Prediction of Streamflow at the Pemali catchment area using Shetran model

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Abstract. Central Java is one of the provinces in Indonesia which has the most flood events, with a total of 1330 flood events in the span of 1819 to 2020. One of the watersheds in Central Java is the Pemali Watershed, most of which are in Brebes Regency. According to the National Disaster Management Agency (BNPB), there were 57 floods in Brebes Regency in 1994 - 2019. Therefore, to predict the occurrence of a flood disaster, it is necessary to know how much changes in river flow rates in the Pemali watershed. The purpose of this study was to determine the flood discharge at the Pemali river. The streamflow used is the maximum daily streamflow in a year from 2001 to 2017. The method used is the SHETRAN hydrological model. The data used in the SHETRAN model are the data derived from satellite measurements, namely digital elevation model data, MODIS land use land cover, soil type from the Harmonization World Soil Database, rainfall from the Tropical Rainfall Measuring Missions, and evaporation data. The results of this study indicate that river flow rates can be predicted by modeling using SHETRAN.

1. Introduction

Flood is an occurrence of inundation in a flat area around a river due to the overflowing of river water that is unable to accommodate the river flow. Besides, flooding is an interaction between humans and nature and the natural system itself. Flood disaster is an aspect of the interaction between humans and nature that arises from a process in which humans try to take advantage of nature that is beneficial to humans themselves [5,8]. It could be the result of locally high rainfall and poor drainage [3]. Floods can also occur when the river water level rises above the river bank [2]. Raising river water levels can be caused by high water runoff from upstream and the influence of high tide at the river mouth. Furthermore, flooding occurs due to changes in land use, extreme rainfall values, and human behaviour. There are several losses due to flooding, including damage to public facilities, damage to housing, injuries, losses, and even death.

Flood disasters always occur every year in various regions in Indonesia. The flood severity varies depending on the magnitude of the flood hazards. Based on data from the National Disaster Management Agency (BNPB), floods are the most frequent occurrence of natural disasters, among other natural disasters in Indonesia. During the period 1918-2020, floods hit Indonesia as many as 9053 floods. In the first half-year of 2020, floods in Indonesia reached 441 incidents, and the Central Java is ranked first with more than 150 flood events this year.

The Pemali River Basin is one of the watersheds located in the north of the island of Java, and it is part of the Central Java Province. The upstream area is mountainous regions, and the downstream area is relatively flat. The administrative area covering the Pemali River Basin is Brebes Regency and parts of Tegal Regency, Central Java Province. The number of missing or dead victims was 13 people, and the number of affected victims was 20,457. Whereas in Tegal Regency, 40 flood events occurred annually from 2003 - 2019. The number of missing and dead victims was 10, and a total of 4,354 people had to be evacuated.

As an effort to prevent and warn of flood hazards, remote sensing derived datasets can be a facility. The remote sensing system uses satellites with an image as output. One method used in the use of remote sensing technology with the hydrological model is the SHETRAN method. SHETRAN comes from the SHE (Systeme Hydrologique European) developed by the collaboration of the Danish Hydraulic Institute, the British Institute of Hydrology and SOGREAH, France. SHETRAN itself comes from the SHE - Transport developed by the Water Resource Systems Research Laboratory at Newcastle University in the United Kingdom. SHETRAN is a physical-based spatial distribution model that simulates the primary soil phase process of the hydrological cycle and can be used to predict flood events by knowing changes in river flow rates.

This study aims to determine the streamflow of the Pemali river from 2001 to 2017. This study can be expected to help in reducing flood risks.

2. Data and Study Location

The Pemali Watershed is one of the watersheds located in Central Java. Most of the Pemali River Basin, covering the Brebes and Tegal Regencies, is bordered by Banyumas and Cilacap Regencies in the south, in the west with West Java, in the east by Tegal City. The Pemali has a downstream in the north to the Java Sea, and the upstream part is a Penjalin reservoir located in Winduaji village, Paguyangan District, Brebes Regency. The location of the Pemali watershed, when viewed from the Brebes Climatology station, is 109 ° 02' 58" E and 6 ° 52 '77 "S. The morphology of the Pemali watershed, in general, is a mountain for the upstream with irregular topography. The downstream area is relatively flat because most of it consists of rice fields, fields, and ponds [2]. The Pemali River Basin Map is shown in Figure1.

