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ORIGINAL ARTICLE

Infiltration ability in the area of land use change, Bogor, West Java

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Abstract

The upstream of the Cisadane Watershed is included in the Mount Halimun Salak National Park area as the water catchment area. Water resource conservation is important because of land use change. Rainfall analysis was carried out to determine the rain intensity amount. Then, infiltration observations were also carried out in Ecosystem Restoration (ER) areas. ER is an area in the rehabilitation zone that requires improvement, especially in biophysical improvement. Several ER areas are in Cibunian Village and Purwabakti Village. The analysis determined the infiltration rates in the ER areas. Field surveys carried out data collection on infiltration sample measurements. Sample points were selected using Stratified Random Sampling. The results show the average rainfall in the study area is around 3950 mm/year. The results show the infiltration ability in the ER area is relatively slow. However, there are still results of rapid infiltration at several sample points. Due to limited water absorption capacity, soil characteristics with clay texture influence slow infiltration conditions. Even though the rainfall is high, surface water runoff is quickly formed. The rainfall in the Cisadane watershed should be stored to reserve water supply, especially during the dry season. In detail, water storage can be an infiltration pit, artificial water storage tanks, reservoirs, or ponds. The limited availability of water resources challenges water uses in the Cisadane Watershed. This research is essential as an initial study to find out more about the watershed hydrological system and the water demand level.

Keywords Infiltration · Land use change · Precipitation · Water · Watershed

Introduction

Increasing population growth is directly proportional to the need for clean water sources. Meanwhile, the availability of water resources is dwindling. Water is a limited natural resource that needs management in every use for water sustainability.

The upstream Cisadane Watershed is included in the Mount Halimun Salak National Park area, one of Indonesia's clean water sources. The water needs are used for consumption, domestic, agriculture, animal husbandry and industry. However, the phenomenon of land use change is quite dynamic in the Cisadane watershed. Land use conversion from forest to agriculture area or buildings. The current condition of forest cover is only 36.6% remaining. If forest conversion continues, it will affect the existence and availability of water. Land use changes also switch the health of watersheds (Ampofo et al. 2022). Land rehabilitation must be done, especially in the Mount Butak Resort Area, Mount Halimun Salak National Park. Water resource conservation is challenged because massive land use changes reduce the water catchment (Aryanto and Hardiman 2018). Most land use changes are in the water catchment area upstream of the watershed.

The research focuses on rehabilitation zones spread across Ecosystem Recovery (ER) locations. Several ER areas are in Cibunian Village and Purwabakti Village in Pamijahan Subdistrict, Bogor Regency. Analysis was carried out to determine the water absorption in ER areas. In addition, rainfall analysis is carried out to determine the rainfall intensity. This research is an initial study of Cisadane watershed rehabilitation related to climatic and hydrological aspects.

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Material and methods

Study area

The research location is in the Upstream Cisadane Watershed, Gunung Butak Resort area.

The scope of work activities focuses on several ER areas in the rehabilitation area in the Upstream Cisadane Watershed. That area is part of the Mount Halimun Salak National Park in Bogor Regency, West Java Province.

Material

Some tools include GIS software (ArcGIS), GPS, Avenza and Timestamp in smartphones. Tools such as cameras, automatic infiltrometer (mini disk), 50 m meter, clino compass, shovel, and field observation checklist were used. Material requirements include types of annual rainfall data, watershed boundary maps, climate data, regional administration maps, land use maps, national park maps, soil type maps, river network maps, road maps, and slope maps. The tools and materials are based on the parameters used to measure rainfall and infiltration.

Methods

The data collection technique used in this activity was a field survey. Field surveys are used to obtain primary data from observations, measurements, and calculations in the field. Field surveys were conducted in all ER areas to observe and collect infiltration data. Observations were made to determine the condition of the water catchment area from morphological conditions, slopes, altitude, soil types, differences in land use, and land use conversion that have occurred.

