Suroso_2021_Groundwater depth prediction using Shetran

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Groundwater depth prediction using Shetran model in Citarum River basin

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Abstract. Drought is a natural disaster that lasts a long time and has an impact on various things that can seriously affect human life, economy, agricultural production, and also ecological environment. In Indonesia, floods and droughts become annual disasters that often occur and are difficult to avoid, even in big cities. Drought cannot be considered a trivial problem because its impact is very detrimental to every aspect of life. Drought can be seen from several indicators. The depth of groundwater can be an indicator of drought. The purpose of this study was to predict the depth of groundwater in the Citarum River Basin. This study uses a spatially distributed Shetran model. The Shetran model was developed by the School of Civil Engineering and Geosciences at Newcastle upon Tyne University. The hydro-climatological data from satellite measurements during 2001 to 2017 were used in Shetran model. Input data in this study consisted of digital elevation models, TRMM rainfall data, evaporation data, soil properties, and land-use change land cover change data. The results showed that within 17 years the land use types in the Citarum watershed had undergone significant changes. This land use change affects the depth of groundwater in the Citarum watershed.

1. Introduction

Water is a basic requirement of every living thing on earth. Humans desperately need water not only for household needs but also for production, such as agriculture and industry. Groundwater is the main water source that is easily accessible and utilized for human needs [1]. This is because groundwater has relatively better quality than surface water which is prone to pollution and is often seasonal [2]. Groundwater is also available in large quantities, has good stability, and is not easily contaminated by pollutants [2]. Therefore, humans are very dependent on the availability of groundwater, particularly in areas with dry and semi-arid conditions. In addition, the availability of groundwater is essential for the management of water resources for flood disaster control and early detection of drought disasters.

Along with industrial development and increasing population, the need for clean water is also increasing every year [3]. It is estimated that 15% of Indonesia's clean water needs come from groundwater. Even in some areas, the dependence on groundwater availability as a source of clean water needs reaches 70%. For example, in West Java, particularly Bandung City and Bandung Regency, many industrial companies use groundwater as their main water source for production needs [3].

Excessive use of groundwater can cause a decrease in quantity and/or quality of groundwater [4]. Seawater intrusion in areas close to the coast can also occur if groundwater use is not controlled [3]. Sea water enters the aquifer so that the quality of groundwater decreases and can no longer be used. In addition, uncontrolled use of groundwater also causes an extraordinary land subsidence [3]. Bandung is an area with a severe land subsidence rate. From 2000 to 2011 it can be seen that several locations in Bandung experienced land subsidence, with an average rate of around −8 cm/year and increasing around −23 cm/year in certain locations [5]. GPS results detect a significant decline in areas of the textile industry, where groundwater use is very large [5].

Under these conditions, it is necessary to predict groundwater depth to avoid excessive groundwater exploration. However, until now groundwater depth information is very difficult to find because the measurement process is quite complicated. So far, groundwater measurements have only been carried out in a conventional way, namely by monitoring through community wells or using pump wells. In fact, measuring groundwater in this way can be time consuming and expensive.

The purpose of this study was to predict the depth of groundwater as an alternative measurement using conventional wells in the Citarum watershed area. Modeling was carried out from 2001 to 2017. This modeling is expected to be a new method in predicting groundwater depth fluctuations effectively and accurately.

2. Study location and data

2.1 Study location

The research was conducted in the Citarum River Basin, West Java Province. The Citarum watershed is the largest functional watershed in West Java with an area of 11,3[illegible].34 km^2 and a length of 269 km (Figura 1). The Citarum watershed covers 12 administrative areas, namely: Bandung Regency, West Bandung, Bekasi, Cianjur, Bogor, Indramayu, Karawang, Purwakarta, Subang, Sumedang, Bandung City, and Cimahi City.

The Citarum watershed is also the main water supplier for 3 large reservoirs in West Java, namely Jatiluhur, Cirata, and Saguling Reservoir. This reservoir is used as the main supplier of hydroelectric power, which is not only used in Java but also in Madura. Citarum is also the main water source for 30,000 Ha of agricultural land in West Java.