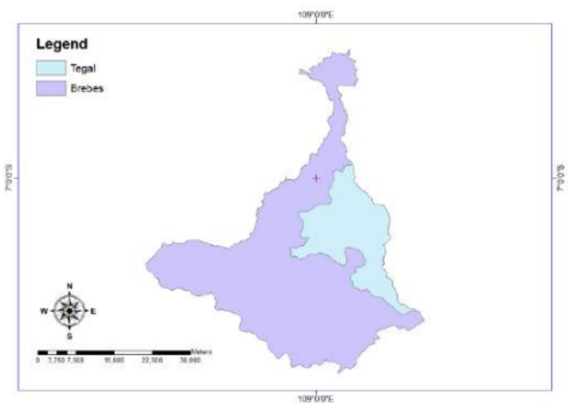

Figure 1. Pemali Watershed

Data used in this study are mostly obtained from satellite observations such as digital elevation model (DEM), land use land cover (LULC), and Tropical Rainfall Measuring Missions (TRRM).

2.1 Digital Elevation Model

Digital Elevation Models (DEMs) are collected from the Shuttle Radar Topography Mission (SRTM) that are belonging to the United States National Aeronautics and Space Administration (NASA) [8,11]. The digital elevation model is a computer graphics representation of the Earth's surface. It provides a basic data set from which topographic parameters can be generated digitally [12]. DEM is also often used for a variety of applications, including hydrology, water resources, geology, geomorphology, civil engineering projects, vegetation surveys, glaciology, volcanology, and modeling of natural hazards such as floods, landslides, as well as coastal inundation [10]. Figure 2 presents digital elevation model for the Pemali watershed.

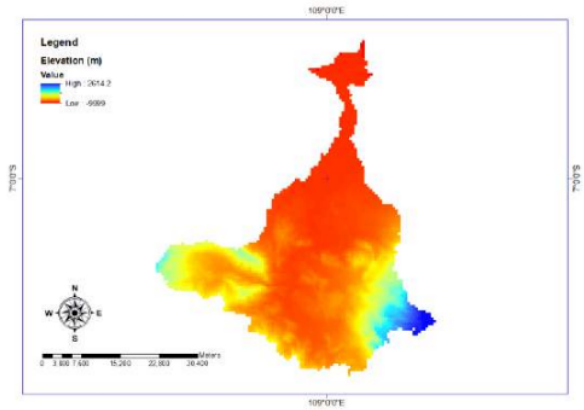

Figure 2. Digital elevation model in Pemali Watershed

2.2 Land Uses and Land Covers (LULC)

EOS (Earth Observing System) is the centrepiece of NASA's Earth Science mission. The EOS AM-1 satellite, later named TERRA, is the flagship of the first and was launched in December 1999[4,6]. It carries five remote sensing instruments, including a Moderate Resolution Imaging Spectroradiometer (MODIS) [13]. LULC is land use data derived from MODIS. The MODIS usage class is then grouped based on the SHETRAN class, which consists of arable, bare ground, grass, deciduous forest, evergreen forest, shrub, and urban. Investigations of changes in land use and land cover in this study utilize the MODIS data observed from 2001 - 2017. As shown in Figure 3, an example of LULC spatial data sets during the year of 2017 at the Pemali watershed is presented.

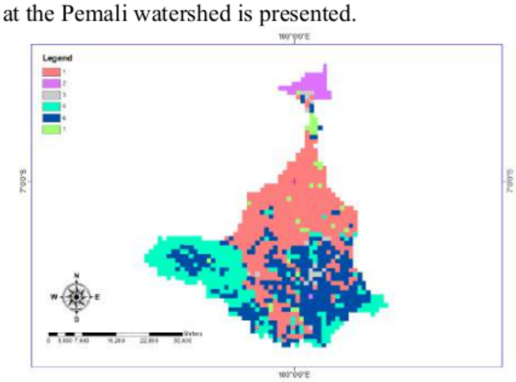

Figure 3. Land uses and land covers in 2017 over Pemali Watershed

2.3 Harmonization World Soil Database

Harmonization World Soil Database (HWSD) is a map of the distribution of soil types in the world created by the Food and Agriculture Organization (FAO) and the International Institute for Applied Systems Analysis (IIASA) by combining regional and national land maps. More than 16.000 different maps of soil types are recognized in HSWD [1,7]. Spatial data used in GIS includes ESDB (European Soil Database), Land Map of China, SOTWIS (various regional data SOTER or The Soil Map of the