Sampling was done by Stratified Random Sampling. The method was chosen by making the slopes and land use as strata. Samples were taken on each slope within a specific range with different land uses. The assumption is that each slope buckling difference has a different infiltration value. Infiltration measurements were carried out side by side with land identification. Sample point selection was conducted in the entire ER study area. The samples are spread evenly to represent the characteristics of the study area.

Rainfall measurement

The calculation of rainfall is done by looking at a comparison of annual rainfall patterns for the last ten years. In 2022, Indonesia will experience a La Nina phase which causes more rain intensity than usual. Rainfall from 2021 to 2022 is also analysed to compare annual rainfall patterns. Rainfall intensity is calculated from 2011 to 2020 to get the average annual rainfall.

The historical precipitation data from 2011 to 2020 is from open access data from the Center of Hydrometeorology and Remote Sensing (CHRS), University of California, Irvine (UCI). Data selection is made because there are historical data over a long period. In addition, YKAN also records rain data on a local scale using Meteostat. There are rainfall observation posts in Cianten and Cisuren. Rainfall data from Meteostat is expected to provide factual information for supporting analytical data.

Infiltration results analysis

Infiltration analysis is carried out to determine the rainfall that falls on the soil surface and seeps into the soil vertically. Infiltration data is used to analyse water absorption in the ER area. Infiltration sampling considers several aspects, including land use/land cover differences, soil types, elevation, and slope (Kumar et al. 2021). The infiltration measurement technique was carried out using an Automatic Infiltrometer/Minidisk. Research by Alagna et al. (2016) proved that minidisks are practically used for alternative measurements of hydrodynamic properties. Clay soil properties affect hydrological processes (Alagna et al. 2017). The measurement results are entered into the Excel input using the infiltration calculation formula. Infiltration data can be converted into units of cm/second, m/day, and m/year to compare accumulation.

The infiltration measurement was taken on untouched areas. It would avoid soil compaction, such as in road areas or areas where massive crop management has been carried out. The infiltration data collected will be reasonable, more valid, and represent the actual conditions in the study area.

The calculation of infiltration results is classified in the Hydrologic Soil Group (HSG) according to Table 1. The classification is based on hydrological calculations on soil groups with four categories of potential runoff. Group A soils have high permeability with little runoff, while group D soils have low permeability levels with lots of runoff. The lower the infiltration value, the greater the resulting runoff value.

Table 1 Hydrological soil group (HSG) classification

Group	Infiltration rate (mm/h)		Soil texture
A	High	> 25	Sand, loamy sand, or sandy loam
B	Medium	12.5–25	Silt loam or loam
C	Low	2.5–12.5	Sandy clay loam
D	Very low	< 2.5	Clay loam, silty clay loam, sandy clay, silty clay/clay

Results

Precipitation intensity

The upstream rainfall intensity is known by analysing the upstream watershed rainfall. Wet months generally occur from November to April due to the influence of the West Monsoon. Meanwhile, the dry months make the dry season occur around May to October. However, there are other influences, climate change, which cause a shift in monsoon wind patterns (Fig. 1).

The rainfall calculation is based on local-scale rainfall recording data with a meteostat. Rainfall recording posts are in Cianten and Cisuren (Fig. 2). Data processing from the rain plots is carried out by calculating rain from October 2021 to July 2022 according to data availability. The historical rainfall data shows that the rainfall amount has a different pattern from the usual rainfall in Indonesia. Rainfall in mountainous areas is more dynamic and erratic than in other areas. High and low rainfall will affect infiltration rates (Rahmati et al. 2018). Rainfall intensity will significantly affect the formation of puddles and even surface water runoff. In addition, it is also more difficult for water to infiltrate if the soil characteristics are difficult to absorb water. Moreover, the slope gradient was more influential on runoff with increasing rainfall intensity (He et al. 2023).

