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Assessment of rainwater absorption zone in Citarum Watershed using GIS and AHP

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Abstract: Watershed performance can be seen from various aspects, including the ability of the land to absorb water, the amount of erosion, water quality, and water regime index. This study is an effort to manage critical watersheds in managing water absorption based on biophysical parameters such as soil type, slope, geology, rainfall, and land cover. This research was conducted in 2021 in the Citarum watershed, limited to shallow aquifers. It is important to be mapped because it is part of 15 critical watersheds in Indonesia. The method used is to integrate RS, GIS, and Analytical Hierarchy Process (AHP). The results showed that there was a distribution of water absorption in the Citarum watershed, including very low 1.04%, low 21.33%, Medium 25.20%, high 38.80%, and very high 13.63%, with a total area of 638,511.57 ha. The dominant absorption rate is relatively high, 38.8%, and very high, 13.63%, influencing water availability in the Citarum watershed. From this study, AHP shows that the most influential in water infiltration into shallow aquifers is soil, with a score of 0.5, followed by Rainfall Criteria with a score of 0.26, followed by the land cover at 0.13, then slope and geology.

1. Introduction

The portion of rainwater that seeps into the ground is the main supply for the realization of water resource conservation. Rainwater seeping into the soil can flow into the root zone and continue into the shallow aquifer. During the dry season, the water helps stabilize river water flow as a baseflow with a small speed [1]. However, the part of rainwater not absorbed by the soil surface flows into rivers. If the amount is excessive, it can cause flooding and also cause accelerated soil erosion. Therefore, the greater the rainwater that seeps from the ground surface, the risk of flooding, drought, sedimentation in rivers or lakes, and a decrease in soil fertility [2].

The process of infiltration of rainwater into the soil surface until it enters the cracks of weathered rock (percolation) is part of forming groundwater above the impermeable layer. This process is part of the hydrological cycle and includes five essential aspects, namely: a. rain that falls on the ground, how much rainfall is available or has the potential to be absorbed; b. the slope of the land, this is related to the speed of the land surface in absorbing rainwater, so the smaller the slope, the greater the land can absorb rainwater; c. the nature of the soil in absorbing rainwater, influenced by the pores, texture and water content; d. the nature of the rock in draining water from the unsaturated zone to the saturated zone;

e. groundwater table (water table), this affects soil moisture. The shallower the groundwater level, the higher the soil moisture, so the process of entering rainwater into the groundwater zone is slower. Other research in China also stated that many factors influence the occurrence and movement of groundwater in an area. It includes topography, lithology, geological structure, weathering depth, fracture area, primary porosity, secondary porosity, slope, drainage pattern, landform, land use/ land cover, and climate [3].

The Citarum – West Java Watershed (DAS) is one of the national priority watersheds for rehabilitation because it is classified as critical. This watershed can represent the environmental conditions of the watersheds, especially on the island of Java. The upstream Cimanuk watershed is a water catchment area (DTA) for the Jatiluhur, Cirata, and Saguling reservoirs located in the Citarum watershed, administratively, including the province of West Java. Sustainability of water supply for the Saguling, Cirata, and Jatiluhur reservoirs in the Citarum watershed must be sought for stability through controlling biophysical conditions, especially soil and land cover. These three reservoirs are the mainstay of supplying irrigation water, electricity, and drinking water in parts of West Java and DKI Jakarta. Weaknesses in the management of the Citarum watershed cause high levels of erosion, runoff, flooding, erosions, drought, and pollution that occur in the watershed area. One of the leading causes of natural disasters related to water (water-related disasters) is that the carrying capacity of the watershed as an ecosystem unit is still very low [4].

The process in the watershed of converting inputs into outputs is influenced by many complex factors, some of which are land use and soil conditions [5]. Groundwater recharge potential zones have been assessed in many countries [6], where GIS and remote sensing are very important instruments. However, the groundwater recharge potential zone has not yet been assessed in Citarum watersheds, especially in shallow aquifers. This shallow groundwater is the upper aquifer, also known as phreatic water [7]. The community commonly uses shallow groundwater as a home-scale water source obtained by making wells. In this study, the weights of different factors for groundwater recharge potential and the score under various characteristics were assessed based on the characteristics of the Citarum Watershed. According to [8], upstream and middle watershed areas are essential in water conservation. Therefore, Citarum watershed conservation is significant to do. In this study, the GIS and RS instruments tried to add AHP in considering the weights between the existing criteria. At the same time, this study aims to develop rainwater catchment zoning as a reference in land use policies (space allocation) to reduce the risk of drought and flooding.

