Strategies for rehabilitation of Tuk Anjar springshed in Mount Merbabu National Park

A W Nugroho¹, A Miardini¹, P D Susanti¹, Siswo¹, K Dewi², Rusiani² and A S Aprazah²

¹Watershed Management Technology Center, Jl. A.Yani Pabelan, Surakarta, Indonesia
²Mount Merbabu National Park, Jl. Merbabu No. 136, Boyolali, Indonesia

*E-mail: agung_nugroho96@yahoo.co.id

Abstract. Spring is one of the freshwater sources for human life and as a groundwater potential indicator. The springs' quality and the quantity depend on the springshed condition. However, anthropogenic activities such as forest burning, forest encroachment, illegal logging, and land-use change have caused springshed degradation. Therefore, a proper and efficient springshed rehabilitation strategy is urgently needed. This research was carried out during September-December 2020 to formulate Tuk Anjar springshed rehabilitation strategies at Mount Merbabu National Park, Indonesia. The strategies cover methods to delineate the springshed, identify site characteristics and design rehabilitation plots. Springshed delineation was done using spatial analysis. Site characteristics were obtained by field surveys and laboratory analysis through data collection in a 10x10 m sample plot (spring protection) and 20x20 m (springshed protection). The spatial analysis result showed that Tuk Anjar springshed area was 35.06 ha, with zone I: 0.01 ha, zone II: 2.54 ha, and zone III: 32.5 ha. The priority area to rehabilitate is zone II with a low tree density. Tree species selection is based on on-site species matching, optimal rainwater storage, and having fruits as an animal feed source. Species from the genus of *Ficus* like *wilodo*, *kebeg* and *beringin* should be used since it has great potential in water storage.

1. Introduction

Water can come from many natural sources such as surface water, rivers, lakes, and springs which are the best sources for drinking and household water use for residents living in the surrounding areas [1]. One of the most important natural water sources is springs because they produce high-quality water, are inexpensive to protect, and do not require a pump to bring water to the surface [2]. Springs are the natural outlet points for groundwater [3]. Therefore, the emergence of springs is also an indicator of groundwater potential. Most of the springs appearing on the edge of the basin or hillside are evidence of shallow aquifers with low hydraulic conductivity [4]. Springs are formed as a result of geological, hydrological, or cutting in the subsoil and rock through which water moves. Water from rain seeps into the soil collects in geological formations, and flows through permeable geological formulations such as sand and gravel. When the water meets a layer of impermeable rock, or the water flows sideways, it will flow out as springs [5].

The quality and quantity of water produced by a spring depend on the recharge area’s conditions around it. Those areas of land that contribute groundwater to spring are called the springshed. The
water recharge area is emphasized concerning regional groundwater flows. The regional recharge area means that the area absorbs rainwater and will supply groundwater locally where the water permeates and the entire basin [6]. The utilization of water resources tends to increase with the increase in population, while the cumulative availability of water is relatively constant. The availability of natural resources even decreases if there is land and vegetation degradation in the recharge area. Therefore, conservation efforts are needed sustainably to maintain and improve natural resources. However, water conservation efforts carried out through rehabilitation are often inadequate, which is indicated by decreasing water sources. This happened because several problems included the springshed not being identified, the plant species selected were not suitable for the springshed, and the rehabilitation plants could not grow well. These problems have prompted a breakthrough in vegetation rehabilitation technology in affected areas, especially around springs, appropriately and efficiently. One of the methods developed is vegetation rehabilitation through planting water-storing tree species. The research aims to formulate strategies for Tuk Anjar springshed rehabilitation at Mount Merbabu National Park. The strategies cover methods to delineate the springshed, identify site characteristics and design rehabilitation plots. Tuk Anjar is one of the springs located in Mount Merbabu National Park and is utilized to meet community drinking water needs in Taru Batang Village, Selo District, Boyolali Regency. However, water users are still limited because water debit is small.