World and the Soil and Terrain) and DSMW (Digital Soil Map of the World). Soil map of the Pemali watershed is given in figure 4.

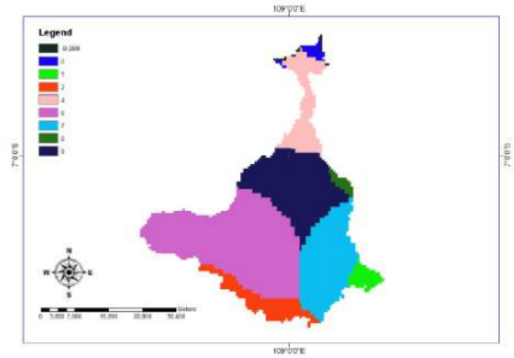

Figure 4. Soil map over Pemali watershed based on HWSD

2.4 Tropical Rainfall Measuring Missions (TRRM)

TRMM satellites are satellites developed to measure rainfall in the area tropical, for example, Indonesia. Initially, TRMM satellites were the result of collaboration from the US National Aeronautics and Space Administration with Japan's National Space Development of Japan NASDA, which is currently changing its name to JAXA (Japan Aerospace Exploration Agency) [8,11]. TRMM has three sensors, namely PR (Precipitation Radar), TMI (TRMM Microwave Imager), and VIRS (Visible and Infrared Scanner). The TRMM precipitation radar (PR) is the first spaceborne rain radar and the only instrument on TRMM that can directly observe vertical distributions of rain [9]. TRRM is applied in the form of a grid measuring 0.25º x 0.25º (27.75 km x 27.75 km) and is a rain map used to process rainfall data [12]. The spatial rainfall distribution derived from TRRM in the Pemali watershed is presented in Figure 5.

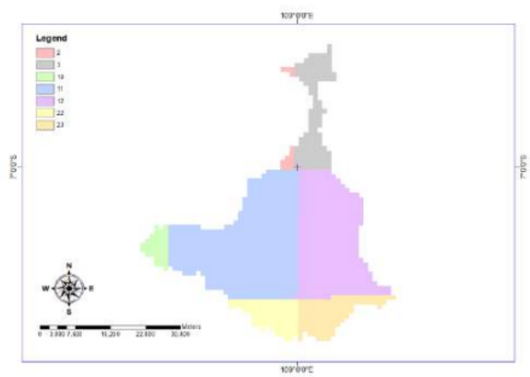

Figure 5. TRMM rainfall spatial map over Pemali watershed

2.5 Evaporation

Evaporation is the vaporization of water, both water on land and water in the ocean. Evaporation occurs because of the latent heat that is the heat needed by a substance to change shape even though the temperature is below the boiling point of water. The evaporation data in this study came from The Global Land Evaporation Amsterdam Model (GLEAM). GLEAM is a set of algorithms dedicated to the

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estimation of terrestrial evaporation and root-zone soil moisture from satellite data. In this study, evaporation data sets measured from 2001 – 2017 are used.

3. Method

The method used in this study is the SHETRAN hydrological model where the inputs are collected from satellite measurements. The remote sensed data sets include digital elevation model data, MODIS Land Use Land Cover, Harmonization World Soil Database soil data, Tropical Rainfall Measuring Missions data, and evaporation data. Research stages are described as follows:

a) SHETRAN input data is satellite data, first processed using Arcgis to produce ASCII data.
b) The ASCII data is then written to the XML file and then running the data using SHETRAN easy setup and the standard version.
c) After running the data, we will get the output from SHETRAN. The SHETRAN output contains output data in the form of land flow, groundwater level, surface depth, phreatic depth, and daily outlet discharge.

