Suroso_2021_Estimating of soil moisture using shetran

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Estimating of soil moisture using shetran model at Cisanggarung catchment area

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Abstract. Soil moisture is one of the essential controls for the hydro-climatology processes. Soil moisture value can be used as an indicator of soil fertility so that it has a vital role in increasing agricultural and plantation production. Understanding the soil moisture variability on a spatial-temporal scale is very interesting in many practical applications such as drought prediction and agricultural modelling. The purpose of this study was to estimate the soil moisture value which distributed in space and time in the Cisanggarung River Basin with the spatial resolution of 500 m × 500 m and daily temporal resolution. The Shetran physical-based hydrological model was applied by utilizing hydro-climatological data derived from the remote sensing measurements from 2001 to 2017. The Shetran model input data consisted of the digital elevation model, land use land cover, TRMM rainfall data, evaporation data, and soil properties data. The results of this study indicate that Shetran hydrological model is reliable to estimate soil moisture in a watershed. This soil moisture values are then validated with the historical data of drought disaster.

1. Introduction

Soil moisture is the amount of water stored among the pores of the soil which is very dynamic, as it is affected by evaporation through the soil level and percolation [1]. Soil moisture is also an important variable of the climate system [2]. Furthermore, soil moisture variations are closely related to predictions of surface temperatures, droughts, and flood variations [3]. Soil moisture levels also affect various aspects, such as environmental, health, economic, and food aspects.

Information about soil moisture is very important in the agricultural sector because extreme soil moisture can adversely affect the agricultural sector [4]. Agricultural and irrigation management, especially in dry areas, is highly dependent on the dynamic character of soil moisture because it can affect production, plant health status and play a major role in structuring natural ecosystems and biodiversity. For the government, soil moisture has a very important role, including knowing information on the potential for surface runoff, flood control, water resource management, and water quality. For the government, soil moisture has a very important role, including knowing information on the potential for surface runoff, flood control, water resource management, and water quality [5].

Soil moisture is also one of the main indicators of drought [6]. Soil moisture is closely related to drought and is often used as a monitoring tool for drought disasters [7]. The National Disaster

Management Agency (BNPB) recorded 103 drought cases in the Cisanggarung watershed from 2001 to 2017, as shown in Figure 1.
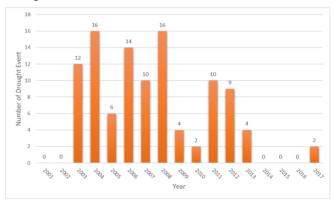

Figure 1. The number of drought cases in Cisanggarung watershed

Soil moisture data can be obtained in the traditional way, namely by measuring the moisture content in the soil, but this method is laborious and expensive [8]. Soil moisture data that is spatially accurate and sustainable in an area is often difficult to obtain, so focused research is needed to obtain soil moisture data through remote sensing technology by utilizing satellite data through the Shetran program. Shetran is a distributed and physical-based model capable of calculating spatial heterogeneity or variability from hydro-climatological data (rain, evaporation), land use land cover (LULC), soil type, topography and can simulate all soil phases of the hydrological cycle including moisture [9]. The purpose of this study was to predict soil moisture in Cisanggarung watershed by utilizing satellite-based technology through a remote sensing system as input for the Shetran model to determine soil moisture modeling in 2001 to 2017. This soil moisture prediction can be an input for the Shetran model to overcome difficulties in obtaining soil moisture data in an area.