Vegetation can carry out the process of flowing fluids and gases, distributing and transforming substances (phyto-process) through phytostabilization, rhizo-filtration, rhizo-degradation, phytoextraction, phyto-degradation, phyto-volatilization, groundwater hydraulic control, and rainwater vegetation cover [7]. Trees store rainwater through the crowns, including leaves, twigs, branches, and trunks with a stem flow mechanism. Water storage in tree trunks accounts for 6-28% of the tree's daily water balance, depending on the species. Apart from trees, water is also stored in the soil around the tree by the presence of decomposed leaf litter to form horizon 0. Research by [8] through spatial simulations shows that planting trees with moderate density can optimize groundwater filling. In addition, moderate canopy cover causes low surface runoff, evaporation, and transpiration, thus optimizing groundwater replenishment. In general, the morphological features of water storage trees are lush green, and the number of stomata is less [9].

2. Materials and Methods

2.1. Study site

The research was carried out from September-December 2020 at Tuk Anjar, which is geographically located at 7° 28' 41.72" S and 110° 27' 43.59" E. Tuk Anjar is one of the springs located in Mount Merbabu National Park (TNGBm) and utilized by the people of Taru Batang Village, Selo District, Boyolali Regency (Figure 1). Geomorphologically, this area is located in the volcanic cone and volcanic slopes of Mount Merbabu. The morphology of the volcanic cone also encourages the formation of orographic rainfall so that this area has relatively high rainfall. The appearance of a spring belt along the bending of the slope and the foot of the volcano is an indicator of the high potential of water resources, which is very important for the survival and fulfillment of the water needs by the surrounding community.
2.2. Materials
The materials used were outlet points of Tuk Anjar, spatial data on area boundary and zoning maps, 1:25000 scale RBI maps, DEMNAS 1408-52, and high-resolution imagery. The tools used include phi band, haga, hypsometer, shovel, plastic sample, label paper, GPS, camera, notebook, ArcGIS 10.3 software, Microsoft Office 2019, spatially explicit individual-based forest simulator (SExI-FS) software.

2.3. Research method

2.3.1. Mapping of springshed areas. Determination of springshed areas is carried out using the guidelines of the Minister of Energy and Mineral Resources Number 31 of 2018 concerning Guidelines for Establishing Groundwater Conservation Zones. Determination of springshed areas is approached based on slope bending, river flow patterns, and the emergence of springs. Map of springshed areas is analyzed using DEMNAS data to derive the location of slope bending and flow patterns to obtain rivers of third and fourth-order or lower order. The springs are the places where groundwater emerges or is released to the ground surface so that the water point is designated as an outlet to limit the recharge area. After determining of springshed map, then the zoning for the protection of springs is carried out.

2.3.2. Identification of site characteristics. The first step in carrying out rehabilitation measures is the identification of initial site characteristics. Site characteristics can be identified by characteristics of the soil (physical, chemical), vegetation (structure, composition), and climate (temperature, humidity, sunlight). This activity is important to assess and evaluate whether this rehabilitation activity is successful or not by comparing the site conditions before and after rehabilitation. In addition, this information can be used to determine suitable vegetation types to be developed in the area.
Site characteristics were obtained by field surveys and laboratory analysis. Data on site characteristics were collected in a sample plot of 10 x 10 m (spring protection) and 20 x 20 m (springshed protection). The observed vegetation variables were: species, distance X and Y, total height, branch free height, trunk diameter, crown depth, crown curve, and crown radius. Climate variables measured include air temperature, air humidity, sunlight intensity, and altitude. Soil conditions observed directly in the field include geomorphological conditions (slope, relief form, rock type), physical soil (color, texture, structure, solum, drainage, temperature, humidity, and infiltration rate). Soil chemical properties were observed by collecting soil samples for analysis in the laboratory. Soil samples were taken randomly with three replications representing the soil conditions of the entire location. The soil infiltration rate was measured using a double-ring infiltrometer.

2.4. Data analysis
The vegetation analysis used to describe the stand structure was the calculation of the importance value index (IVI) and species diversity (H'). The higher the IVI of a species, the higher the level of mastery in the community concerned. IVI is calculated by the formula [10]:

\[
IVI = \text{relative density} + \text{relative dominance} + \text{relative frequency}
\]

Species diversity was clarified by the Shannon-Wiener index and calculated based on following formula [11]:

\[
H' = -\sum p_i \ln p_i
\]

where:
- \( H' \) = species diversity index
- \( p_i \) = number of the individual species-i/number of individuals of all species

If \( H' < 1 \): low diversity
If \( 1 \leq H' \leq 3 \): moderate diversity
If \( H' > 3 \): high diversity

The vegetation structure was visualized using spatially explicit individual-based forest simulator (SExI-FS) software [12].