Rainfall recorded at the two recording posts is paternally similar in each month. It has differences in the rainfall produced. Rainfall in April starts high and peaks in June. The lowest rainfall is in January. The lowest total rainfall value in one month is still above 100 mm. In comparison, the highest rainfall reached more than 900 mm. Mountainous areas have higher rainfall intensity even though the duration of rain is not too long.

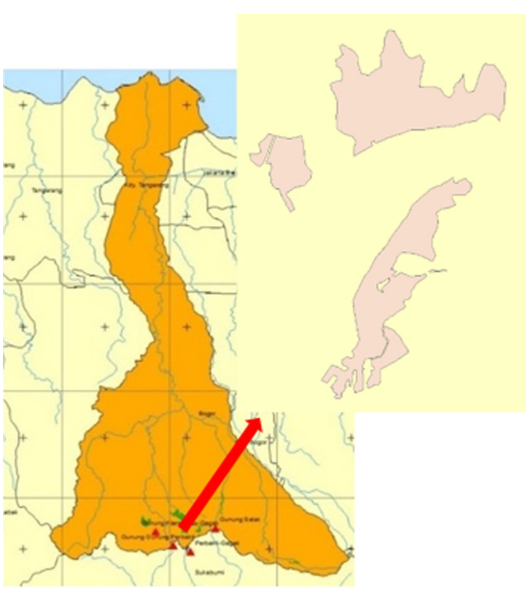

Fig. 1 Ecosystem recovery area in the upstream Cisadane Watershed

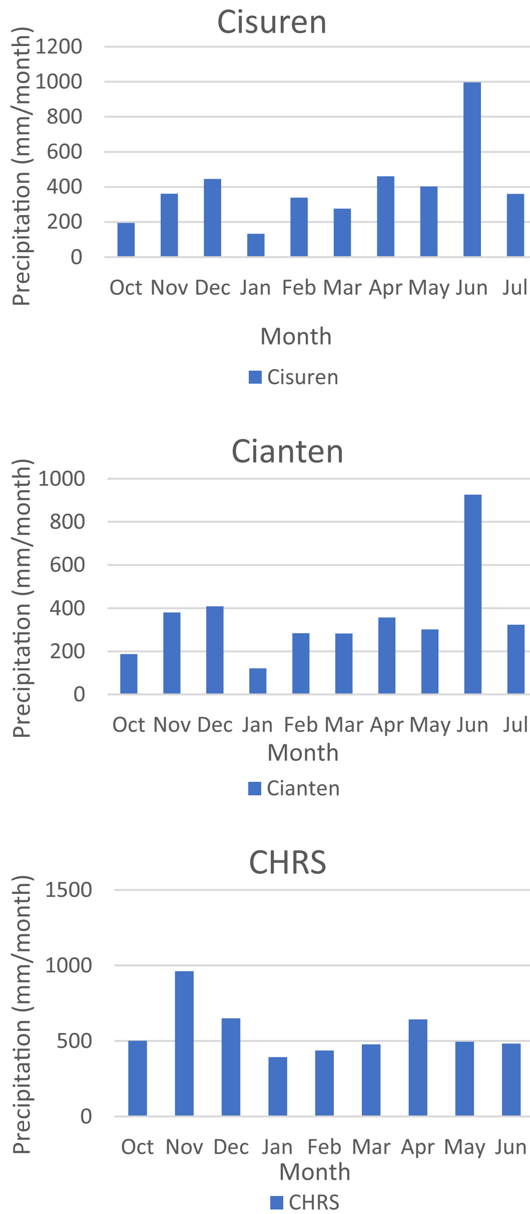

Fig. 2 Precipitation pattern from Meteostats and CHRS data

Comparing rainfall data from Meteostat with CHRS has apparent differences in June and November. In addition, the calculation of CHRS has a higher value. Differences in measurement results occur due to differences in data recording sources. Meteostat uses an automatic rain gauge, while CHRS uses satellite data. The resulting detail and bias are also different. However, due to the lengthy historical data, CHRS data can still be used for annual rainfall pattern analysis.