2. Study location and data

2.1 Study location

The research site was in Cisanggarung watershed which located in West Java and Central Java Province. In West Java, Cisanggarung watershed is the territory of Cirebon, Kuningan and Majalengka while in Central Java Province belongs to Brebes and Cilacap. The upper area of Cisanggarung Watershed is in Kuningan Regency (Figure 2.) In addition, Cisanggarung watershed has an area of 863 km^2 with the length of the main river 62.50 km.
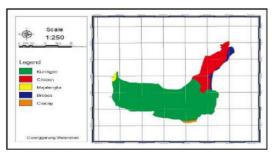

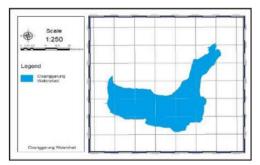**Figure 2**. Map of Cisanggarung Watershed

According to the Meteorology, Climatology and Geophysics Agency, the Cisanggarung watershed is in a drought-prone area, so it is not surprising that the problem that is often experienced by residents around the Cisanggarung watershed is the difficulty of getting water for household needs.

2.2 Data

The data used is secondary data obtained from government and non-governmental agencies in charge of spatial and hydrological data recording. The data collection method in this study is a quantitative method with analysis. The following data are inputted into the Shetran:

2.2.1 Cisanggarung watershed map. The main input data is a map of the Cisanggarung watershed as a limitation in this study. The map used is a basic map with a shapefile (.shp) format which will be processed using ArcGIS as the boundary of the area to be reviewed (Figure 3.)

2.2.2 Digital elevation model (DEM). The Digital Elevation Model (DEM) was used to calculate the hydro-geomorphological variables required by a distributed hydrological model [10]. The DEM data was obtained from the Shuttle Radar Topography Mission (SRTM) data of United States National Aviation and Space Administration (NASA) [11]. The DEM data used in this study is STRM data in Java with a resolution of 30 × 30 meters to describe the topography in the Cisanggarung watershed as shown in Figure 4.

Figure 3. Cisanggarung Watershed

Figure 4. Digital Elevation Model in Cisanggarung watershed

2.2.3 Daily rainfall data. The rainfall data of Cisanggarung watershed was obtained from TRMM satellite measurements from 2001 to 2017. In this study, TRMM data was used in the form of a grid measuring 0.25^0 x 0.25^0 or 27.75 km x 27.75 km. In Cisanggarung watershed there are 6 rain codes as as shown in Figure 5.
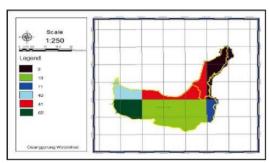
Figure 5. Map TRMM Cisanggarung watershed

2.2.4 Daily evaporation data. Daily evaporation rate data are obtained from the Global Land Evaporation Amsterdam Model (GLEAM). The (GLEAM) is a series of algorithms dedicated to estimating terrestrial evaporation and soil moisture "root zone" from satellite data [12]. GLEAM is one model that uses remote sensing data and a simple conceptual modeling framework to estimate terrestrial evaporation on a global scale [13]. Daily evaporation data from 2001 to 2017 were applied in the form of a grid measuring 0.250 x 0.250 or 27.75 km x 27.75 km.

2.2.5 Land use land cover. Land use land cover (LULC) can influence regional climates by changing surface roughness, soil moisture, and heat flux partitioning so that LULC information can provide an understanding of land atmosphere interactions [14]. Land use land cover (LULC) is information from various satellites at various spatial, spectral, temporal and radiometric resolutions obtained from MODIS satellites. The Moderate Resolution Imaging Spectrometer or MODIS is a key instrument of the Terra and Aqua satellites [15]. This study uses land cover land use data from 2001 to 2017 with a resolution of 500 mx 500 m and classifies 17 land cover types from the MODIS MCD12Q1 data into 7 classification categories for the Shetran program. The seven categories are consisted of fertile, bare soil, grass, deciduous forest, evergreen forest, shrubland, and urban areas (Figure 6)

2.2.6 Land data. The Land Database or Harmonized World Soil Database (HWSD) uses a raster format to present the spatial extent of the soil mapping units [16]. HSWD data was used with a data resolution of 500 m x 500 m and tested with the British pyramid system to find out the soil type from a point through its content percentage. In the Cisanggarung watershed there are eight land codes (Figure 7).
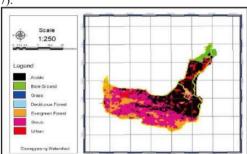

Figure 6. Map of land use land cover in Cisanggarung watershed
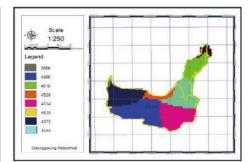
Figure 7. Map of Harmonized World Soil Database in Cisanggarung watershed

2.2.7 Drought event data. Based on the drought disasters recorded by the National Disaster Management Agency, there were 103 cases during 2001 to 2017 (Table 1).