The infiltration rate was analyzed using the Horton equation. The infiltration equation is a three-parameter equation which is commonly expressed as [13]:

\[
f = f_c + (f_o - f_c)e^{-kt}
\]

Where:
- \( f \) = infiltration rate at time \( t \) (cm minute\(^{-1}\))
- \( f_c \) = final infiltration rate (cm minute\(^{-1}\))
- \( f_o \) = initial infiltration rate (cm hr\(^{-1}\))
- \( k \) = rate constant in dimension of time

3. Results and Discussion
3.1. Mapping of springshed areas
Determination of springshed areas is approached based on slope bending, river flow patterns, and spring emergence. Slope bending is the boundary between the morphology of the plains and hills, generally the foothills area or the foot of the mountains with recharge areas, which are generally above the bending of the slope. The afflux area is characterized by several relatively short and straight tributaries, occupied by rivers of the third and fourth-order or lower order. An area with the
morphology of the area occupied by the main river flow or several branches of the main river flow, which is relatively long, is a discharge area. The area upstream from the point of spring emergence is generally a recharge area, while downstream is a discharge area.

The spring protection area is divided into three zones. Zone I is a radius of 10 m from the springs, which is a protected area that aims to protect water from all pollutants that cause water quality degradation, directly and indirectly. Zone II is a protected area that aims to protect raw water sources from the danger of pathogenic bacterial contamination that can cause water quality degradation. This zone boundary is determined based on the distance from the spring to the upstream as far as 200 m. Finally, zone III is a protected area that aims to protect raw water sources from chemical and radioactive pollution that cannot be degraded in a short time, with an area determined based on the size of the water catchment [14, 15]. A map of the Tuk Anjar springshed can be seen in Figure 2. Springshed Tuk Anjar has 35.06 hectares consisting of protection zones 1, 2, and 3, respectively, covering 0.01, 2.54, and 32.51 hectares. About 52.96% of these areas are covered by low tree density.

3.2. Site characteristic
Based on survey results, the soil type in the research location is inceptisol, with a crumbly soil structure, sandy loam soil texture, and igneous rock. Inceptisol soils are immature soil found in volcanic areas and develop from volcanic material dominated by basalt [16, 17]. Springshed areas are at an altitude of 1,880-2,186 m asl. Dominant soil colors are 5 YR 3/3 and 5 YR 2.5/2 (dark reddish-brown). In general, these areas have deep soil solum with moderate-slow drainage rates. The land has a slope that varies from 4-85%. The relief shape is generally hilly, and erosion types were surface erosion with a mild to moderate level. Temperature ranges from 17-21.2 °C.
Meanwhile, humidity ranges from 68-90%, and soil temperature is 15-18 °C. Therefore, the infiltration rate is very influential in regulating groundwater availability. One of the physical properties of soil that affects infiltration rate is soil texture. Sandy loam soil texture has large pores that allow water to infiltrate quickly. This is inversely proportional to clay soil texture. The texture of sandy loam is usually coarse, slightly sticky, and slightly plastic consistency [16, 18]. The infiltration rate in each zone of the Tuk Anjar springshed can be seen in Table 1. The infiltration rate is classified as moderate. The soil in this location has high C-organic, low cation, and moderate CEC (cation exchange capacity). This indicates that cation leaching has occurred by erosion. Analysis results show that soil fertility status is moderate (Table 2).