2. Material and method

2.1. Study area

The study area covers the Citarum watershed from upstream to downstream, which is the catchment area of the Saguling, Cirata, and Jatiluhur reservoirs, with a total area of 638,511.57 ha. The research was conducted in 2020 administratively located in Bandung Regency, Purwakarta Regency and Sumedang Regency, Cianjur Regency, Bogor Regency, Bekasi Regency, West Java Province. as shown in Figure 1

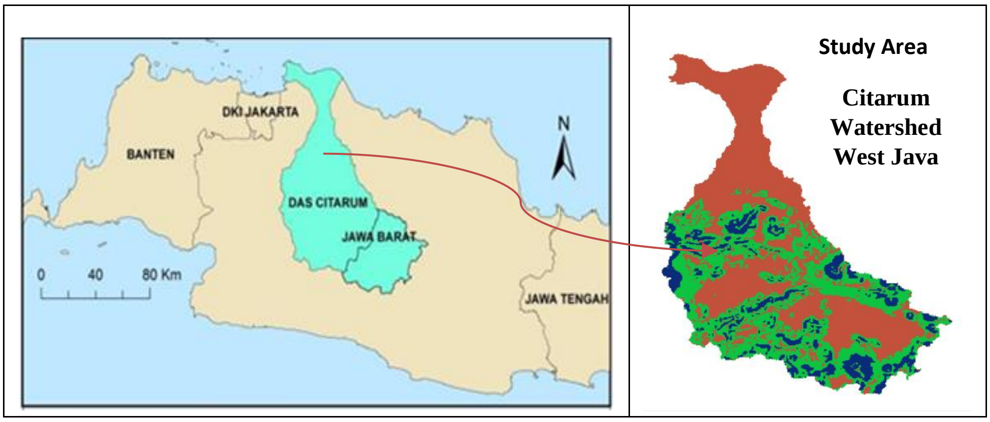

Figure 1. Study area

2.2. *Data source*

The secondary data used include a 1:25 000 digital map of Indonesia, an 8 m resolution DEM (Digital Elevation Model) map, a soil type map (scale 1:100,000 from Puslittanak Bogor), and a 2019 land cover map with a scale of 1:100,000 interpretation results. Spot imagery from Lapan, climate and daily rainfall data obtained from the Meteorology, Climatology and Geophysics Agency from the nearest station, and administrative boundary of West Java Province.

2.3. *Data processing*

The National Remote Sensing Agency (NRSA 1987) in India was the first to integrate information from remote sensing and the geographical information system (GIS) technology for delineating the groundwater recharge potential zone. GIS is used to manage, utilize, and classify remote sensing results, explore sites, combine the factors of groundwater recharge potential, and provide appropriate weight relationships [9].

The initial step of this research is to determine the watershed boundaries with the DEM basis. It is cropping other layers according to the research area. Rainwater infiltration on land is determined by several factors, such as rainfall, soil type, slope, rock type, depth of groundwater table, and land use factors. Root systems and plant litter can increase soil organic matter so that soil porosity increases. Land use is a factor under the influence of human activities, while other factors are more natural. This study uses a method that integrates RS, GIS, and Analytical Hierarchy Process (AHP). Remote sensing for landcover interpretation, GIS for spatial analysis, and AHP for weighting factors influencing rainwater absorption. The methodology used in this study is divided into five stages, namely (i) determining the weight of each criterion, (ii) determining the sub-criteria, (iii) preparing derivative thematic maps, and (iv) making a performance map for the Citarum watershed. It is based on the ability to absorb water and (v) test the model's accuracy.

The mapping of rainwater catchment zones is divided into potential and actual. Potential rainwater infiltration is formulated based on soil, rock, slope, rain factors, and groundwater level. The shallow groundwater depth in the Citarum watershed is relatively far below the ground surface, approximately 4 m above the water table layer [11], so its effect on rainwater infiltration is relatively small [5]. Therefore, in this study, the groundwater level was not considered or assumed to be uniform in determining the zoning of rainwater infiltration.