Table 2 Total rainfall from 2011 to 2020

Year	Precipitation (mm/year)
2020	4314.76
2019	4072.29
2018	4241.71
2017	4698.24
2016	5375.59
2015	2845.71
2014	3774.59
2013	4331.17
2012	4100.12
2011	3358.82
Annual average	4111.30

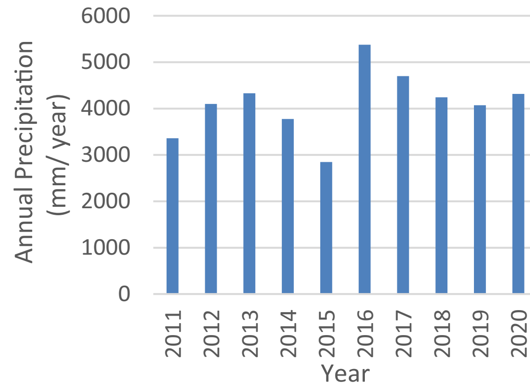

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Fig. 3 Graph of Cisadane Watershed Rainfall from 2011 to 2020

The average rainfall data from the Cisadane and Cisuren plots is 3771.1 mm/year. The assumption used is that August–October is the dry month. However, aspects that are not considered are phenomena such as El Nino, which brings a dry phase and La Nina which brings a wet phase.

The previous rainfall data correlated with the rainfall patterns in the past ten years. The pattern shows the rainfall trend in the Cisadane watershed. The average annual rainfall from the CHRS satellite for ten years is 4111.3 mm/year. Thus, rainfall in the Cisadane watershed ranges from 3700 to 4200 mm/year, as shown in Table 2.

The Cisadane watershed has rainfall above 2500 mm/year (Fig. 3). This figure represents high rainfall as the availability of water resources. However, the rainfall distribution is unevenly distributed throughout the year, which became an obstacle in the Cisadane watershed. The higher water demand is not directly proportional to dwindling water availability, especially during the dry season. Therefore, water management is essential to be used together with a sustainable system.

Infiltration measurement

Infiltration measurements were carried out at points scattered throughout the ER area in the Upstream Cisadane watershed. The determination of infiltration measurement points considers the weather and terrain. Terrain and access were interrupted after the landslides and flash floods on June 22, 2022, so several sample points were taken. Nevertheless, the number of samples of 35 points can represent infiltration conditions in all ER areas.

The results obtained from all infiltration measurements varied widely (Fig. 4). Infiltration is the parameter with a measured value. The data is not biased by mathematical formulations, as in the case of determining hydraulic conductivity (Ghosh and Pekkat 2019). Infiltration measurement methods can provide reliable yield estimate effects (Qi et al. 2020). Factors such as soil texture, land use, and rainfall influence the infiltration measurement results. Soil texture dramatically affects the infiltration rate (Tamod et al. 2020). Soil texture from observations in the field includes loam, clay loam, sandy clay loam, sandy clay, and silty clay loam. Based on the texture of the soil found in ER area, most of the soil has a texture of clay (clay) and loam (loam). Clay is a mixture of sand and dust particles in clay soil with different characteristics (Mahida UN 1984).

A low permeability level is a condition that significantly affects the infiltration process. It shows that the soil texture in clay is difficult to absorb water. It is not suitable for use as agricultural land or plantations. However, land with a clay texture in the ER area can still be used as dry agricultural land. The clay composition is also mixed with other materials, such as clay and sand.