| Zone | Infiltration rate | Criteria | Horton model | R square |
|------|-------------------|----------|--------------|----------|
| 1    | 50.76             | Moderate | y = -2.7787x + 1.7681 | 0.826    |
| 2    | 53.63             | Moderate | y = -15.552x + 1.5789  | 0.866    |
| 3    | 55.53             | Moderate | y = -5.1468x + 1.8531  | 0.841    |

| No. | Soil chemical properties | Value | Level | Value | Level | Value | Level |
|-----|----------------------------|-------|-------|-------|-------|-------|-------|
| 1   | C-organic (%)             | 3.63  | High  | 5.97  | Very high | 7.76  | Very high |
| 2   | N (%)                     | 0.20  | Low   | 0.44  | Moderate | 0.55  | High   |
| 3   | C/N                       | 18    | High  | 14    | Moderate | 14    | Moderate |
| 4   | P₂O₅ HCL 25% (ppm)       | 150   | Very high | 110  | Very high | 123   | Very high |
| 5   | K₂O HCL 25% (ppm)        | 22    | Moderate | 19   | Low     | 11    | Low    |
| 6   | P₂O₅ Olsen (ppm)         | 9     | Low   | 13    | Moderate | 12    | Moderate |
| 7   | P₂O₅ Bray 1 (ppm)        | 0.0   | Very low | 0.0   | Very low | 0.0   | Very low |
| 8   | CEC (me/100 g)           | 12.33 | Low   | 19.84 | Moderate | 17.10 | Moderate |
| 9   | Ca (me/100 gr)           | 4.08  | Low   | 10.16 | Moderate | 8.54  | Moderate |
| 10  | Mg (me/100 gr)           | 0.63  | Low   | 1.23  | Moderate | 0.82  | Low    |
| 11  | K (me/100 gr)            | 0.31  | Low   | 0.24  | Low     | 0.13  | Low    |
| 12  | Na (me/100 gr)           | 0.10  | Low   | 0.16  | Low     | 0.12  | Low    |
| 13  | Basa saturation (%)      | 42    | Moderate | 59   | Moderate | 58    | Moderate |
| 14  | Soil fertility status    | -     | Moderate | -    | Moderate | -    | Moderate |

The importance value index (IVI) measures how dominant a species is in a given forest area. Analysis results of IVI (IVI >40%) show that the dominant tree is *bintami*, *puspa*, and *kesowo* (Table 3). *Wilodo* (*Ficus fistulosa*) tree has a low IVI value (23.91%) and is only found around springs (zone I). The dominant understorey vegetation are *kirinyu* and *ceremah*. The dominant vegetation is species that can utilize the environment efficiently and have a great opportunity to maintain growth and preserve species. Species diversity is influenced by the density of the number of stems/ha, the number of species, and the level of distribution of each species. Species diversity index (H') describes the level of stability of a standing community. The H' analysis results show that H' value <1 means that species diversity is low and less stable due to environmental disturbance in which the vegetation grows [19]. Forest disturbance, such as forest fire and forest conversion, can degrade species diversity and is generally caused by anthropogenic activities. Forest species change in composition after a fire. Many native trees died while grazing, and shrub quickly recovered after fire [20].
Table 3. Vegetation analysis in Tuk Anjar springshed.

