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Application of GIS for Assessment of Water Availability in the Cianten Watershed, West Java

A A Mirrah and E Kusratmoko*

Department of Geography, Faculty of Mathematics and Natural Science, Universitas Indonesia, Depok 16424

eko.kusratmoko@sci.ui.ac.id

Abstract. Spatial information about the water availability in a region is very important in the management of sustainable water resources. Geographic information systems allows spatial information about water availability in watersheds to be assessed and monitored over time and within a predefined unit of space. This paper describes the application of GIS to assess the water availability and water demands spatially in the Cianten watershed, Bogor District, West Java. The availability of water for each sub-watershed was assessed using the water balance equation. Rainfall and temperature data for the 2007-2016 period, data of elevation, slope, soil type and land use for research area were used to calculate the water availabiliy, both annual and dry season. While the data on population size and land use were used to calculate water demands (domestic and non-domestic) for each sub-watershed based on the standards issued by the Ministry of Public Works and Agriculture. The analysis results using GIS platform shows a spatial variation of annual water availability and dry season. The water availability ranges from 9266 m3 / ha to 15,991 m3 / ha, while the dry season ranges from 2285 m3/ha to 4147 m3 / ha. Comparing water availability and water demands show that during the dry season most sub-watersheds in the study area experienced a high to low water deficit.

Keywords: SWAT Model, Water Availability, Water Balance, Water Demand

1. Introduction

Spatial information about the availability of water resources in a region is essential for sustainable management of water resources. Geographic information systems (GIS) facilitate the management of water resources more effectively and efficiently so as to enable spatial information about the availability of water resources in the watershed can be assessed and monitored over time and within a predefined unit space scale [1].

Definition of the water availability on earth space varies depending on the point of view of interest. Most studies and reviews on the subject of water availability focus on blue water or water available on the surface and subsurface of the earth [2]. [3] defined the availability of water as the amount of water expected to be continuously present at a given location (rivers, dams, lakes, reservoirs and other water structures) for a certain amount and within a certain period of time. In the hydrological cycle, the watershed is an open system in which the hydrological process takes place. The quantity of output (output) in the form of river flow discharge depends on the quantity of input (input), rainfall and watershed characteristics [4]. Thus, the water availability between watersheds will be different due to differences in climate factors, especially rainfall, and watershed characteristics, such as geological factors, topography, soil and land cover.

Spatial information on the water availability in a region, both regionally and locally, is essential to determine the potential of available water resources compared to the water demands of the area. The water availability index with an indicator of the comparison between human needs compared to water availability is one of the main parameters that is often used as a reference for addressing water and drinking water demands in an area [2]. In this study, we used GIS technology to assess water availability in the Cianten watershed, Bogor regency, West Java. The Cianten watershed is part of the Cisadane Basin located upstream. This watersheds was chosen because of the dynamic of land use changes, especially the increasingly widespread of built-up areas [5]. The problem of water shortage, especially in the dry season, is a classic problem that often occurs in most areas of the Cianten watershed. In this paper we describe how the spatial pattern of the water availability index in the Cianten watershed, especially during the dry season.

2. Methods

2.1 Study Area

The Cianten watershed is a part of the Cisadane Basin located in upstream and geographically located at 6°28'45"- 6°43'0" South Latitude and 106°30'15"- 106°44'30" East longitude. The watershed area is 507.2 km^2 or 50,715.2 hectare and is administratively part of West Bogor Regency, West Java Province (see Figure 1).

