do RStudio analysis, the map of Progo Watershed in ASCII format and files in H5 format are needed, which is one of the outputs of the standard version of the SHETRAN Model for the Rstudio programming language. After the programming language is created, then RStudio is running to produce an output file in CSV format that contains the maximum height of flood inundation of the Progo Watershed. The following graph shows the maximum flood inundation for Progo watershed 2001 - 2017 RStudio analysis results can be seen in Figure 10.
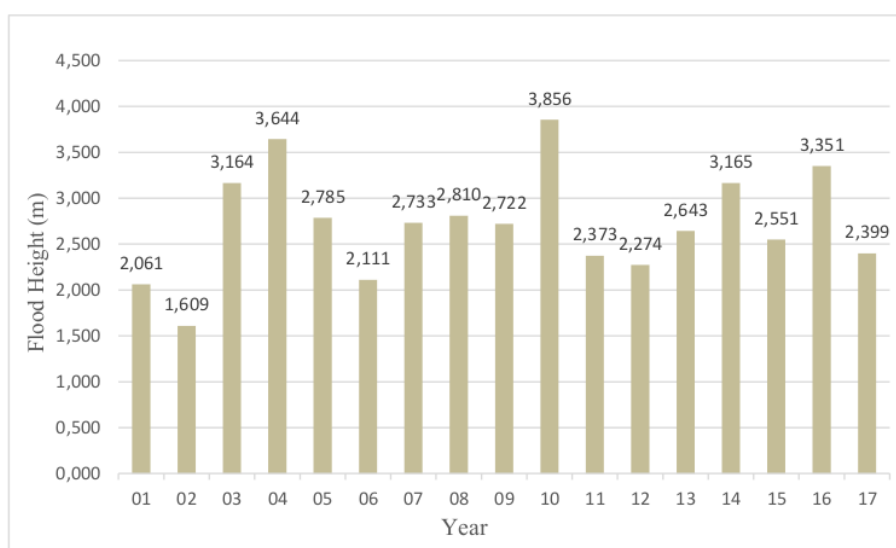
Figure 10. The Maximum Height of Flood Inundation in the Progo Watershed Chart for 2001 - 2017 Results of Rstudio Analysis

5. Conclusion

Based on the results of the research that has been done, it can be concluded that the results obtained are as follows:

- The maximum height of flood inundation results of the correlation between flood event data in the field with the phreatic depth results from the SHETRAN Model in the range from 2001 to 2017 is 0.606 m which occurred on January 17, 2013 in Tirta Rahayu Village, Sub-district Galur, Kulon Progo Regency.
- The maximum height of flood inundation for Progo Watershed in the range from 2001 to 2017 RStudio analysis results were 3.856 m which occurred in 2010.

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