Table 1. Number of drought cases in district/city study site

District	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17
Brebes	0	0	0	2	3	3	2	1	3	2	1	0	0	0	0	0	0
Cilacap	0	0	4	2	0	3	1	4	0	0	2	3	1	0	0	0	2
Majalengka	0	0	2	2	1	3	1	4	0	0	1	3	0	0	0	0	0
Cirebon	0	0	5	4	0	2	2	3	1	0	3	3	2	0	0	0	0
Kuningan	0	0	1	6	2	3	4	4	0	0	3	0	1	0	0	0	0

Source: National Disaster Management Agency, 2020

3. Method
To achieve the purpose of research, namely to know the estimated soil moisture in an area, several stages of data processing are required.

3.1 Data processing using ArcGIS

Data processing using ArcGIS is a spatial input data processing with output in the form of a data grid that will be read by Shetran. Output data generated in ArcGIS is a file with ASCII format. The ASCII format file contains the processing numbers of each data used, and will form coordinates in the form of dots assembled to form rows and columns as the basis for creating a map on Shetran. The data used in hydro-climatological data such as Land use land cover data from 2001 to 2017 were obtained from MODIS, soil data from the Harmonized World Soil Database (HWSD), topographical data in the form of a Digital Elevation Model (DEM) obtained from SRTM, as well as rain data and evaporation were obtained from TRMM and GLEAM. All data are inputted into ArcGIS worksheet, and grid cutting is done according to the location of the study (Cisanggarung Watershed). Furthermore, data processing is carried out in such way as to generate files in ASCII format.

3.2 CSV data processing

Data processed in excel obtained from the TRMM satellite, namely rain data and evaporation data. The TRMM data rows are rain records and evaporation data set at intervals, either per 3 hours, 6 hours, 12 hours, or 24 hours. Meanwhile, the TRMM data column is the code from the existing grid. Of the many existing codes, only taken according to the grid that enters the reviewed watershed, for the Cisanggarung watershed there are seven rain and evaporation data codes.

3.3 XML data processing

If the ASCII and CSV data have been processed, the next step is to create XML to run the Shetran program. The file contains data related to Shetran modeling, including the types of vegetation present in Shetran, river modeling arrangements, groundwater advances, and discharge simulations. When running the Shetran program, all files used as insert data in ASCII, CSV and XML form must be used as one folder without other files. At this stage, soil type analysis is also carried out by referring to the British Standard System. Soil types were obtained from HSWD data which has been processed into ASCII files by ArcGIS. The code in the ASCII file was then adjusted according to the British Standard System and the results of soil type grouping were entered into an XML file to run Shetran's easy setup program.

3.4 Processing using shetran

Figure 8. Example of modeling results from the Shetran

In this drought study, the Shetran Easy Setup version was used. Running the Shetran Easy Setup program version requires a special folder containing the required ASCII, CSV, XML files. Then the next step is to run the Shetran Easy Setup program version 2001 to 2017. After successfully running

to Shetran Easy Setup version, the next step is to open the Shetran result viewer to find out the results of soil moisture modeling in the Cisanggarung watershed, then the results of the Shetran are extracted using the R programming language through the R Studio. The result of soil moisture modeling using the Shetran program is presented in Figure 8.