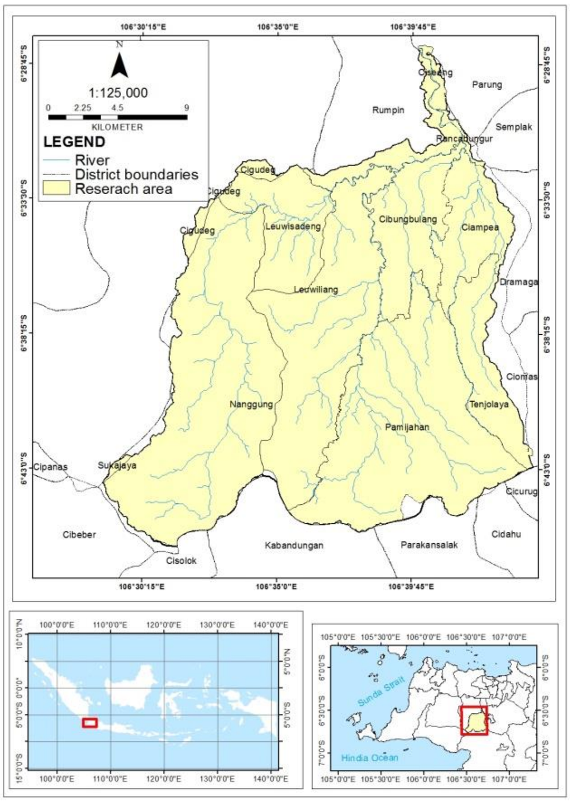

Figure 1. Map of the Cianten watershed, Bogor Regency, Province of West Java

2.2 Data and Materials

The spatial and tabular data used and how to obtain it are described as in Table. 1. The GIS software used was ArcGis Ver. 10.1.

Table 1. Data collecting

Data	Data acquisition
DEM (*Digital Elevation Model*)	DEM data derived by processing the SRTM data, which obtained from USGS Glovis.
Land use	Land use data derived from a digital Land use map in 2015 with a scale of 1: 100,000 issued by the Ministry of Land and Spatial Planning.
Soil type	The soil type data derived from a digital map of soil type with a scale of 1: 100.000 issued by Soil Research Institute, Ministry of Agriculture of the Republic of Indonesia.
Climate (rainfall and temperature) Suhu)	All data obtained from the Meteorology, Climatology and Geophysics Agency. The average monthly rainfall data for the period of 2007-2016 are available from 8 stations, namely Cianten Plantation, Leuwiliang, Kuripan, Dramaga, Rancabungur, Cigudeg, Kracak, and Cicurug. While the average data of monthly temperature for the same period obtained from Dramaga Climate Station.
Drainage network	Data were derived by the processing of the digital topography map with a scale of 1: 25.000 issued by Geospatial Information Agency (BIG).
Total Population	Secondary data obtained from the Central Bureau of Statistics, Bogor Regency, in 2016.

2.3. Data Processing and Analysis
Water availability for each sub watershed were calculated by the equation [5]:

$$Q = (1 - C) \times (P - Ea) \times A \tag{1}$$

where Q is the water availability (mm / year), P is the average rainfall annual (mm / year), Ea is the actual evapotranspiration (mm / year), C is the runoff coefficient, and A is the watershed area (ha). The workflow to compute the water availability based on GIS technology is shown in Figure 2. The GIS database system for the Cianten watershed is built with layers of sub-watershed boundary, river network, slope, land use, rainfall and temperature.

Delineation process of the Cianten watershed to the sub-watershed unit is done using ArcSWAT software with ArcGIS 10.1 interface. Then, the hydrological unit for each sub-watershed were determined by the overlay processing of thematic layers of slope, land use and soil type. The classification for each thematic layer refers to the Cook method classification [7][8].

Spatial distribution of the annually and seasonally rainfall of the study area are calculated by Thiessen Polygon method based on the eight (8) available rainfall stations. Furthermore, the actual evapotranspiration is calculated using the Turk-Langbein equation [5]:

$$Ea = \frac{P}{(0.9 + \frac{p}{Eo})^2} \tag{2}$$

where Ea is the actual evapotranspiration, P is the average annual rainfall, and Eo is the potential evapotranspiration. The amount of Eo is calculated using the Langbein equation:

$$Eo = 300 + 25Ty + 0.05Ty^3 \tag{3}$$

where Ty is the annual temperature distribution. The water demands in a watershed are calculated based on the population's water demands and the water requirements for agriculture and crops. The population water demands in this study refer to the needs of the rural population of 60 liters/day per person [10]. While water requirements for agriculture and crops based on land use type [11] as follow, forest crops (1000 mm/ year per hectare), shrublands (1000), mixed garden (1000), non-irrigated field ("tegalan" in bahasa) (1350 mm), rice field with twice harvest (2400), rice field with one harvest (1200).