Actual water absorption is the current condition of the land in its ability to absorb rainwater. The value of potential and actual water absorption is a relative value in the area of a watershed. Rainwater catchment zoning is obtained by overlaying thematic maps with Geographic Information Systems. In the potential water absorption, the maps that are overlaid are infiltration class maps, rock/soil permeability class maps, slope class maps, and rainfall class maps. In contrast, the actual water absorption is added with a land use class map. The infiltration score can be calculated based on the sum of the multiplication between the weights and the ranking value of the determinants of rainwater infiltration [10] or by the formula:

$$\text{absorption score} = \mathrm{Sp.Sb} + \mathrm{Ip.Ib} + \mathrm{Kp.Kb} + \mathrm{Pp.Pb} + \mathrm{Lp.Lb} \qquad (1)$$

Where:
S= slope
p= rank
I= Infiltration
b= weight
K= soil/rock permeability
P= rainfall
L= land use

Figure 2 is a framework for thinking about the groundwater infiltration model in the Citarum watershed.

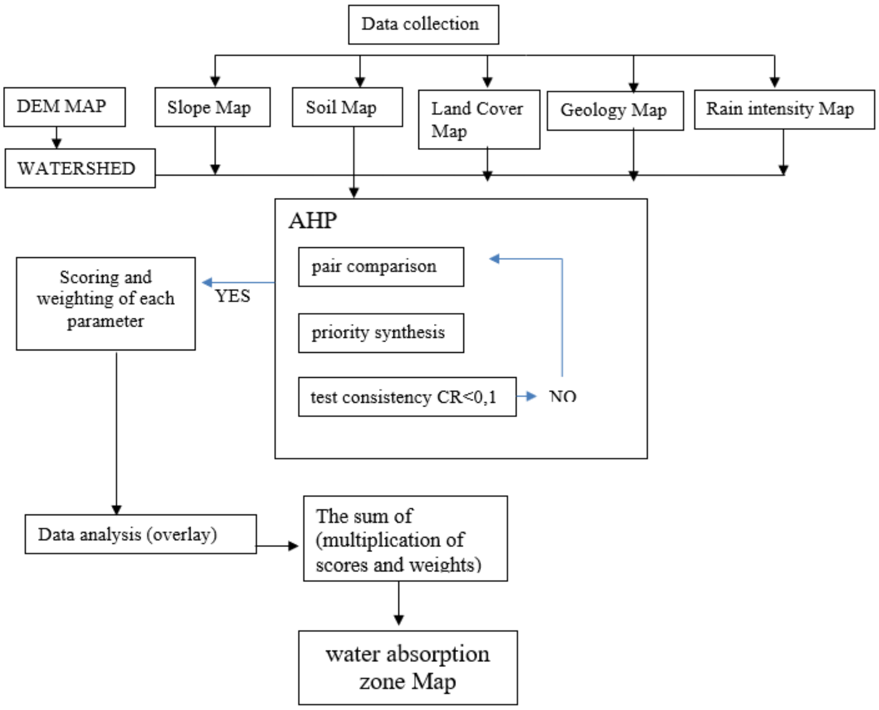

Figure 2. Flowchart of the study

Data collection is done by paying attention to the details of the same scale and format because it is for spatial analysis purposes. Therefore, the Analytical Hierarchy Process (AHP) is carried out first before performing an overlay analysis of several layers. The AHP process includes: performing pairwise comparisons with the guidelines in the table.1, normalizing decisions and calculating the weight of each criterion, (ii) determining sub-criteria, (iii) preparing derivative thematic maps, (iv) making Citarum watershed performance maps based on the absorption capacity of water, and (v) model accuracy test.

Table 1. Paired comparison rating scale

intensity of interest	description
1	both elements have the same value
3	one element is slightly more important than the other elements
5	one element is more important than the other elements
7	one element is very important from the other elements
9	one element is absolutely important for the other elements
2,4,6,8	element values that have adjacent values

3. Results and discussion

3.1. Weights and scores with the AHP method

The AHP process is carried out on five factors that affect the ability to absorb rainwater in the Citarum watershed. After the pairwise comparison, the priority synthesis and consistency test showed the following results. AHP: Max eigenvalue (γmax) = 5.373946, n = 4 , Consistency index (Ci) = (γmax - n)/(n - 1) = 0, 0935 , Random index (Ri) = 1.12 and Consistency ratio (Cr) = Ci/Ri = 0.08347. The CI value is 0.0935, which means that the weighting is not very consistent, but because the value of CR=0.08 is less than 10%, the inconsistency is still acceptable. The order of weighting from the most influential to the least influential is presented in table 2.