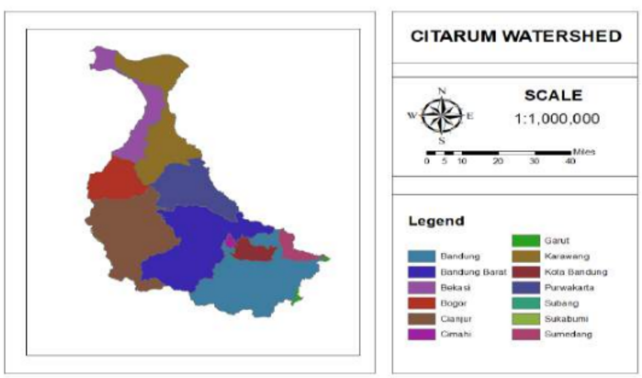

Figure 1. Citarum Watershed

2.2 Data

This study used secondary data from government and non-government agencies in charge of recording spatial and hydrological data. The data inputted for Shetran modeling are:

2.2.1 Digital elevation model (DEM). Digital elevation model (DEM) is data that shows the geometry of the earth's surface and its part which is a collection of points sampled from the surface [6]. DEM data are widely used for various mapping purposes including hydrology and water resources, geology and geomorphology, and modeling of natural disasters [7]. The DEM data is obtained from the Shuttle Radar Topography Mission (SRTM) data belonging to the United States National Aeronautics and Space Administration (NASA). The SRTM satellite was first launched in February 2000 [8]. The data resolution used is a resolution of 30×30 meters and 90×90 meters with data usage from 2001 to 2017.

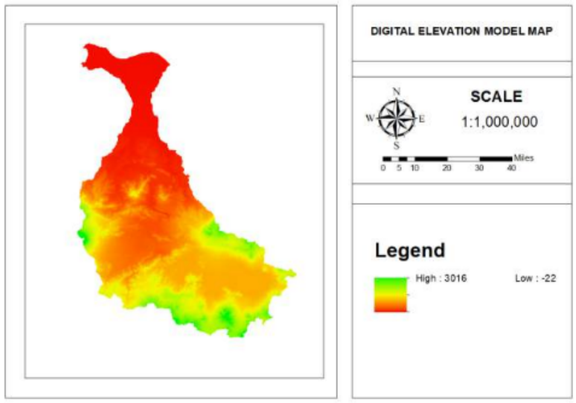

Figure 2. Digital Elevation Model in Citarum watershed

2.2.2 Daily rainfall data. Daily rainfall data is obtained from Tropical Rainfall Measuring Mission (TRMM) satellite data from 2001 to 2017. The TRMM satellite records and predicts global rainfall based on various meteorological satellites. The TRMM satellite is a collaboration between the United States Aeronautics and Space Agency (NASA) and the Japan Aerospace Exploration Agency (JAXA) [9]. There are several types of rainfall measurements carried out by the TRMM satellite, namely 3B40, 3B41, and 3B42 [9]. The data used in this study is the TRMM product type 3B42 V7 which records daily rainfall data (every 24 hours) with a spatial resolution of 0.25°×0.25°.

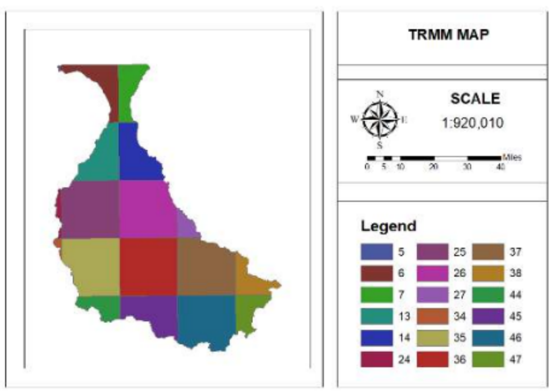

Figure 3. Map TRMM Citarum watershed

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2.2.3 Daily evaporation data. The evaporation data used for this study were obtained from the evaporation measurement station belonging to the Meteorology, Climatology, and Geophysics Agency (BMKG) and also from the Global Land Evaporation Amsterdam Model (GLEAM) satellite. The data used for this research are data from 2001 to 2017. GLEAM satellite is a series of algorithms to estimate the amount of terrestrial evaporation and soil moisture using satellite data [10]. Since it was developed in 2011, this model has undergone several revisions periodically [11].