Population water demands (Wpo in m^3) in a watershed is calculated by the equation:

$$Wpo = n \times p \times \frac{q}{1000} \tag{4}$$

where n is the number of days, p is the number of population per village, and q equals 60 liter/day per person. Furthermore, the water requirement for each land use (Wlu in m^3) are calculated by the equation [1]:

$$\text{Wlu} = 10 \text{ x n x A x r} \quad (5)$$

where n is the number of days, A is the area of each type of land use and r is the water requirement for each type of land use. Therefore, the total water demands = Wpo + Wlu. We determined a water availability index (WInd) in a watershed with the basis of the comparison between total water demand to water availability,

$$\text{WInd (\%)} = \frac{WN}{W\ x\ 100\%} \quad (6)$$

Based on the value of WInd for each watershed, which can be positive (surplus) or negative (deficit), we classified the Wind, in five classes, is deficits or surplus: high, slightly high, medium, slightly low, and low.

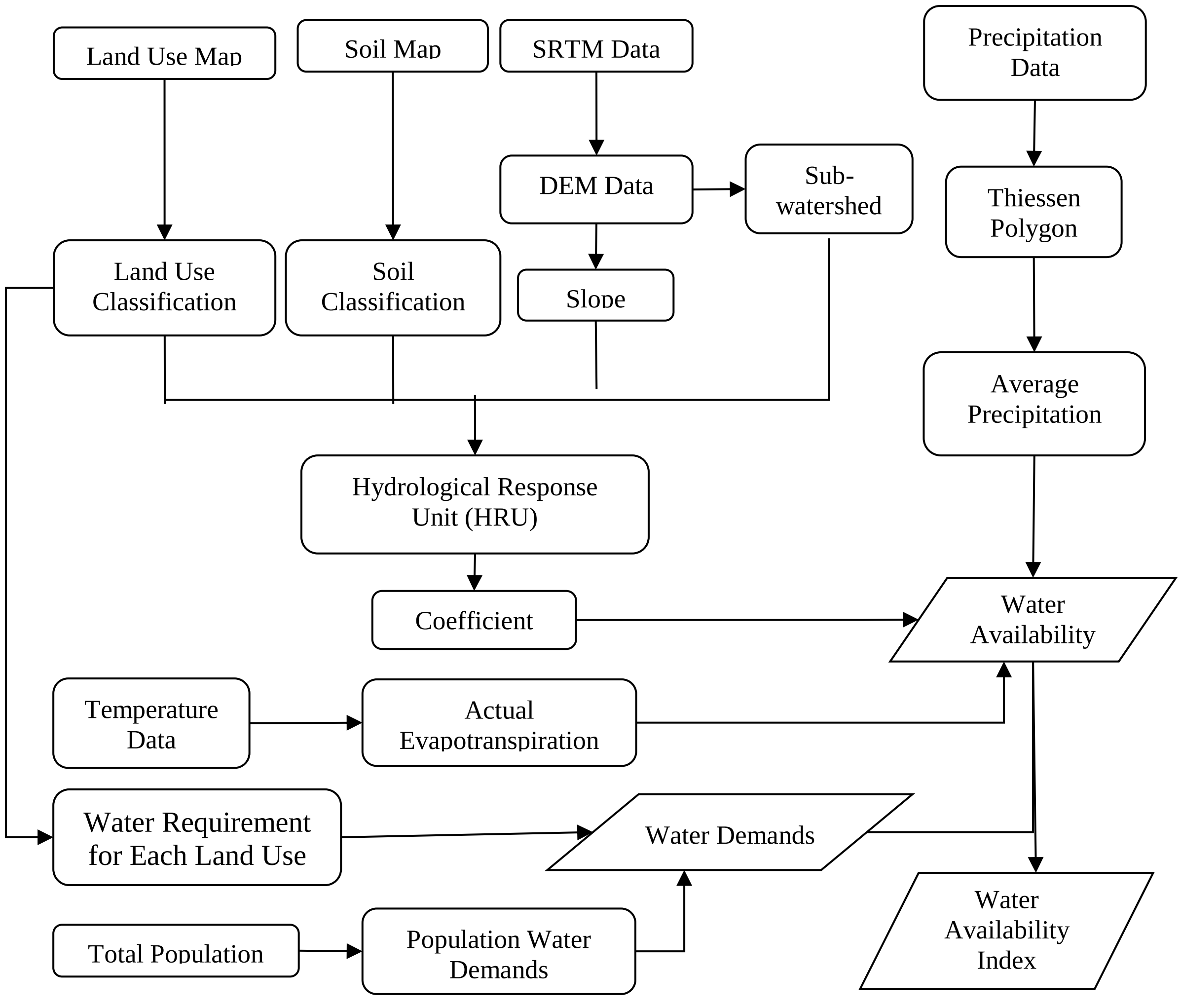

Figure 2. Workflow to calculate water availability based on GIS techology

3. Results and Discussion

3.1 Annual and Seasonal Water Availability

The GIS modeling process produced two maps, ie a map of annual water availability and a map of water availability for the dry season in the Cianten watershed (see Figures 3a and 3b). The annual water availability varies with the range between 125,5 10^6 m^3 (3019 m^3/ha) to 6.1 10^6 m^3 (While in the dry season, its amount ranges from .67 10^6 m^3 to 30.1 10^6 m^3. The availability of water in the dry season is only a quarter of the annual water availability. The size of the watershed area affects directly the amount of the water availability, both annual and seasonal. . Statistically, the average annual water availability of Cianten watershed is 42.3 10^6 m^3 (10.1 10^6 m^3 in dry season) and with an inter-watershed variability of 84% and 83% respectively.