| Zone | Tree life stages | Scientific name | Local name | IVI   | H'   |
|------|------------------|-----------------|------------|-------|------|
| 1    | Trees and poles  | Cupressus sp.    | Bintami    | 43.61 | 0.14 |
|      |                  | Macropanax dispermus | Pampung | 32.48 | 0.14 |
|      |                  | Ficus fistulosa  | Wilodo     | 23.91 | 0.15 |
|      | Saplings         | Brugmansia candida | Kecubung gunung | 39.16 | 0.06 |
|      |                  | Macropanax dispermus | Pampung | 35.28 | 0.09 |
|      |                  | Lithocarpus costata | Pasang   | 25.56 | 0.09 |
|      | Seedlings &      | Brugmansia candida | Kecubung gunung | 39.25 | 0.16 |
|      | understory       | Eupatorium triplinerve | Ceremah | 26.30 | 0.15 |
|      |                  | Eupatorium odoratum | Kirinyu  | 24.75 | 0.15 |
|      |                  | Selaginella doederleini | Cakar ayam | 22.25 | 0.15 |
|      |                  | Chrysanthemum sp. | Rumput krisan | 13.50 | 0.12 |
|      |                  | Cycas rumphii    | Pakis      | 11.50 | 0.11 |
|      |                  | Brachiaria mutica | Rumput blabakan | 11.50 | 0.11 |
| 2    | Trees            | Schima wallichii | Puspa      | 52.43 | 0.14 |
|      |                  | Pinus merkusii   | Pinus      | 34.61 | 0.10 |
|      |                  | Cupressus sp.    | Bintami    | 12.96 | 0.06 |
|      | Poles            | Pinus merkusii   | Pinus      | 29.32 | 0.16 |
|      |                  | Ficus fistulosa  | Wilodo     | 19.63 | 0.13 |
|      |                  | Macropanax dispermus | Pampung | 19.63 | 0.13 |
|      |                  | Lithocarpus costata | Pasang   | 18.07 | 0.13 |
|      | Saplings         | Pittosporum mollucanum | Sengir | 13.34 | 0.13 |
|      | Seedlings &      | Pittosporum mollucanum | Sengir | 100  | 0    |
|      | understory       | Eupatorium odoratum | Kirinyu  | 29.28 | 0.16 |
|      |                  | Eupatorium triplinerve | Ceremah | 23.11 | 0.15 |
|      |                  | Selaginella doederleini | Cakar ayam | 14.70 | 0.12 |
| 3    | Trees            | Engelhardia serrata | Kesowo   | 45.89 | 0.12 |
|      |                  | Cupressus sp.    | Bintami    | 32.59 | 0.15 |
|      | Poles            | Engelhardia serrata | Kesowo   | 69.93 | 0.09 |
|      | Saplings         | Engelhardia serrata | Kesowo   | 68.35 | 0.09 |
|      | Seedlings &      | Homalanthus papulneus | Krembi  | 31.65 | 0.15 |
|      | understory       | Eupatorium odoratum | Kirinyu  | 28.63 | 0.16 |

The structure of vegetation consists of individuals forming stands in space. The stand structure can be viewed from two directions, namely: horizontal and vertical stands. The horizontal stand describes the distribution of individual species in their habitat, while the vertical stand expresses the distribution of trees number in various crown layers. Based on measurement results and utilizing capabilities of SExI-FS software, priority rehabilitation location should be carried out in zone 2 (Figure 3).
Figure 3 shows that tree and pole density in the sample plot (20x20 m) of zone 2 is relatively low. Dominating trees are *Schima wallichii* and *Pinus merkusii*. Sunlight intensity is quite low at 14.4%, and it is influenced by the dense cover of the understorey. The dominant understorey is *kirinyu*, with a height that can reach 3 m. The low tree cover affects the lack of water infiltration into the soil. The dominance of understorey (*kirinyu*) makes it difficult to grow natural tillers from existing tree vegetation. In addition, the loss of effective forest vegetation area can reduce evapotranspiration, soil moisture, infiltration and increase surface runoff. Thus, it can affect the hydrological process [21].

### 3.3. Design of springshed rehabilitation

**3.3.1. Goal setting.** Springshed rehabilitation has the main objective of repairing and maintaining the springshed areas. Rainwater can be infiltrated into soil optimally and become groundwater, which will appear as springs and other discharge areas. The role of vegetation is important because it is one of the factors that can affect rainwater infiltration. Vegetation is very influential on runoff water retainer, and retained water will infiltrate into the ground as a groundwater source. Catchment areas covered by vegetation had up to 81% water retention capacity compared to the land without vegetation, with water retention of overland flow only 33% [22]. Not all trees have a good ability to store water. The trees around the springs generally have the following characteristics: deep taproots, many fibrous roots, wide and lush crowns, soft stem, long-lived plants, evergreen, and fewer stomata. Species from the Moraceae family are the most common species found in the area around the springs, especially in areas with volcanic types. One genus of Moraceae is *Ficus* [23]. *Ficus* was widely distributed and has a high value of indicator species around springs in both lowlands and highlands. *Ficus* is one of the potential species for water storage [24, 25]. So that, the selection of suitable plants should be directed to species that can store a lot of water.

Another benefit of springshed rehabilitation is saving and maintaining the diversity of genetic resources of potential water storage trees (especially genus of *Ficus*). The results of vegetation analysis showed that species diversity (H’) and IVI of *Ficus* in Tuk Anjar springshed was low (H’ <1). *Ficus* was only found around springs (zone 1). Therefore, the genus of *Ficus* should be used as rehabilitation plant species in zone 2 of the Tuk Anyar springshed. Long-term benefits of rehabilitation, it can provide a seeds source for water storage trees in the future. Determining rehabilitation objectives will affect the activities, from taking genetic material to designing the springshed rehabilitation [26].