There are several types of land use in the ER area, including shrubs, mixed gardens, mixed dryland agriculture, wetland agriculture, shrubs, buildings, rice fields, tea gardens,

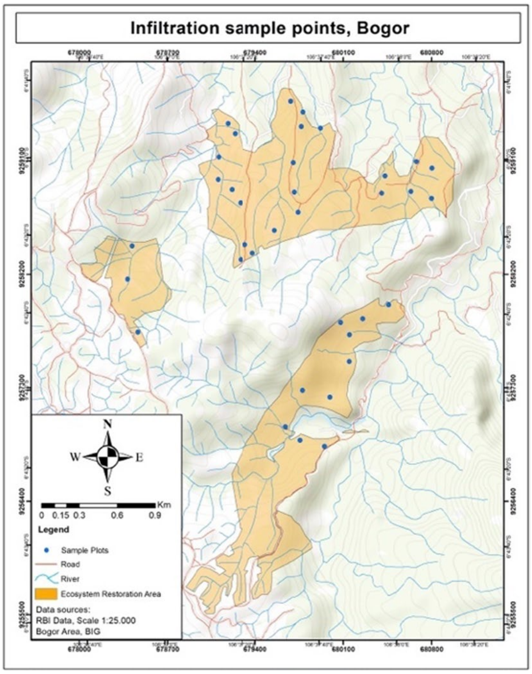

Fig. 4 Distribution of infiltration sample points

Fig 5 Infiltration measurement process

mixed trees, and pine forests. Differences in land use significantly affect the water infiltration rate (Cahyadi et al. 2012). The more land use that covers the soil surface, the slower water will seep into the ground. It applies to built-up land, while the built-up land in the ER area is only a small hut in the garden or moor area. Meanwhile, rainfall can still seep into soils with dense vegetation land cover (Wahyuni et al. 2017).

The water absorption system differs between bare land, shrubs, or shrubs. The ability to absorb water in bare land or shrubs is more easily saturated due to the limited absorption capacity of clay soil. The root system in dense vegetation areas can absorb water according to plant needs (Eliasson and Larsson 2006). Even so, high rainfall intensity can still result in surface runoff. It happens if the infiltration rate with high rainfall is unbalanced. Thus, analysis of the infiltration rate and other factors in the observation area is essential (Fig. 5).

The infiltration value in the ER area is relatively small and has a slow infiltration ability (Fig. 6). It cannot be separated from the dominant soil texture, clay, which is difficult to absorb water. The slow infiltration ability can be shown by the results of infiltration values which are dominated by < 1 m/day. The lowest infiltration rate was only 0.04 m/day in sample 23. If accumulated over a year, sample point 23 only gets a value of 15.97 m/year.

Meanwhile, several points, such as samples 9, 11, and 28, have fast infiltration rates. Then, sample 10 has a very fast infiltration rate of 6.95 m/day or 2503.36 m/year. Differences in infiltration results occur due to differences in the sampling area. The soil texture in this area also contains more sand. In addition, the differences in soil moisture and land cover vegetation can affect infiltration rates. Infiltration in the scrub area, as in sample 23, is very slow due to the soil condition. The soil is already saturated with water due to the land condition with high rainfall intensity.

Slow infiltration condition proves the soil in the Upstream Cisadane watershed is prone to flooding and landslides. The rainfall intensity is unable to seep balanced into the land. As a result, surface runoff increases during heavy rains (Eliasson and Larsson 2006). Also, it would trigger landslide potential (Sugianti et al. 2022).

Clay is the dominant soil texture in the ER area. It makes this difficult for the land to absorb and store water in large quantities. The clay characteristics are difficult to absorb and store water. These conditions cause less water to be stored.