Table 2. Weighting results

No	Criteria	Weight
1	Soil	0.5
2	Rain intensity	0.26
3	Landcover	0.13
4	slope	0.07
5	Geology	0.03

Table 2 shows that the weight value that plays the most role in this study is the soil criteria, with a score of 0.5. followed by Rainfall Criteria with a score of 0.26, land cover 0.13, Slope and geology

3.2. Rainfall distribution

The results of the average monthly rainfall for the period 1997 – 2020 for eight rainfall stations were carried out using the Thiessen Polygon method. The highest order results are more than 3000 mm/yr, only 1.7% as shown in table 3 . the most expansive area with rainfall 2000mm - 2500 mm by 41.8%. The rain pattern in January – April is a wet month. The rainfall ranges from 242 – 336 mm/month. May – October is a dry months. Rainfall ranges from 35 – 122 mm/month, and November – December enters another wet month with rainfall increasing to 240 – 269 mm in other watersheds. Analysis of annual rainfall in the period 1987 – 2020 in the Citarum watershed shows that there has been a trend of decreasing annual rainfall. According to [15] Pawitan et al. (2007), this decrease in annual rainfall is based on an analysis of rain series data over the last hundred years in the upper Citarum watershed and the southern part of Java Island. There has been a significant annual decline, with a reduction in rain rate of approximately 9 mm/year. Suroso et al. 2021 [11] show that a decrease in rainfall has affected the fluctuations in groundwater depth in the Citarum watershed for the last 17 years.

Table 3. Composition of annual rainfall classes for the Citarum watershed

Class	Annual rainfall mm	Score	Area (ha)	percent
1	> 3,000	5	10,855	1.7
2	2,500 – 3,000	4	75,344	11.8
3	2,000 – 2,500	3	266,898	41.8
4	1,500 – 2,000	2	40,226	6.3
5	<1,500	1	245,188	38.4

3.3. Slope

The Citarum watershed is bounded by a ridge of mountains and hills connecting the peaks of Mount Cikurai, Mandalagiri, and Papandayan in the south; the peaks of Mount Cikurai, Kracak. Telaga Bodas and Cakrabuana in the east; and the peaks of Mount Papandayan, Kendang, Guntur, Haruman, and Calancang in the west; and in the northern part, there is a valley plain which is the downstream/estuary of the watershed. The elevation of the upstream Citarum watershed ranges from 230 to 2,998 meters above sea level. The lowest elevation is found around the mouth of the Jatiluhur Reservoir, while the highest elevation is found at the peaks of Mount Cikurai (2,900 m asl.), Papandayan (2,665 m asl).

The interpretation of the Citarum Watershed Topography Map shows that the slopes above 45 % are 72.790 ha (11%), 15 – 30% slopes are 117.486 Ha (18,4%), 5 – 15% slopes are 130.256 ha (20,4 %), and <5% smaller slope area of 90.669 Ha (14,2%). The slope of the land is an important factor that needs to be considered in the conservation of water resources. The slope of the land is directly proportional to the potential for soil erosion and inversely proportional to the opportunity for water to seep into the soil surface. Land with a slope above 2 percent has a significant effect on the infiltration rate [12]. On land with a slope greater than 30%, it is better to plant perennial crops, which require little tillage. Land with a slope of 15 – 30% is cultivated using terraces to reduce the slope and length of the slope so that erosion will be reduced.

Table 4. Slope score in the Citarum watershed

Class	Slope (%)	Score	Area (ha)	percent
1	< 5	5	90,669	14.2
2	5 – 15	4	130,256	20.4
3	15 – 30	3	117,486	18.4
4	30 – 45	2	227,310	35.6
5	> 45	1	72,790	11.4

3.4. Type of soil

Based on the semi-detailed soil map, scale 1: 100,000 Soil Research Center, Citarum Watershed (table.5). The brown latosol soil type was the most common type of soil, reaching an area of 55.7%. Its distribution is mainly in the middle area that stretches from upstream to downstream of the watershed on flat to slightly steep slopes. The second largest soil type is the association of brown and brown regosol, which covers an area of 28.8%, spreading on mountain ridges which are watershed boundaries, especially upstream and on steep slopes. If based on the sensitivity of the soil to erosion, then the two types of soil are soils with a fairly high soil sensitivity to erosion and reach an area of 13.5% of the Citarum watershed [13]. Gray regosol complex) Moreover, litosol is the third largest soil type (1,9%) in the middle of the watershed.. In contrast, other soil types, such as rensina complex, litosol, and brown forest soil, yellowish red podzolic complex, yellowish brown andosol, grumusol complex, and regosol and Mediterranean area ranged from 0.2% - 0.9%.