The amount of water availability in a watershed is divided by the watershed's area generated a water availability per unit area (hectare). The magnitude in the Cianten watershed is in the range of 9,266 to 15,991 m^3/ha for annual and 2285 to 3754 m^3/ha in the dry season. Compared with the total water availability in a watershed, the variability of water availability per unit area (hectare) is relatively smaller (15%), both annual and seasonal. This may provide a clue that the water availability in the Cianten watershed is spatially homogeneous. Spatially, regions (sub-watersheds) with the highest water availability tend to be found in regions with high rainfall (> 4000 mm) with land cover dominated by forest.

Table 2. Annual and seasonal water availability (WA) in the Cianten Watershed

No	**Sub-Watershed**	**Area (Ha)**	**WA in total area**		**WA in ha area**	
			Dry season (in 10^6 m^3)	Annual (in 10^6 m^3)	Dry season (m3/ha)	Annual (m3/ha)
1	Cisadane 1	740.5	1.69	6.7	2285	9266
2	Cisadane 3	911.9	3.8	14	2608	9541
3	Cisadane 2	642.8	1.67	6.1	3828	14201
4	Cianten 2	1767.9	5.8	23.8	2997	12356
5	Cikaniki 2	9955.0	30.1	125.5	3019	12611
6	Ciaruteun	2011.6	7.7	30.1	3835	14982
7	Citeureup	3019.2	7.4	30.5	2446	10110
8	Cibungbulang	2327.5	8.2	33.9	3260	13467
9	Cinangneng	2248.5	7.5	31.5	3355	14031
10	Cigamea	2237.1	6.9	29.4	3103	13153
11	Cianten 1	7105.8	18.6	79.4	2623	11171
12	Ciampea	2820.4	10.1	42.1	3309	13791
13	Cisarua	2359.5	8.1	34.4	3421	14574
14	Cipuraseda	2455.9	7.9	33.6	3221	13670
15	Cikaniki 1	7545.3	28.3	120.6	3754	15991
16	Cikuluwung	2566.1	8	35.6	3135	13856
	Average	-	10,11	42,33	3137	12923
	Std Deviasi	-	8,4	35,6	469,6	1966,1
	Var (%)	-	82,8	84,0	15,0	15,2
	Total area	50715.2	161,76	677.20	50198	206771