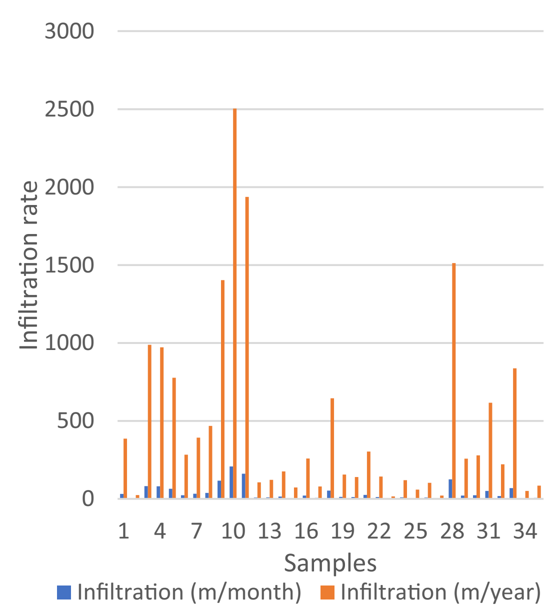

Fig. 6 Monthly and yearly infiltration graphs by sampling point

Water that does not infiltrate will become surface runoff. The infiltration rates in the ER area are still not optimal. The infiltration rates in the ER area are still far from ideal.

The infiltration rate comparison based on sampling data is shown in Table 3. Areas with fast infiltration rates have land cover in pine forests, mixed plantations, mixed non-irrigated agriculture land, and mixed trees. It is also influenced by the soil texture condition, which mostly has sandy elements (Paratin et al. 2020). The results of infiltration data collection show land cover with dense vegetation results in better infiltration rates.

ER area management is currently dominated by mixed plantations such as cloves, chives, bamboo, bananas, galangal, durian, rasamala, puspa, jackfruit, guava, and pine. In addition, there is mixed non-irrigated agricultural land such as cassava and bananas. Cultivated plants are plants that have production values. Products from plantations and agriculture can contribute to the community's economy.

Table 3 Infiltration rate from maximum to minimum rate *Source* Data analysis, 2022

No	Land cover	Soil type	Infiltration (cm/s)	Infiltration (m/day)	Infiltration (m/year)
1	Pine forests	Sandy clay loam	0.008048	6.954	2503.360
2	Mixed plantations	Sandy clay loam	0.006227	5.380	1936.698
3	Mixed plantations	Clay loam	0.004864	4.203	1512.960
4	Mixed plantations	Sandy clay loam	0.004512	3.899	1403.553
5	Mixed plantations	Sandy clay loam	0.003178	2.745	988.362
6	Mixed non-irrigated agricultural land	Loam	0.003125	2.700	972.084
7	Mixed non-irrigated agricultural land	Sandy clay loam	0.002693	2.327	837.642
8	Mixed non-irrigated agricultural land	Clay loam	0.002499	2.159	777.173
9	Mixed non-irrigated agricultural land	Sandy loam	0.002077	1.794	645.937
10	Mixed non-irrigated agricultural land	Sandy clay loam	0.001982	1.713	616.571
11	Mixed plantations	Sandy clay loam	0.001504	1.300	467.841
12	Mixed plantations	Sandy clay loam	0.001263	1.092	392.980
13	Mixed trees	Clay loam	0.001242	1.073	386.232
14	Mixed plantations	Sandy clay loam	0.000978	0.845	304.086
15	Mixed non-irrigated agricultural land	Clay loam	0.000913	0.788	283.833
16	Mixed non-irrigated agricultural land	Sandy loam	0.000897	0.775	279.098
17	Mixed plantations	Sandy clay loam	0.000834	0.720	259.356
18	Scrub	Clay loam	0.000829	0.716	257.760
19	Mixed plantations	Silty clay loam	0.000714	0.617	222.130
20	Scrub	Clay loam	0.000568	0.490	176.577
21	Mixed plantations	Sandy clay	0.000504	0.436	156.855
22	Mixed plantations	Sandy clay	0.000460	0.398	143.179
23	Mixed non-irrigated agricultural land	Sandy clay	0.000451	0.390	140.366
24	Mixed non-irrigated agricultural land	Sandy clay loam	0.000393	0.339	122.176
25	Mixed plantations	Clay loam	0.000387	0.334	120.285
26	Tea plantations	Sandy clay loam	0.000343	0.296	106.537
27	Scrub	Sandy clay loam	0.000331	0.286	103.059
28	Paddy field irrigated agricultural land	Silty clay loam	0.000273	0.236	84.874
29	Scrub	Sandy clay loam	0.000257	0.222	80.062
30	Mixed non-irrigated agricultural land	Sandy clay loam	0.000237	0.205	73.768
31	Scrub	Clay loam	0.000192	0.166	59.775
32	Mixed non-irrigated agricultural land	Sandy clay loam	0.000164	0.142	51.067
33	Paddy field	Clay loam	0.000080	0.069	24.838
34	Scrub	Clay loam	0.000071	0.061	22.086
35	Scrub	Sandy clay loam	0.000051	0.044	15.970