4. Results and Discussion

The daily discharge simulation of the SHETRAN model shows that at the beginning and end of the year, in general, there is an increase in river flow, especially from 2010 to 2012. Thus, it proves that the SHETRAN model is generally able to capture the flow characteristics of seasonal river flows. In the SHETRAN model, the results show that the beginning and end of the year are the rainy seasons. Meanwhile, in the middle of the year is the dry season, which is marked by low rainfall. Figure 6,7, and 8 are shown the output of SHETRAN in the form of monthly debit data for 2001, 2005, and 2007.

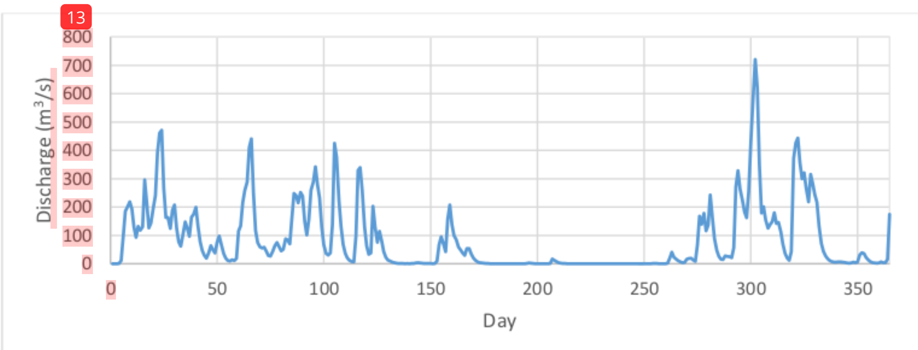

Figure 6. Simulated daily discharge at Outlet of Pemali watershed in 2001

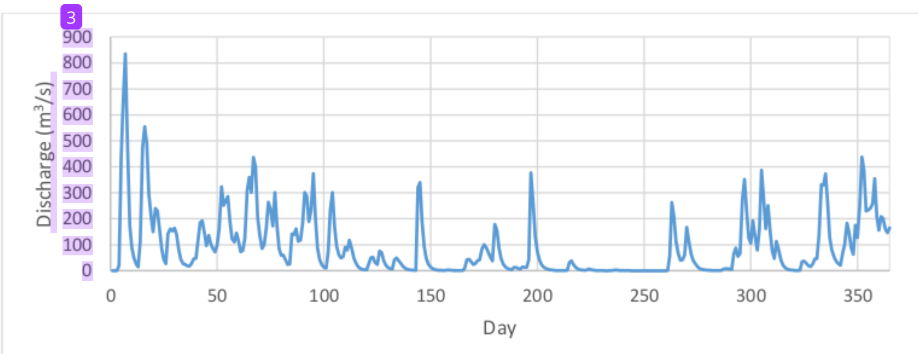

Figure 7. Simulated daily discharge at Outlet of Pemali watershed in 2005

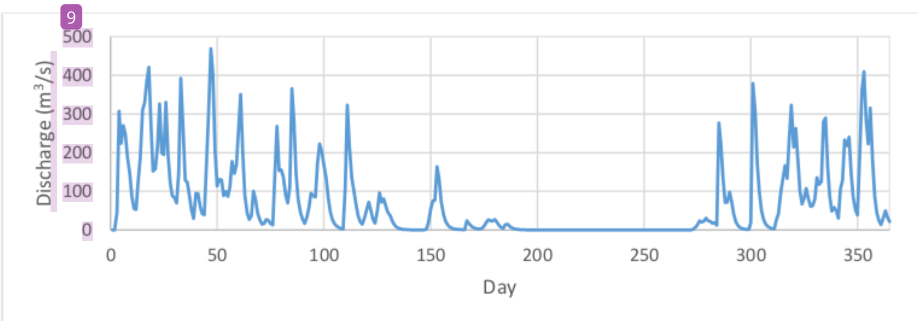

Figure 8. Simulated daily discharge at Outlet of Pemali watershed in 2017

For the maximum daily discharge pattern in a year (flood discharge), the results of the SHETRAN work have a stable but fluctuating trend as shown in Figure. Meanwhile, the maximum debit at outlets generally occurs in wet months, such as January and December as presented in Table 1. The maximum daily discharge recorded by SHETRAN occurred in 2005, amounting to 835,187 m^3 / second.