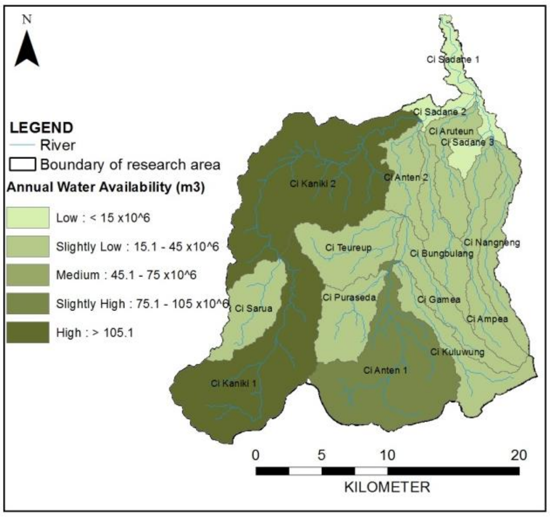

Figure 3a. Annual Water availability in Cianten watershed

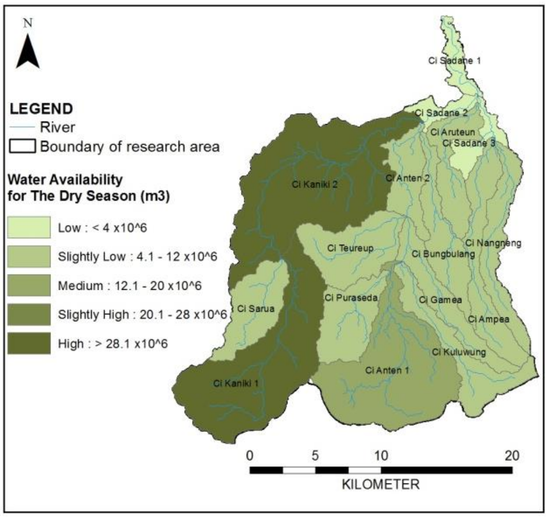

Figure 3b. Water availability for the dry season in Cianten watershed

3.2. Water Availaibility Index

We have calculated the total water demand for each sub-watershed in the Cianten watershed, both annual and dry season, and then we compared it with the water availability for each sub-catchment (see Figure 4 and Figure 5). Spatially, the distribution of WInd for each sub-watershed are shown in Figures 5a and 5b. It is clearly seen that based on the annual water availability index, most of the sub-watersheds (11 of 16 sub-watersheds) in the Cianten have surplus water resources. The sub-watersheds categorized deficit of water availability can be found only in the downstream area, ex. the Cisadane_2, Cinangneng. The average of water deficit is less than 15%.

The opposite happens during the dry season. Most sub-watersheds are characterized by the greater water demand more than its water availability. There are five sub-watersheds, ex. the Cisadane_1, Cisadane_2, Cianten_2, which the water deficit is classified by high (>30%). The sub-watersheds located in the downstream area. Only one watershed (the Cikaniki _1) is not water deficits.

In general, the results of this study indicate that the calculation of water availability based on annual rainfall data, especially in areas with high rainfall, does not guarantee a careful calculation of the index of water availability in a region. We need to consider the spatio-temporal factor of rainfall in the study area and the characteristics of the land use.