Discussion

Water use challenges

The Cisadane watershed is the priority area for rehabilitation because it is one of the critical watersheds in Indonesia. It is due to the significant increase in population, land use conversion, and conservation without applied sustainable management. Most of the conversions are due to the increasing need for building and agriculture production. As a result, the watershed system cannot accommodate the water discharge. It is one of the biggest challenges that cause impact water scarcity. In addition, increased runoff triggers flooding in the middle and downstream of the watershed, especially during the rainy season. Water conservation is needed to prevent flooding (Situmorang et al. 2021; Tahfazona et al. 2022).

The critical watershed condition increased because of no integrated watershed conservation and preservation. The government should have strict policies in conservation areas regarding land utilities. The complex issues are because some conservation areas have become villages with dense settlements and agricultural land. This phenomenon has been going on for a long time before being designated as conservation areas. In addition, other activities include gold, galena, and geothermal mining. Moreover, there are infrastructure development and forest product utilisation. Massive land use activities without control will degrade the Cisadane watershed.

Many stakeholders who need water resources should be appropriately accommodated. It is to avoid a conflict of interest. The infiltration measurements are carried out to determine the hydrological distribution condition. It is part of a rehabilitation implemented in the Upstream Cisadane watershed.

Water infiltration conditions

Covering land with vegetation has the effect of increasing the infiltration rates (Arsyad 2006; Suprayogo et al. 2020). Land use indicates that vegetation has a significant role in determining infiltration capacity (Saputra et al. 2021; Utaya 2008). Infiltration capacity in areas with vegetation will tend to be higher. Infiltration is very important to know the water catchment area. In addition, it can be the direction for spatial planning in flood disaster management (Ihza et al. 2022).

Water volume that can be contributed back to the ground is 1.127 billion m^3/year in an Ecosystem Recovery area of 266 hectares. The water infiltration level is still relatively small for the ER coverage area. The water volume depends on the infiltration rate and is strongly influenced by the vegetation type. According to Irawan and Yuwono (2016), the tree root system can increase water absorption and infiltration rate. It has also been proven by (Pratiwi et al. 2020) that plant age will affect the root system and water absorption capacity. It has an impact on the fast or slow infiltration rates.

Conclusions

The infiltration ability in the ER area is relatively slow, even though several points have fast infiltration. The dominant soil texture is clay and loam, with the highest proportion of clay. Slow infiltrations are influenced by soil characteristics with clay textures. Therefore, when there is high rainfall, the infiltration reaches a saturation point, and surface water runoff will form more quickly.

The hydrological system of the Cisadane watershed from the upstream reaches of Mount Halimun Salak to the downstream of Muara Angke has a very complex flow. The study was not carried out thoroughly downstream of the watershed. It is one of the research limitations. In addition, several other factors, such as soil moisture and soil characteristics, are not considered, which also influence the infiltration rate.

The rainfall amount in the Cisadane watershed should be stored for water availability during the dry season. The restoration of water absorption capability needs to be supported by other efforts. At a glance, making infiltration pits and rainwater harvesting is a technical execution in a relatively short time. It can be done by building a reservoir through ponds or artificial water storage tanks. In addition, optimising existing dams along the Cisadane River should also be carried out to prevent future droughts.

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Declarations

Ethical approval All subjects gave informed consent for inclusion before participating in this research.

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