Table 1. Maximum Simulated daily discharge at Outlet of Pemali watershed (2001-2017)

Year	Maximum Daily Discharge Outlet (m^3/second)	Month	Year	Maximum Daily Discharge Outlet (m^3/second)	Month
2001	720,80	October	**2010**	621,05	April
2002	601,98	January	**2011**	422,41	March
2003	775,04	January	**2012**	481,93	March
2004	595,37	December	**2013**	571,76	January
2005	835,17	January	**2014**	705,21	February
2006	508,57	December	**2015**	498,77	April
2007	499,01	March	**2016**	603,19	September
2008	762,69	January	**2017**	469,40	February
2009	572,99	February			

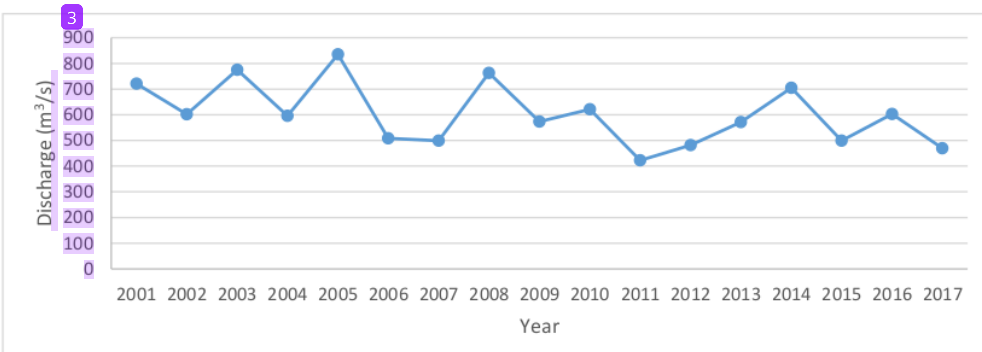

Figure 9. Simulated daily discharge at Outlet of Pemali watershed (2001-2017)

To find out whether SHETRAN is good enough to be used to predict river flow is to compare the calculation results with discharge measurements in the field. Based on data from www.pusdataru.jatengprov.go.id, there are three river flow stations, namely Brebes, Bantarkawung, and Notog stations. Figure 10 is the location of the stations in the Pemali watershed.

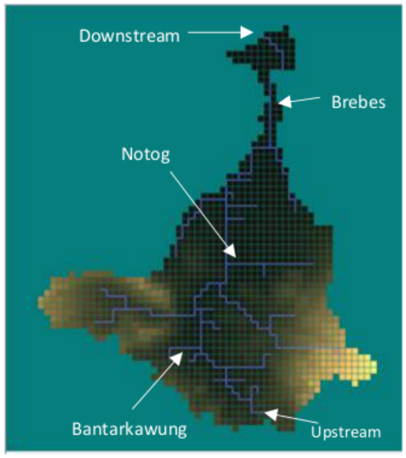

Figure 10. Locations of river flow gauge Stations.

Seeing from the location, Brebes Station is the closest station to the downstream area. From the available data, we use 2010, 2011, and 2012 data (See figures 11, 12, and 13). We compare the average monthly discharge data from the SHETRAN output results in the downstream area and the field data based on the Brebes station measurements. As seen in Figures 11, 12, and 13, the results from the SHETRAN output tend to be similar to the field data. In 2010, the measurement of monthly discharge was fluctuating and tended to be stable. Likewise, the results of SHETRAN output in 2010 also tended to be fluctuating and stable. For 2011 and 2012, the recorded measured discharge has a small value in the dry month. Meanwhile, for 2011 and 2012, the measured discharge has a small value in the dry month. With this ease of predicting flow rates, SHETRAN has the potential to be used as an effort to mitigate flood disasters.