The genetic material used is native mountain species and has great potential to store a lot of water from *Ficus*, such as wilodo (*Ficus fistulosa*), kebeg (*Ficus fulva*), beringin (*Ficus benjamina*). The
considerations are site species matching, optimal storage of rainwater, and fruit as a source of animal food.

3.3.2. **Design of planting.** Making planting designs should consider some aspects, including topography, sunlight intensity (shade), soil type, slope, and cropping pattern (spacing, density) to maintain ecosystem stability, increase plant growth, and optimize the function of the plant as water storage.

Tree planting should consider slope stability to minimize landslides because dominant areas have a slope >35%. These aspects are related to reducing the weight of trees, including tree placement, density regulation (not too dense), and plant diversity (multiple crowns and roots). Small vegetation (grass, shrubs) should be placed at the top of the slope, while large vegetation (trees) is placed near the foot of the slope to strengthen it [27]. The combination of water storage trees and soil conservation with individual terraces can be applied for rehabilitation techniques at slope areas. Trees spacing must be regulated not too tight (>10x10 m) to minimize landslide. This is intended to reduce heavy loads and pressure between trees. Light vegetation such as shrubs and grasses can be planted between trees. In addition, it is necessary to make a good drainage channel from the peak area to keep water flowing into the recesses of the hill slopes.

3.3.3. **Planting and maintenance.** Planting activities start from land preparation, making planting holes, applying organic fertilizer, planting, and maintenance. Silver plastic mulch can be applied around the planting hole to inhibit weed (*kirinyu*), maintain soil moisture around the roots, and reduce maintenance costs. Maintenance activities (weeding, fertilizing, growth evaluation) are routinely (every three months) carried out to facilitate the adaptability and growth of trees.

4. **Conclusion**

Determination of the Tuk Anjar springshed based on slope bending, river flow patterns, and the emergence of springs obtained an area of 35.06 ha with details of Zone I: 0.01 ha, zone II: 2.54 ha, and zone III: 32.5 ha. Rehabilitation location is prioritized in Zone II that has low trees cover. Rehabilitation of the Tuk Anjar springshed should use native plant species from the genus of *Ficus* such as *wilodo* (*Ficus fistulosa*), *kebeg* (*Ficus fulva*), *beringin* (*Ficus benjamina*) by considering site species matching, optimal storage of rainwater, and their fruits as a source of animal food. In addition, some aspects should be considered in designing the planting, including topography, sunlight intensity (shade), soil type, slope, and cropping pattern (spacing, density) in order to maintain ecosystem stability, increase plant growth and optimize the function of the plant as water storage.

**References**

[1] Batool A 2018 Spring water quality and human health: An assessment of natural springs of Margalla Hills Islamabad zone-III *International Journal of Hydrology* 2 41-6

[2] Vilane B R T and Dlamini J 2016 An assessment of the Mhlambanyoni spring water quality at Sigombeni, Swaziland *Journal of Agricultural Science and Engineering* 2 40-5

[3] Green J A, Barry J D and Alexander E C J 2014 Springshed assessment methods for paleozoic bedrock springs of southeastern Minnesota Minnesota Environment and Natural Resources Trust Fund p48

[4] Soulilos G 2010 Springs (classification, function, capturing) *Bulletin of the Geological Society of Greece* 43 196-215

[5] Ranjana P and Pandey P K 2019 Reviving, development and protection of springs to increase water security in the Himalayan region In *Proceedings of 5th International Conference on Computers & Management Skills (ICCM)* North Eastern Regional Institute of Science & Technology pp 25-9

[6] Wibowo M 2006 Model penentuan kawasan resapan air untuk perencanaan tata ruang berwawasan lingkungan *J. Hidrosfir* 1 1-7