4. Result and discussion

4.1 Soil moisture analysis

Soil moisture is one of the outputs of an integrated surface and subsurface modeling system based on physical, distributed, deterministic methods through the Shetran program. In this study, the results of soil moisture modeling from 2001 to 2017. The minimum soil moisture data in the Cisanggarung watershed can be seen in Table 2.

Table 2. Value of soil moisture minimum in Cisanggarung Watershed

Year	Soil Moisture Minimum	Months	Year	Soil Moisture Minimum	Months
2001	0.271	September	2010	0.393	July
2002	0.245	October	2011	0.259	October
2003	0.252	September	2012	0.246	October
2004	0.253	October	2013	0.268	October
2005	0.307	October	2014	0.265	October
2006	0.244	November	2015	0.239	October
2007	0.262	September	2016	0.324	August
2008	0.253	September	2017	0.276	September
2009	0.261	October			

The minimum soil moisture value detected by Shetran modeling occurs in drought-prone months. This proves that Shetran modeling can be used as one of the alternatives in obtaining a predicted soil moisture value of a region.

4.2 Validation of result

After analyzing soil moisture using the Shetran model, the results of the soil moisture value where be compared with drought events in an area in the Cisanggarung watershed. The comparison of Shetran's results with the cases of drought is shown in Table 3.

Based on the validation of several sample areas and years, it is known that when an area experiences drought at one time, the soil moisture value in terms of the Shetran model also shows a smaller number than when a drought did not occur. In validating of this study, sampling was carried out in Kuningan and Cirebon districts because these two areas are the largest areas in Cisanggarung river basin, which are expected to represent the entire river basin. It is evident that in an area experiencing drought the value of soil moisture is relatively lower than when it is not experiencing drought.

Table 3. Validation of Shetran results with disaster events

Location	Months	Soil Moisture Value	Recorded Disasters	Months	Soil Moisture Value	Recorded Disasters
Kuningan	01/2007	0.49	no drought	01/2011	0.49	no drought
	02/2007	0.49	no drought	02/2011	0.49	no drought
	03/2007	0.49	no drought	03/2011	0.49	no drought
	04/2007	0.49	no drought	04/2011	0.49	no drought
	05/2007	0.49	no drought	05/2011	0.439	no drought
	06/2007	0.422	no drought	06/2011	0.401	no drought
	07/2007	0.37	drought	07/2011	0.384	drought
	08/2007	0.342	drought	08/2011	0.349	drought
	09/2007	0.324	drought	09/2011	0.33	drought
	10/2007	0.303	drought	10/2011	0.453	no drought
	11/2007	0.46	no drought	11/2011	0.49	no drought
	12/2007	0.49	no drought	12/2011	0.49	no drought
Cirebon	01/2008	0.49	no drought	01/2012	0.463	no drought
	02/2008	0.49	no drought	02/2012	0.49	no drought
	03/2008	0.475	no drought	03/2012	0.489	no drought
	04/2008	0.459	no drought	04/2012	0.426	no drought
	05/2008	0.434	no drought	05/2012	0.442	no drought
	06/2008	0.4	no drought	06/2012	0.407	no drought
	07/2008	0.365	drought	07/2012	0.373	drought
	08/2008	0.358	drought	08/2012	0.353	drought
	09/2008	0.34	drought	09/2012	0.337	drought
	10/2008	0.46	no drought	10/2012	0.427	no drought
	11/2008	0.476	no drought	11/2012	0.464	no drought
	12/2008	0.49	no drought	12/2012	0.49	no drought

5. Conclusion

Based on the results obtained in this study, it can be concluded that:

a. Shetran's modeling results can be used as an alternative to address the difficulty of obtaining information on soil moisture in a region.

b. Shetran modeling can detect catastrophic drought events by showing a lower soil moisture output value than when drought does not occur.

c. The lowest soil moisture value in Cisanggarung watershed during 2001 to 2017 was 0.239 which occurred in October 2015.

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