Table 5. The score of soil infiltration class in the Citarum watershed

Class	Infiltration_Rate	Score	Area (ha)	percent
1	fast	5	12,132	1.9
2	Fairly fast	4	86,199	13.5
3	medium	3	178,783	28.0
4	slow	2	355,651	55.7
5	Very slow	1	5,747	0.9

3.5. Land cover

The results of the interpretation of spot satellite imagery in 2019 and field checks carried out in 2020 show in table 6 that the land use of the Citarum watershed is dominated by gardens/tegal, which is 29.5%, followed by forests and shrubs (13.5%), settlements and built-up areas (15.9%). %), rice fields 7% , seasonal crops (11.56%), plantations (5.4%) and water bodies 6.8%.

Rice fields are land uses that require much water in the middle and downstream Citarum watersheds with almost even spatial distribution. Most rice fields are on flat to gentle slopes and alluvial plains around the river. In some paddy fields, crop rotation is carried out with seasonal crops. Processing paddy fields can result in a relatively impermeable thin layer of water at the bottom of the rice field, thereby reducing water infiltration into the soil. However, rice fields require a large amount of water, and on the other hand, as stated above, there is a tendency to decrease annual rainfall in the Citarum watershed. For this reason, it is necessary to innovate technology/culture that saves water, such as the SRI (System of Rice Intensification) method. SRI uses six principles: young seedlings, single planting, wide spacing, use of organic fertilizers, water regulation, and organic pest and weed control. Research results [14]. shows that the use of SRI can save 28% of water requirements compared to the SCH (Stagnant Constant Head) method.

In cultivation areas that need attention, especially on horticultural agricultural land, food crops, and community forests, land use for agricultural cultivation is currently causing significant erosion. Land conversion from non-agricultural land to agricultural land and deforestation need to be controlled to reduce the increase in critical land. In reducing erosion, plant factors have the following functions: a. rainwater interception, which reduces rainwater energy (splash erosion) and runoff, b. decrease in runoff velocity, c. reduce ground displacement, d. increase soil aggregation and porosity, e. increase biological activity in the soil, f. transpiration which will decrease soil moisture and increase storage capacity [12].

Table 6. Scoring landcover of Citarum watershed

Class	Landuse	Score	Area (ha)	percent
1	Forest	10	16,374	2.56
2	Shrubs	9	71,276	11.16
3	Gardens/Tegal	8	188,620	29.54
4	Plantation	7	34,424	5.39
5	Seasonal Plants	6	7,970,	1.25
6	Open Ground	5	131,119	20.53
7	Waterbody	4	43,378	6.79
8	Ricefield	3	45,340	7.10
9	Settlement	2	50,986	7.99
10	Non-Residential Building	1	49,024	7.68

3.6. Geology

Rock types or geologycal factor in relation to infiltration zoning is influential when rainwater that has seeped (infiltrated into the soil surface) continues to move following the earth's gravity or lateral. This movement speed affects the continuous percolation when it rains for a long time. Land graduation classes in the Citarum watershed are primarily fast. This condition is not favorable in terms of water resource conservation. Most of the physical properties of the Citarum watershed have a fast class in absorbing rainwater, which is 346,71 ha (54.3%) and very fast in an area of 238,803 ha (37.4%) (Table 7).