[7] Mangkoedihardjo S and Samudro G 2010 *Fitoteknologi terapan* Yogyakarta Graha Ilmu
[8] Ilstedt U, Tobella A B, Bazié H R, Bayala J, Verbeeten E, Nyberg G, Sanou J, Benegas L, Murdiyarso D, Laudon H, Sheil D and Malmer A 2016 Intermediate tree cover can maximize groundwater recharge in the seasonally dry tropics Scientific Reports 6

[9] Ulfah M, Rahayu P and Dewi L R 2015 Kajian morfologi tumbuhan pada spesies tanaman lokal berpotensi penyimpan air: Konservasi air di Karangmanggis, Boja, Kendal, Jawa Tengah In Seminar Nasional Masyarakat Biodiversitas Indonesia pp 418-22

[10] Mueller-Dombois D and Ellenberg H 1974 Aims and methods of vegetation ecology Canada John Wiley & Sons

[11] Magurran A E 1988 Ecological diversity and its measurement New Jersey Princeton University Press

[12] Harja D and Vincént G 2008 Spatially explicit individual-based forest simulator-User guide and software: World Agroforestry Centre (ICRAF) and Institut de Recherche pour le Developpement (IRD)

[13] Morbidelli R, Corradini C, Saltalippi C, Flammini A, Dari J and Govindaraju R S 2018 Rainfall infiltration modeling: a review Water 10 1-20

[14] Ekklesia R, Sukandarrumidi and Hendrayana H 2005 Penentuan zona perlindungan sumber air baku pada sumur bor Mojosongo, Kadipiro, dan Jebres Kota Solo Provinsi Jawa Tengah Manusia dan Lingkungan 12 88-103

[15] Hendrayana H 2002 Zona perlindungan sumber air baku Yogyakarta Geological Engineering Dept. Faculty of Engineering Gadjah Mada University

[16] Muslim R Q, Kricella P, Pratamaningsih M M, Purwanto S, Suryani E and Ritung S 2020 Characteristics of Inceptisols derived from basaltic andesite from several locations in volcanic landform Journal of Soil Science and Agroclimatology 17 115-21

[17] Rajamuddin U A and Sanusi I 2014 Morphological characteristics and soil classification of inceptisol at some land system in The Jeneponto District of South Sulawesi J. Agroland 21 81-5

[18] Hardjowigeno S 2010 Ilmu tanah Jakarta Akademika Pressindo

[19] Mawazin and Subiakto A 2013 Species diversity and composition of logged over peat swamp forest in Riau Indonesian Forest Rehabilitation Journal 1 59-73

[20] Negi G C S 2019 Forest fire in Uttarakhand: causes, consequences, and remedial measures international Journal of Ecology and Environmental Sciences 45 31-7

[21] Muchtar A and Abdullah N 2007 Analysis of factors influencing the river discharge of Mamasa Jurnal Hutan dan Masyarakat 2 174-87

[22] Sancayaningsih R P, Saputra A and Fatimatuszhahra 2014 Tree vegetation structure analysis around springs that potentially to springs conservation

[23] Yuliantoro D, Atmoko B D and Siswo 2016 Pohon sahabat air Surakarta Balai Penelitian dan Pengembangan Teknologi Pengelolaan Daerah Aliran Sungai

[24] Siswo, Yun C W and Abdiyani S 2019 Distribution of tree species around springs and trees-springs interplay possibility in the springs area of Soloraya, Central Java, Indonesia Forest Science and Technology

[25] Supriyanto 2010 Ada ara ada air In Trubus Jakarta PT Tubus Swadaya

[26] Widyatmoko A Y 2014 Manual pembangunan plot konservasi eks-situ Shorea penghasil tengkawang Samarinda Balai Besar Penelitian Dipterokarpa

[27] Nugroho A W 2016 Silvikultur untuk stabilisasi lereng dalam pengurangan longsor. In: Seminar nasional peran pengelolaan DAS untuk mendukung ketahanan air, ed N P Nugroho, et al. (Surakarta: Balai Penelitian dan Pengembangan Teknologi Pengelolaan Daerah Aliran Sungai (BPPTPDAS)-Program Pasca Sarjana Universitas Sebelas Maret (UNS)-Fakultas Geografi Universitas Muhammadiyah Surakarta (UMS) pp 202-22
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