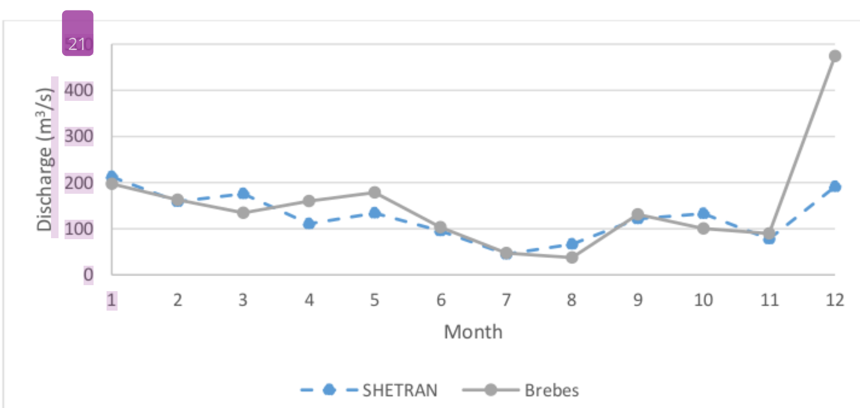

Figure 11. Average simulated monthly river flow in 2010

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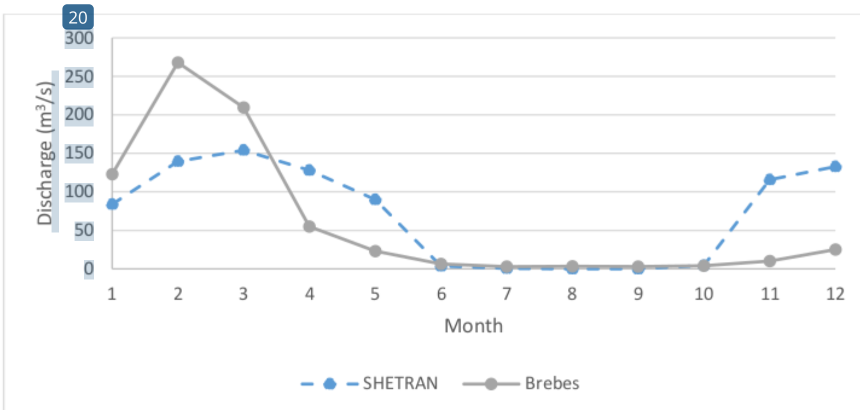

Figure 12. Average simulated monthly river flow in 2011

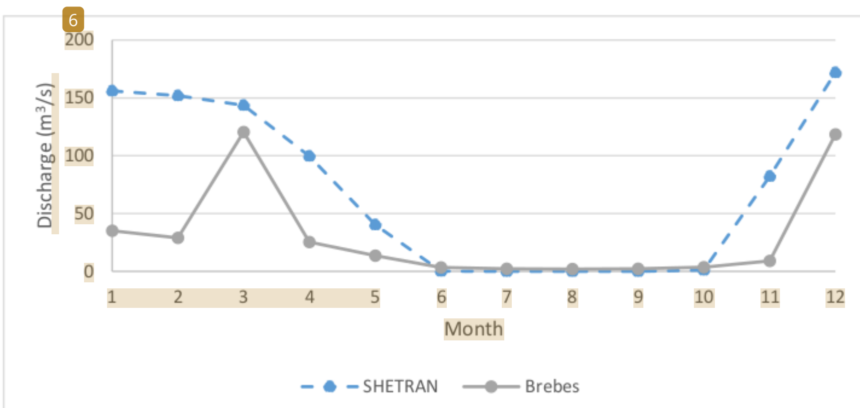

Figure 13. Average simulated monthly river flow in 2012

5. Conclusion

The conclusions of this study are:

a) The daily discharge from SHETRAN modeling is generally able to mimic the characteristics of seasonal rainfall (rainy season and dry season)
b) The maximum daily discharge that has the potential for flood disasters mostly occurs in the wet months (October-April), which usually appears as well
c) The monthly mean discharge from the SHETRAN simulation results is similar to the measurement results
d) There is a potential use of the SHETRAN model for flood disaster mitigation

6. References

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