2.2.4 Land use land cover (LULC). Land use data (LULC) was obtained from the TERRA MODIS satellite. The TERRA MODIS satellite is a land cover measurement satellite that is commonly used to map vegetation or land use in an area [12]. The TERRA MODIS satellite product used is a level 3 combination product from the Terra and Aqua satellites (MCD12Q1). The MCD12Q1 product identifies the geographic distribution of 17 land cover classes using the International Geosphere-Biosphere Program (IGBP) scheme [13]. The data used for this research are data from 2001 to 2017.

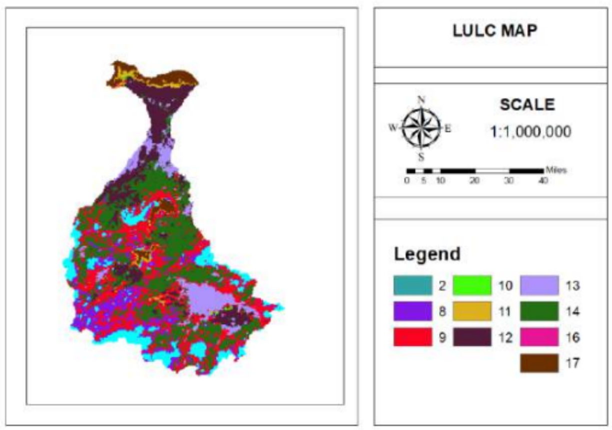

Figure 4. Land use land cover Citarum watershed

2.2.5 Soil properties data. Harmonized World Soil Database (HWSD) is developed by the International Institute for Applied System Analysis (IIASA) and the Food and Agriculture Organization (FAO) of the United Nations [14]. The data used for this research are data from 2001 to 2017. This data is very important because the HWSD data can determine the types of soil contained in each layer. In contrast to other geospatial data, HWSD data is not obtained by observation using a remote sensing system but is carried out by direct field surveys or by using land databases from various countries in the world [15].

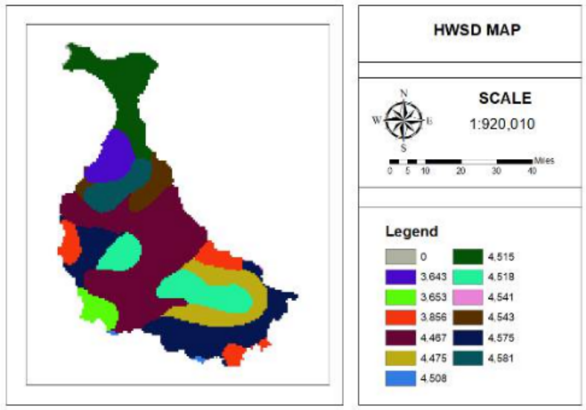

Figure 5. Map of Harmonized World Soil Database in Citarum watershed

3. Methods

The Shetran model was used to predict the groundwater depth. Shetran is a physical and spatial model to simulate water flow, sedimentation transport, and transport of pollutants into water in a watershed [16]. This model has three components and is designed in a modular fashion which represents groundwater, sediment transport, and solute transport in water. Shetran provides details about spatial and temporal data which can be depicted as animation on computer devices [17]. This makes modeling using Shetran is very useful for simulating soil erosion, pollution, land use effects, climate change, and calculating surface runoff and groundwater depth [18].

In Shetran, catchment area, spatial data, and other input data are represented as grids forming columns [19]. Each grid contains a stack of cells containing information about the input data [20]. Spatial data including DEM, land use land cover, as well as soil properties data are used in raster format with a maximum grid size of 200×200 [19].