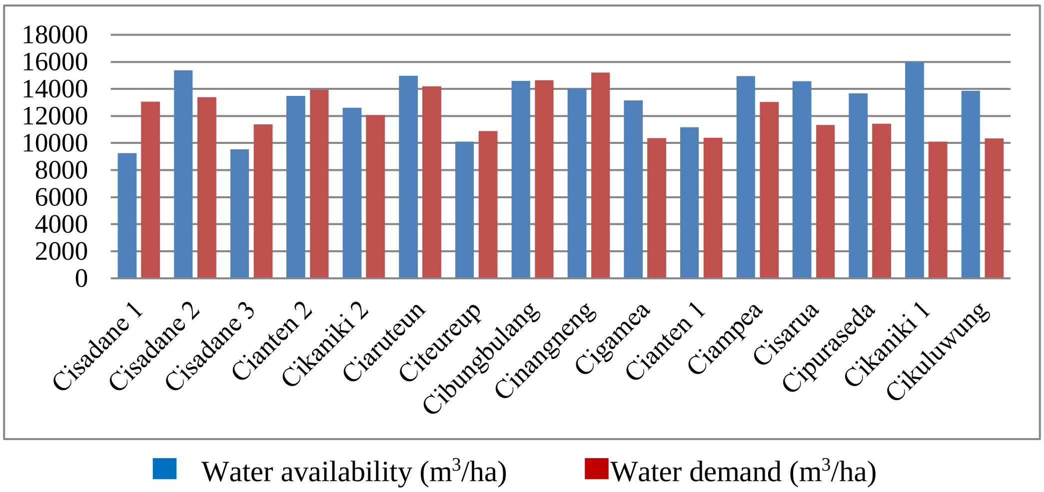

Figure 4. Annual water availability and water demand in the Cianten watershed

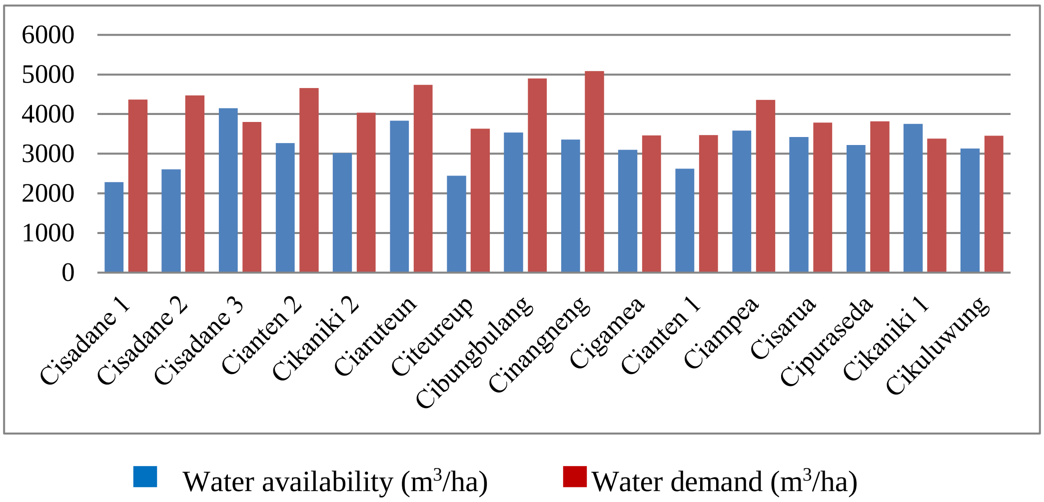

Figure 5. Water availability and water demand for dry season in the Cianten watershed

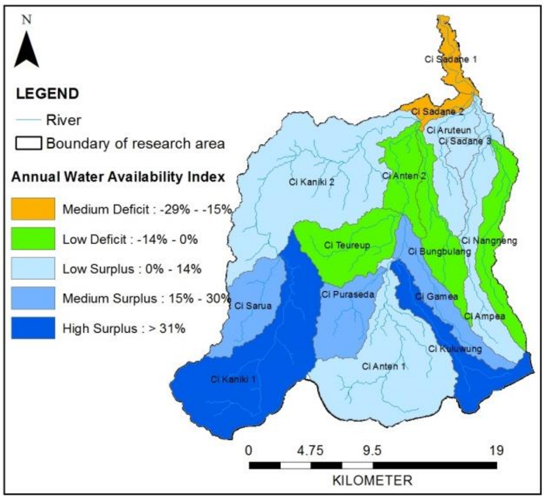

Figure 6a. Annual water availability index in the Cianten watershed

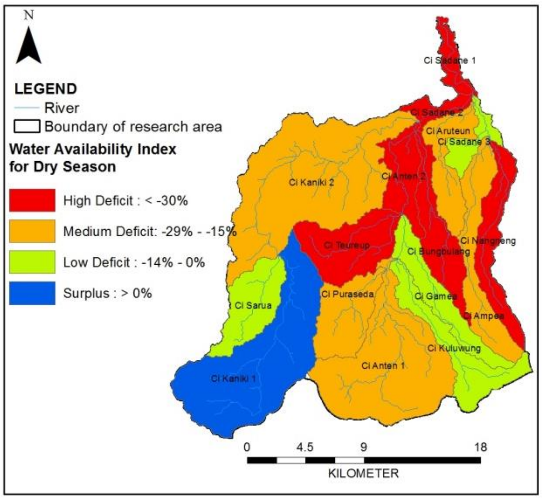

Figure 6b. Water availability index for dry season in the Cianten watershed

4. Conclusions

Based on the GIS modeling, this study has been able to calculate and assess the availability of water in the Cianten River Basin, Bogor, West Java, both spatially and temporally. The annual water availability index in the Cianten watershed shows that most of the sub-watersheds are classified as surplus. A factor of the high annual precipitation in the study area supports these results. However, an indication of water resource deficit in all sub-watersheds occurred during the dry season. The worst water deficit can be found especially in the sub-watersheds located downstream of the study area.

Further research of these findings can support sustainable management of water resources. For that, the verification process of the research results should be done through direct observation in the field. It is necessary to validate the results of this study.

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