Table 7. The score of rock transmissibility of the Citarum watershed

Class	Transmissibility	Score	Area (ha)	percent
1	Fast	5	238,803	37.4
2	fairly fast	4	346,712	54.3
3	medium	3	5,747	0.9
4	slow	2	41,503	6.5
5	very slow	1	5,747	0.9

3.7. Absorbtion Rainwater Zone

3.7.1. Potential Rainwater Absorption Zone

Determination of potential rainwater infiltration zoning is the result of the overlapping of various thematic maps, namely: soil type maps, land slope maps, rock permeability maps, and rainfall maps. Weighting is carried out on several factors that affect rainwater infiltration in order of high to low, namely slope, soil type, rock graduation, and rainfall. The rain intensity factor is the highest element, followed by the slope of the land to determine the infiltration class. On flat land, when it rains, water easily stagnates so that more water seeps through the soil surface. On the other hand, if the soil surface has a steep slope, the rainwater will flow directly, and the chance for water to seep gets smaller.

3.7.2. Actual Rainwater Absorption Zone

The actual infiltration zone map is prepared by overlapping the map of the potential infiltration zone with the land use map, where the type of land use greatly affects the ability of the land to absorb rainwater. Land with dense vegetation, such as forest, has a large infiltration capacity, but on the other hand, if the land is cemented (built-up area), the rainwater partially becomes runoff.

The results of the actual water catchment zoning map of the Citarum watershed are presented in Figure 3 and Table 8. The actual infiltration class is relatively high and most high, especially in forest areas, and enters the administrative area of upstream and middle Karawang Regency, Central Purwakarta Regency. On the other hand, the actual absorption zone is fast, especially in East Bogor Regency, upstream Cianjur Regency, and West Bandung Regency. The slow and medium-water absorption potential class is 25.2% and 22.33%, respectively. In comparison, the fast capability zone is 13.63%, and the relatively fast is 38.8%. The division of the catchment zone is very important to become one of the guidelines for managing water resources for the realization of sufficient water for Indonesia in Facing Global Climate Change [15].

Table 8. Actual rainwater absorption zoning of Citarum Watershed

Class	Transmissibility	Score	Area (ha)	percent
1	Very high	5	87,001	13.63
2	High	4	247,753	38.8
3	Medium	3	160,891	25.20
4	low	2	136,198	21.33
5	Very low	1	6,666	1.04

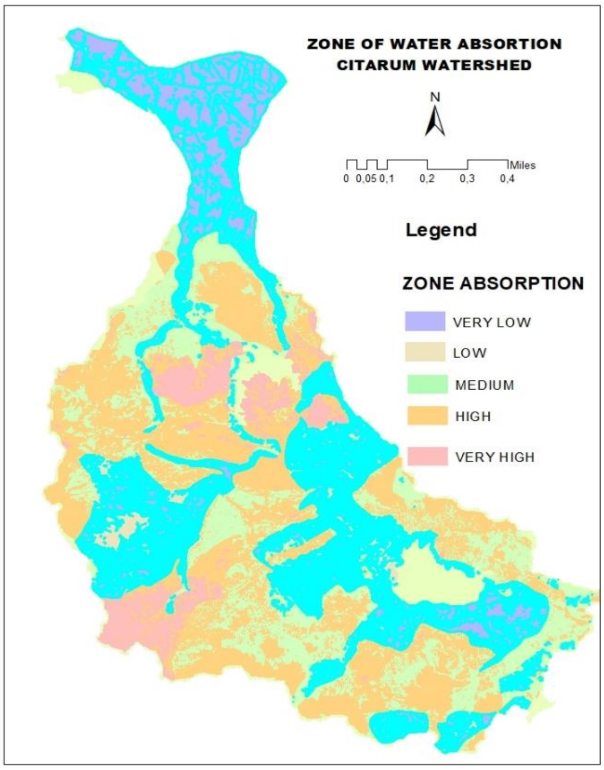

Figure 3. Map of the actual absorption water zone of the Citarum Watershed

4. Conclusion

Based on soil properties, topography, rock graduations, land cover, and rainfall, the Citarum watershed has a varied rainwater absorption rate. The results showed a variation of water absorption in the Citarum watershed, including very low 1.04%, low 21.33%, Medium 25.20%, High 38.80% very high 13.63%, with a total area of 638,511.57 ha. The dominant absorption rate is High 38.8% and very high at 13.63%, very influential on the availability of water in the Citarum watershed. The AHP method can assist in integrating spatial data according to the level of influence (weight) and multi-layer data scores proportionally in making water absorption maps.

Acknowledgment

The authors would like to sincerely thank all those who helped, including the Centre for Research, Promotion, and Cooperation of the Geospatial Information Agency (BIG), for the data and financial support.

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