The core steps from the beginning to the end of this research are:

1) Processing of spatial data in the form of DEM, land cover data, land property data, and hydrological data using ArcGIS to obtain input data in ASCII format which will form the coordinates as the basis for making maps in Shetran.
2) Configure XML for running Shetran models.
3) Running Shetran models using easy set up and standard versions.
4) Extraction modelling results using R program to get groundwater depth values.

4. Results and discussion

4.1 Groundwater depth analysis

Figure 2 shows the simulation results of groundwater depth for 17 years in Citarum using the Shetran model. The depth of groundwater in the Citarum watershed changes which fluctuates every year. From 2001 to 2009, groundwater depth in the Citarum watershed ranged between 1m and 2m. Meanwhile, from 2010 to 2017 groundwater tended to be deeper, ranging from 2m to 4m. The minimum depth occurred in 2009, namely 1.46m, while the maximum depth occurred in 2017 with a depth of 4.09m.

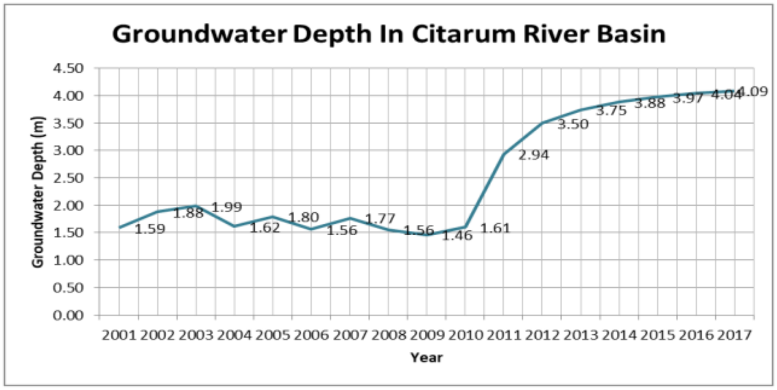

Figure 6. Groundwater depth in Citarum catchment area

4.2 Validation of result

The simulation results are validated by comparing the groundwater depth data and drought event data in the field with the assumption that during the dry season and during the drought groundwater is getting deeper. Drought incidence data is obtained from National Disaster Management Agency (BNPB) Indonesia. Data on drought events is obtained in Bandung Regency because most of the water consumers in the Citarum watershed are in the Bandung Regency area. The data are from 2004 and 2006 because in those years there were many droughts occured.

Table 1. Validation of Shetran Results with Disaster Events at 2004

Month	Groundwater Depth (m)	Drought Event
January	1.47	No
February	1.32	No
March	1.42	No
April	1.55	No
May	1.81	No
June	1.58	Yes
July	2.02	Yes
August	2.08	Yes
September	1.88	Yes
October	1.86	Yes
November	1.66	No
December	1.57	No

Table 2. Validation of Shetran Results with Disaster Events at 2006

Month	Groundwater Depth (m)	Drought Event
January	1.57	No
February	1.45	No
March	1.49	No
April	1.80	No
May	2.14	No
June	1.76	Yes
July	1.59	Yes
August	1.40	Yes
September	1.33	No
October	1.51	Yes
November	1.38	No
December	1.28	No

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In 2004, the drought occurred from June to October (Table 1) and groundwater in that month also tended to be deeper than the other months. The maximum groundwater depth in 2004 occurred in August with a depth of 2.08m. Meanwhile, in 2006 the drought occurred in June, July, August and October (Table 2). In these months, groundwater tended to be deeper than in other months. The maximum groundwater depth in 2006 occurred in May, with a dept of 2.1m.

5. Conclusion

It can be concluded that the depth of groundwater in the Citarum watershed fluctuated over the past 17 years. The minimum groundwater depth occurred in 2009 with a depth of 1.46m, while the maximum depth occurred in 2017 with a depth of 4.09m. After validation by comparing the simulation results with drought event data, the groundwater depth in the dry season tends to be deeper than in other months.

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